Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

WORKING MATERIAL

REPRODUCED BY THE IAEA

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Vienna, 12.07.2013

Objectives

The purpose of the workshop is to assist Member States in developing an adequate capability for protecting the public in the event of a severe accident at a nuclear power plant (NPP) or spent fuel pool based on guidance and tools developed by the IAEA.

The workshop is intended to provide a comprehensive understanding of the actions necessary to protect the public for those responsible for making and for acting on decisions in the event of an emergency involving severe damage to the fuel in the reactor core or spent fuel pool of a LWR. It provides a basis for developing the tools and criteria at the preparedness stage that would be needed in taking protective actions and other actions in response to an emergency.

This workshop is built on the EPR-NPP Public Protective Actions Document: *Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor*

Scientific Secretariat

The Scientific Secretary for the workshop is Mr Thomas McKenna of the Incident and Emergency Centre, Department of Nuclear Safety and Security.

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Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

SCHEDULE

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<tr><td>09:00</td><td>Registration and formal opening
Host Authorities</td><td rowspan="4">Module 5
Timeline of events during the emergency at the TEPCO Fukushima Daiichi NPP</td><td rowspan="4">Module 8 - Part 1
Protective actions for an emergency at an NPP</td><td>Introduction to tabletop</td><td rowspan="2">Module 11
Minimum response capabilities checklist</td></tr>
<tr><td>09:30</td><td>Module 1
Introduction</td><td>Break</td></tr>
<tr><td>10:00</td><td rowspan="2">Module 2
Pre-Workshop Test</td><td rowspan="2">1st Phase of tabletop</td><td rowspan="2">Evaluation and effectiveness of training
Closing
Host Authorities, faculty</td></tr>
<tr><td>10:30</td></tr>
<tr><td>11:00</td><td>Break</td><td>Break</td><td>Break</td><td>Break</td><td></td></tr>
<tr><td>11:30</td><td rowspan="3">Module 3
Overview of the IAEA publication EPR-NPP Public Protective Actions</td><td rowspan="3">Module 6 - Part 1
Overview of emergencies at an NPP</td><td rowspan="4">Module 8 - Part 2
Protective actions for an emergency at an NPP</td><td rowspan="2">2nd Phase of tabletop</td><td></td></tr>
<tr><td>12:00</td><td></td></tr>
<tr><td>12:30</td><td rowspan="2">Lunch</td><td></td></tr>
<tr><td>13:00</td><td rowspan="2">Lunch</td><td rowspan="2">Lunch</td><td></td></tr>
<tr><td>13:30</td><td rowspan="2">Lunch</td><td rowspan="2">Feedback and discussion
(1st and 2nd phase)</td><td></td></tr>
<tr><td>14:00</td><td rowspan="4">Module 4
Quantities and possible health effects relevant for an emergency at an NPP</td><td rowspan="2">Module 6 - Part 2
Overview of emergencies at an NPP</td><td></td></tr>
<tr><td>14:30</td><td rowspan="2">Module 9
Public and media response to an emergency at an NPP</td><td>Break</td><td></td></tr>
<tr><td>15:00</td><td>Break</td><td rowspan="4">3rd Phase of tabletop</td><td></td></tr>
<tr><td>15:30</td><td rowspan="4">Module 7
Environmental Characteristics of a Release during a Severe Emergency at a NPP</td><td>Break</td><td></td></tr>
<tr><td>16:00</td><td>Break</td><td rowspan="3">Module 10
Placing measured operational quantities and calculated doses in perspective</td><td></td></tr>
<tr><td>16:30</td><td rowspan="2">Module 2
Discussion and answers to test questions</td><td></td></tr>
<tr><td>17:00</td><td></td><td></td></tr>
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Introduction

Module 1

Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

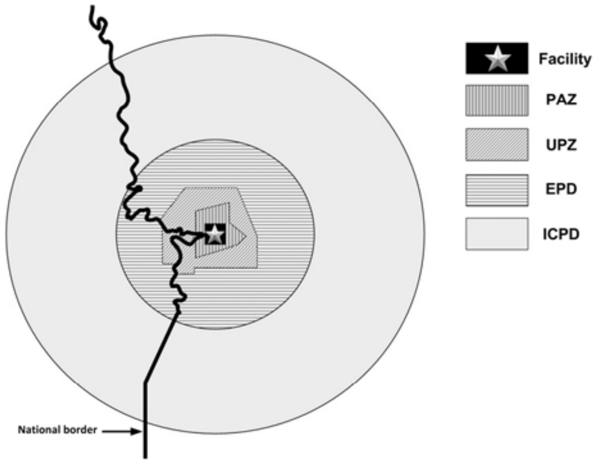
IAEA

International Atomic Energy Agency

Lecture: L-01: Introduction
Purpose: To provide an overview of the training course.
Learning objectives: Upon completion of this lecture, the participants will: know the intended audience and assumed areas of expertise, topics to be covered, what the research and information is based on, objectives of the training course, principle ideas, a demonstration of how protective actions should be implemented, organization of the training course, example questions that participants will be able to answer at the end of the training course and the main issues the training course is focused on.
Duration: 0.5 hour

This training course is for supporting staff of off-site decision makers

- Responsible for implementing actions to protect the public
- Areas within 300 km of > 1000 MW (th) nuclear power plant



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This training course is intended to provide an understanding of the actions necessary to protect the public for those responsible for making and for acting on decisions in the event of an emergency involving actual or projected severe damage to the fuel in the reactor core or spent fuel pool at a light water reactor (LWR) or spent fuel pool. It provides a basis for developing the tools and criteria at the preparedness stage that would be needed in taking protective actions and other actions in response to an emergency.

It is assumed that participants of this training course are experts on:

- Reactor operations
- Emergency preparedness and response
- Effects of radiation exposure
- Public administration (national, local government decision making)
- Public information
- And more…

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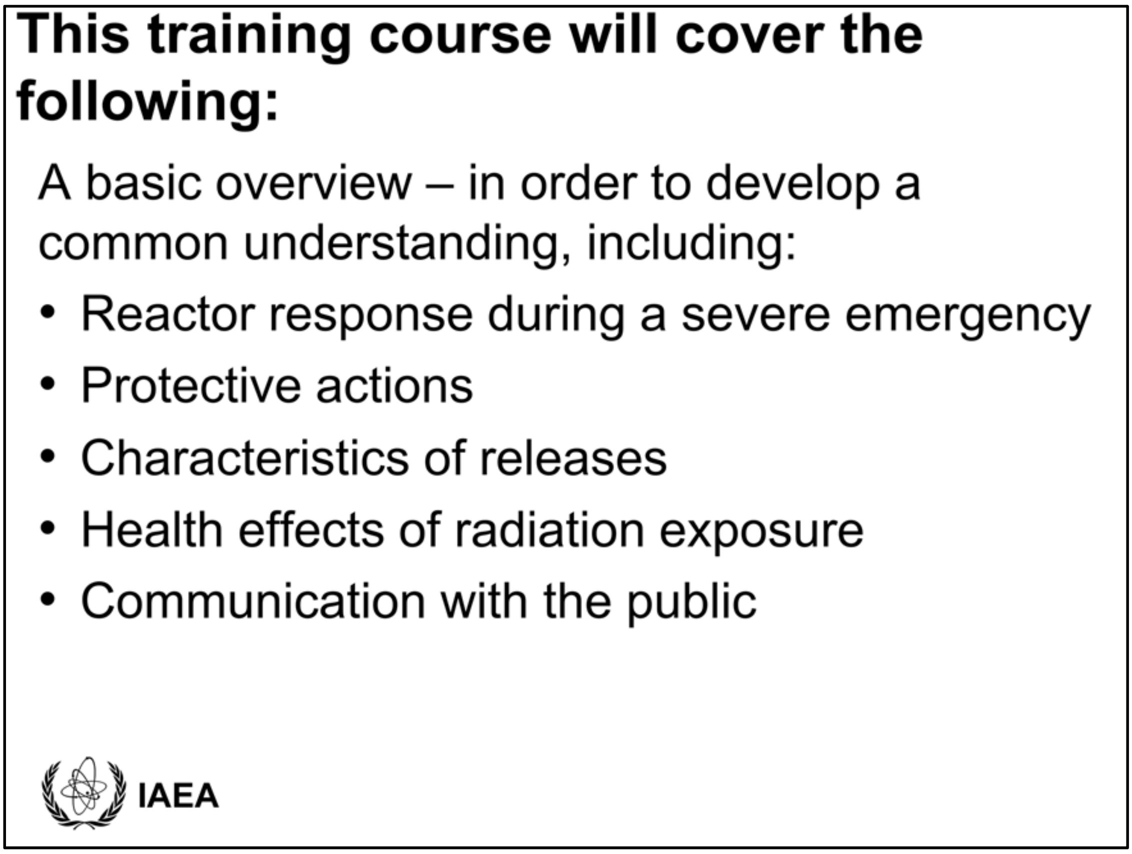
It is assumed that participants of this training course are experts in the following areas:

- Reactor operations;
- Emergency preparedness and response;
- Effects of radiation exposure;
- Public administration (national, local government decision making);
- Public information;

And more…

It is also assumed that none are experts in all of these areas – however all would be important during a response to an emergency at a nuclear power plant or spent fuel pool.



In order to develop a common understanding this training course will cover a basic overview, including:

- Reactor response during a severe emergency;
- Protective actions;
- Characteristics of releases;
- Health effects of radiation exposure; and
- Communication with the public.

This will be based on:

- Experience from past nuclear emergencies such as Three Mile Island, Chernobyl, Fukushima
- Experience in response to other types of emergencies
- Research and analysis
- IAEA guidance
- Fact and not opinion based

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This training course is based on:

- Experience from past nuclear emergencies such as Three Mile Island, Chernobyl, Fukushima;
- Experience in response to other types of emergencies;
- Research and analysis;
- IAEA guidance; and
- Fact and not opinion based.

Objectives

- To know what to expect in the event of a severe emergency at a nuclear power plant or spent fuel pool
- To understand what experience and research demonstrates is needed to protect the public
- To provide tools that could be used if an emergency happens tomorrow

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The objectives of this training course are:

- To know what to expect in the event of a severe emergency at a nuclear power plant or spent fuel pool;
- To understand what experience and research demonstrates is needed to protect the public; and
- To provide tools that could be used if an emergency happens tomorrow.

Principal ideas

- When a severe emergency involving a nuclear power plant or spent fuel pool takes place:
  - The response must be very quick and preplanned to be effective
  - Basic tools and understanding can ensure an effective response

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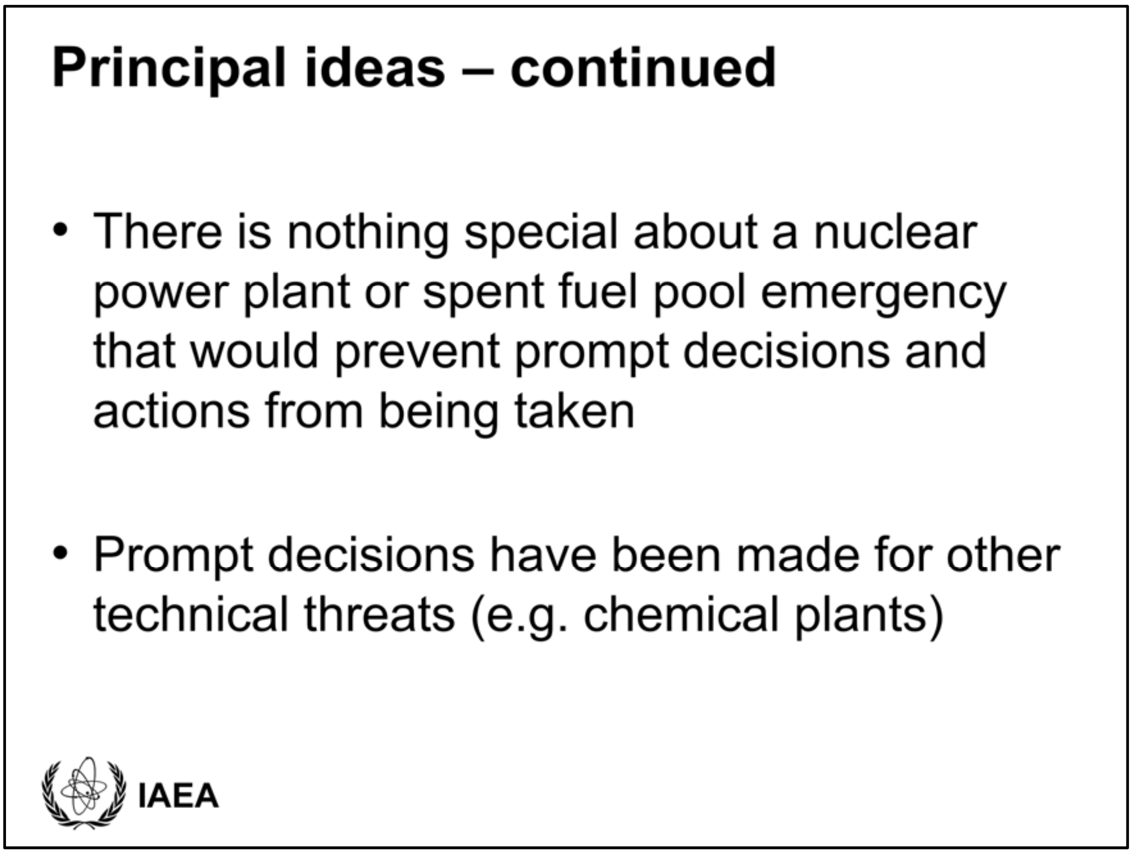
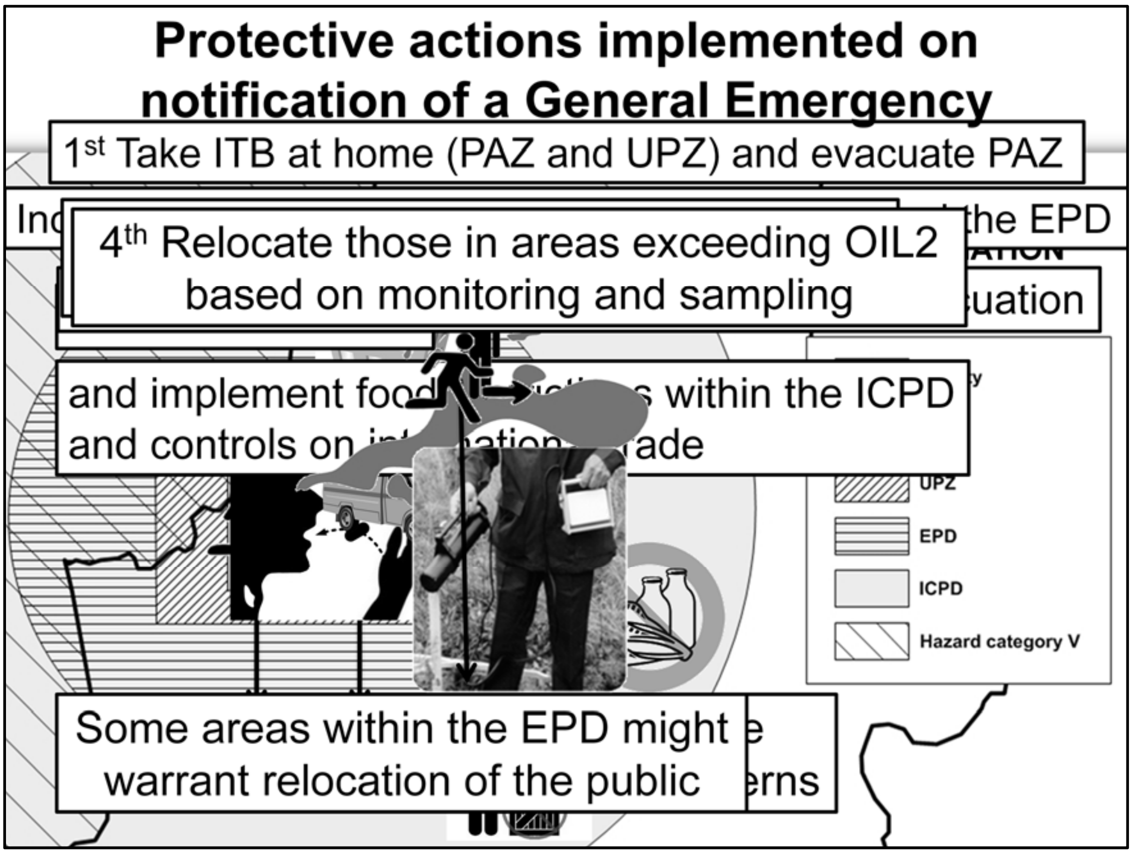
The principal ideas of this training course are that if a severe emergency involving a nuclear power plant or spent fuel pool takes place:

- The response must be very quick and preplanned to be effective; and
- An effective response can be ensured through the use of basic tools and understanding.



It is important to emphasize that there is nothing special about a nuclear power plant or spent fuel pool emergency that would prevent prompt decisions and actions from being taken.
Past experience has demonstrated that prompt decisions have been made for other technical threats (e.g. chemical plants).



This slide shows the protective actions that need to be implemented following a severe emergency at a nuclear power plant or spent fuel pool.
Note to lecturer – click for animation to begin – step 4 ‘Relocate those in areas exceeding OIL2 based on monitoring and sampling’ is the end of the animation.

Abbreviations:
ITB – iodine thyroid blocking
PAZ – precautionary action zone
UPZ – urgent protective action planning zone
EPD – extended planning distance
ICPD – ingestion and commodities planning distance
OIL – operational intervention level

How the training course will be organized:

- Pre-training course test
- PowerPoint presentations
- Discussions held at the end of each day for questions and answers
- A table top exercise scheduled later in the week to provide an opportunity to work together

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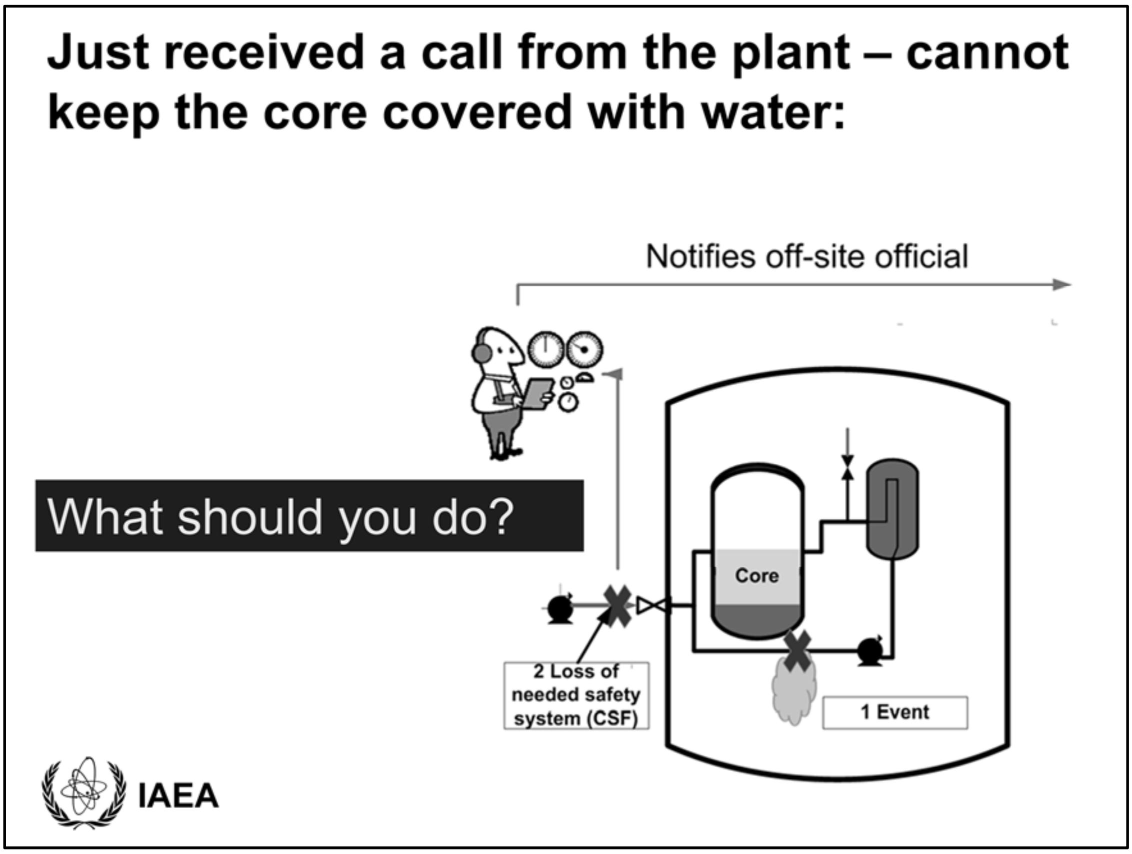
The training course will be organized as follows:

- Pre-training course test that will be distributed at the end of this module;
- 11 Modules given as PowerPoint presentations;
- Discussions held at the end of each day for questions and answers; and
- A table top exercise scheduled later in the training course. It will provide an opportunity to work together and apply the knowledge learnt.

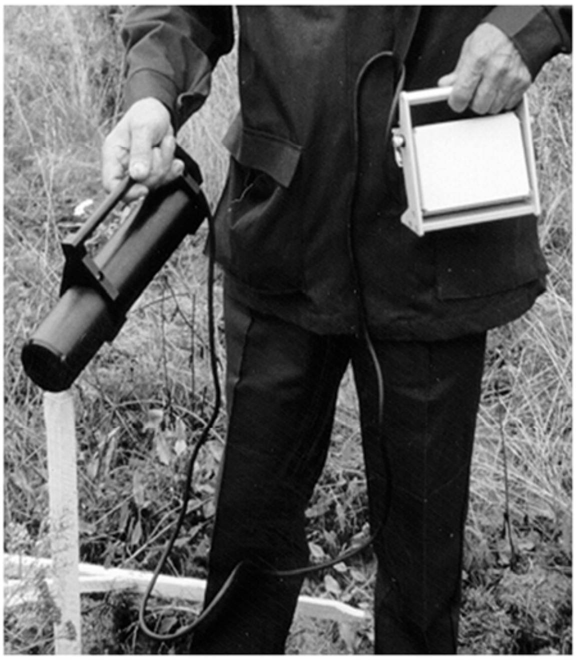


Note to lecturer – the next few slides are questions that participants will be expected to answer after completing the training course. The questions are to help indicate to the participants the subject areas that will be covered during the training course.

Ask participants:

What they should do if they just receive a call from the plant and the operator is advising that they cannot keep the core covered with water?

Dose rate is 50μSv/h at 1 m above the ground – what should you do?



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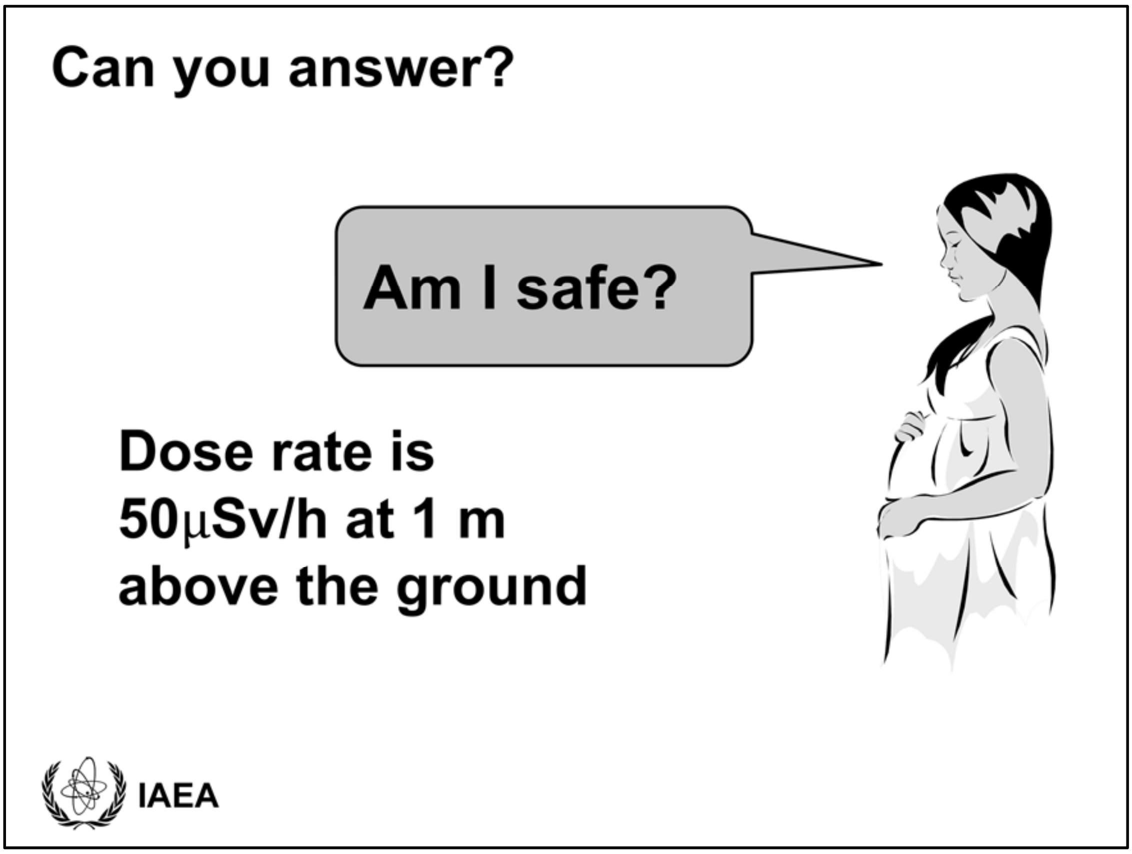
Ask participants:

What would they do if the dose rate is 50μSv/h measured at 1 m above the ground?



Ask participants:

Could they provide an answer to a pregnant woman asking 'Am I safe?' if the dose rate is $50\mu Sv/h$ measured at 1 m above the ground outside her house?

This training course is focused on the following issues:

- Nuclear power plant operators may not recognize that they have a severe emergency
- Off-site officials may not act promptly if notified of a severe emergency
- The public may not be provided with the clear information they need to protect themselves

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This training course is focused on the following issues, which past experience has demonstrated can happen:

- Nuclear power plant operators may not recognize that they have a severe emergency;
- Off-site officials may not act promptly if notified of a severe emergency; and
- The public may not be provided with the clear information they need to protect themselves.

This could result in:

- Deaths or injuries that could have been prevented
- Increased cancer incidence that could have been prevented
- Inappropriate and damaging actions that could have been prevented, such as unsafe evacuations, abortions or unwarranted restrictions on imports

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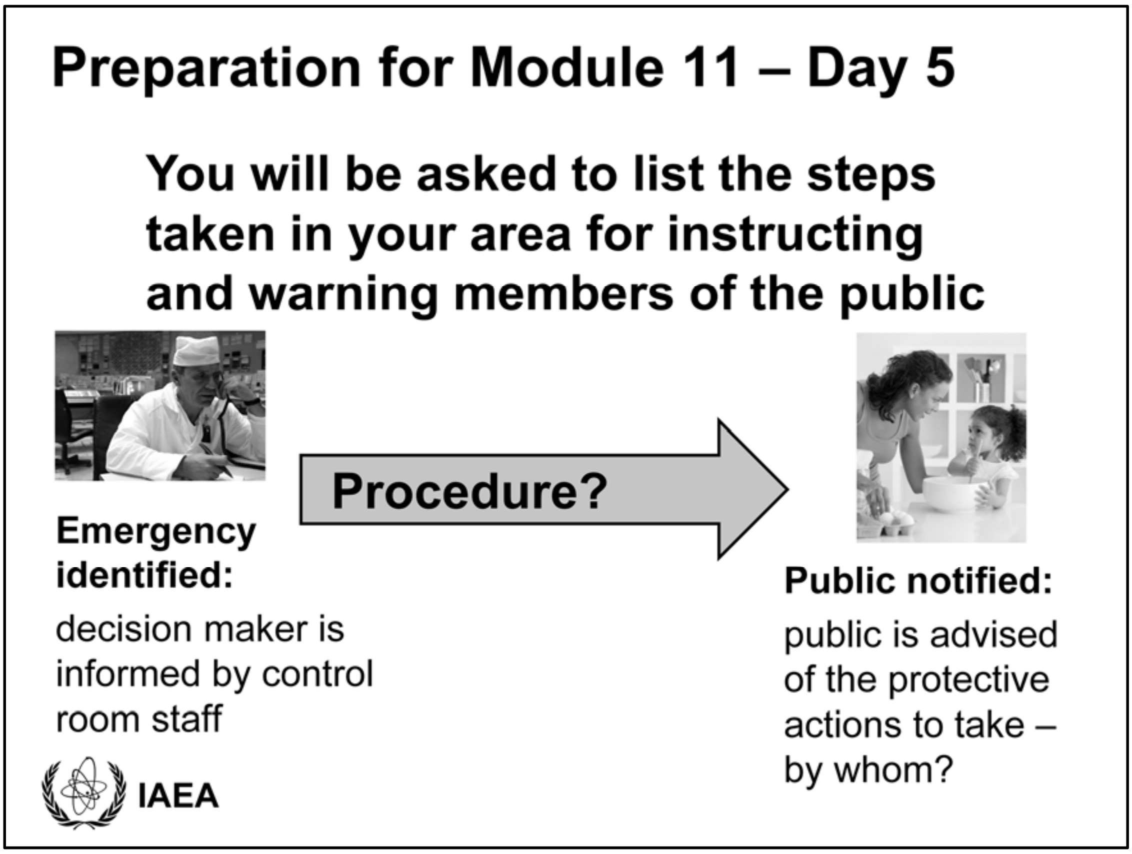
The focus on these issues is due to an emergency at a nuclear power plant involving damage to fuel in the reactor core or in a spent fuel pool can cause deaths, severe health effects and psychological effects, and can also have economic and sociological consequences affecting the public.

These effects can be prevented or mitigated by the prompt implementation of protective actions and other response actions.

In an emergency, various measured quantities, such as dose rate, food concentration, and calculated doses are reported and often used for explaining the possible health hazard from radioactive material released from a reactor core or spent fuel pool. This has often been done incorrectly, which has led to significant confusion between experts, decision makers and the public, resulting in the public taking unjustified actions that do more harm than good in the belief that they are protecting themselves and their families.



Note to instructor: Module 11 will be held on day 5 of this training course and participants should be advised to have their answer prepared for then. An example of what is expected from the participants is provided on the following two slides.

The instructor should explain that on Day 5 of the training course an activity will be held in the framework of Module 11: participants will be asked to list the steps taken in their area for instructing and warning members of the public.

In preparation for this activity, participants should ensure that they will be able to explain the procedures in place, from when the emergency is identified by the control room staff, the decision maker is informed and the public is advised of the protective actions to take.

Picture by: *Dana Sacchetti and Gill Tudor*
http://www.iaea.org/newscenter/focus/chernobyl/25years/

Example of steps taken – procedures for an NPP in U.S.A.

Local officials are required to notify the public within approximately 15 minutes of an event that may require the public to take protective actions.

The steps are:

1. Operator notifies local emergency response centre – staffed 24 hours a day, 7 days a week
2. Local emergency response centre authenticates notification (calls operator back to confirm emergency)

This slide provides an example of the steps taken for notifying the public for one of the NPPs in the U.S.A. It can be used to help the instructor explain to participants the activity on the previous slide.

For this particular NPP, local officials are required to notify the public within approximately 15 minutes of an event that may require the public to take protective actions.

1) The operator notifies the local emergency response centre – staffed 24 hours a day, 7 days a week.
2) The local emergency response centre authenticates the notification (calls operator back to confirm emergency).

Source:
Dominion, 'Nuclear Emergency Preparedness',
https://www.dom.com/about/stations/nuclear/emergency-plans/index.jsp

https://www.dom.com/about/stations/nuclear/millstone/pdf/millstone_guidebook.pdf

Example of steps taken – procedures for an NPP in U.S.A

3. Local officials are notified by the local emergency response centre
4. Emergency sirens located within 16 km alert the public to turn on radio or television and listen for further instructions (considers meteorological conditions and time of day)
5. Emergency services vehicles equipped with public address systems also alert public

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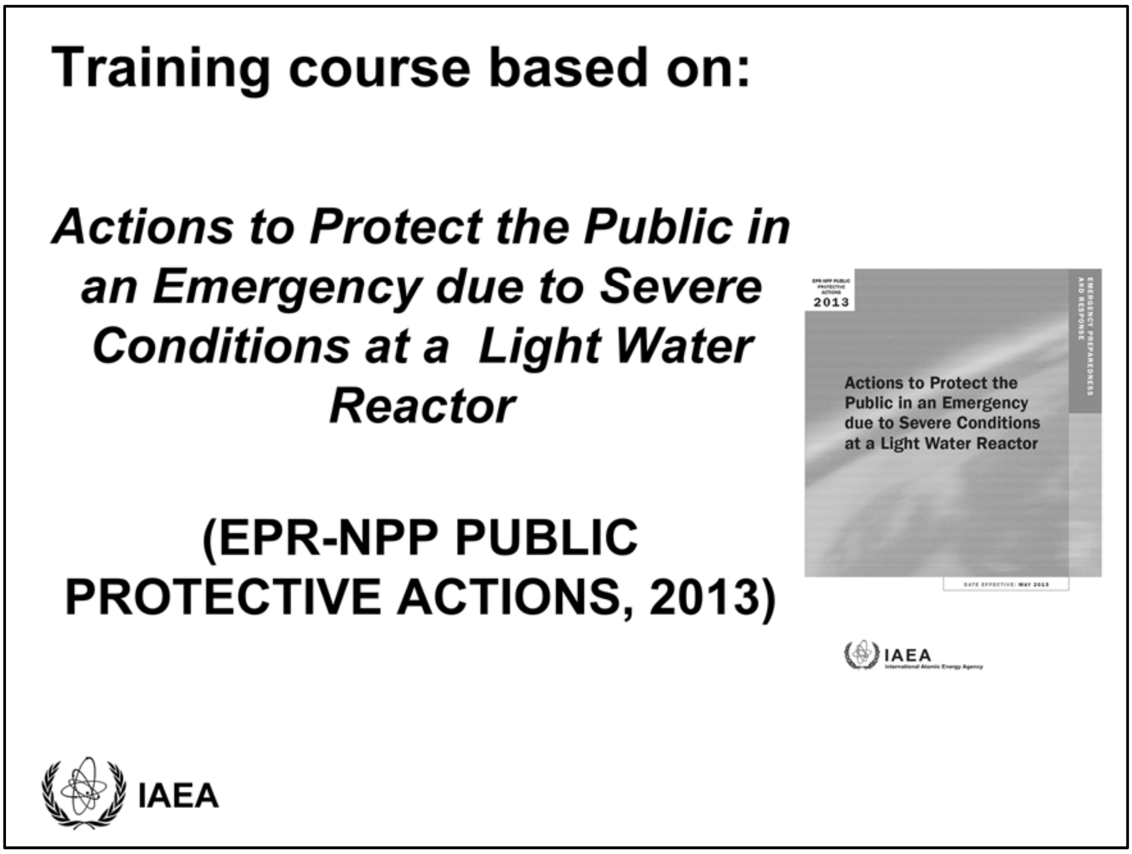
3) Local officials are notified by the local emergency response centre.
4) Emergency sirens located within 16 km alert the public to turn on radio or television and listen for further instructions (instructions are given based on meteorological conditions and the time of day of the emergency – adverse weather (e.g. snow) evacuation may be required to be delayed until safe evacuation is possible. An emergency during the day when children are at school will require instructions on evacuation advising parents they are not required to collect their children from school. Parents should proceed to evacuate the area, as arrangements are in place for the children's evacuation and they will meet at the predesignated evacuation shelter.
5) Emergency services vehicles equipped with public address systems also alert the public.

Source:
Dominion, 'Nuclear Emergency Preparedness',
https://www.dom.com/about/stations/nuclear/emergency-plans/index.jsp

https://www.dom.com/about/stations/nuclear/millstone/pdf/millstone_guidebook.pdf



This training course is based on the material contained in the EPR publication *Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor* (EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013).

Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

PRE-WORKSHOP TEST

Quantities and units

1. Draw lines between each item in each column, matching up each quantity, descriptor and unit.

Effective dose	Accounts for cancer sensitivity	Sievert (Sv)
Absorbed dose	Disintegration rate	Sievert (Sv)
Personal dose equivalent	Energy deposited	Becquerel (Bq)
Activity	Accounts for radiation types	Gray (Gy)
Equivalent dose	Instrument reading in the field	Sievert (Sv)
Ambient dose equivalent	Individual dosimeter exposure	Sievert (Sv)

2. Which of the following types of radiation emitted are of concern for the public exposure following a reactor fuel emergency *(circle all applicable)*?
    a. Alpha
    b. Beta
    c. X-rays
    d. Neutrons
    e. Gamma

3. Write down the symbol for the following:
    a. micro ____
    b. milli ____
    c. mega ____
    d. nano ____
    e. tera ____
    f. 10^3 ____
    g. 10^{-6} ____
    h. 10^9 ____

4. Dose is meaningless for use in communication with the public unless put in terms of health effects *(circle one)*.
    a. True.
    b. False.

Health Effects

5. For a severe reactor or spent fuel pool emergency, indicate which are important sources of public exposure off-site and the type of exposure: external exposure (E), internal exposure (I), both (E+I), not important (N).
    a. Skin contamination. ____
    b. Plume immersion. ____
    c. Direct radiation from the reactor fuel. ____
    d. Eating contaminated vegetables. ____
    e. Drinking milk from animals grazing in the area around the plant. ____
    f. Ground contamination. ____

6. Indicate which of the following are characteristic of severe deterministic effects (D) and which are characteristic of stochastic effects (S).

    a. Effect has a threshold. ____
    b. Risk of effect increases with dose. ____
    c. Severity of effect increases with dose. ____
    d. Cancer. ____
    e. Skin burns. ____
    f. Occurs shortly after dose. ____
    g. Hypothyroidism. ____
    h. Thyroid cancer. ____
    i. Long latency period. ____

7. About how many excess cancer deaths have there been from the Hiroshima and Nagasaki bombs out of 9,335 observed fatal cases of solid cancer *(circle one)*?
    a. 50
    b. 500
    c. 5,000
    d. 50,000
    e. 500,000

8. Which of these have been observed off the site as likely resulting from the Chernobyl accident *(circle all applicable)*?
    a. Increased fatalities.
    b. Increased solid tumours in adults.
    c. Increased leukemia amongst children.
    d. Increased thyroid cancer in children.

9. What is the principal question asked by members of the public following a severe nuclear power plant emergency?

    ____

10. Termination of a pregnancy at fetal doses of less than 100 mGy is not justified based upon radiation risk *(circle one)*.
    a. True.
    b. False.

11. What is the minimum whole body dose from external exposure (effective dose) to a large population that is needed to be able to see an increase in the incidence rate of cancer years later *(circle one)*?
    a. 1 mSv
    b. 10 mSv
    c. 100 mSv
    d. 1 Sv
    e. 10 Sv

Reactor and Spent Fuel Pool Emergencies

12. Control room staff will have no indication of conditions leading to severe fuel damage *(circle one)*.
    a. True.
    b. False.

13. Control room staff may have no way of knowing when a release might occur if there is severe fuel damage *(circle one)*.
    a. True.
    b. False.

14. After the core of a reactor is uncovered (no longer covered with water) when will the fuel pins start to burn in the steam and release large amounts of radioactive material from the fuel – the point at which a severe release is possible *(circle one)*?
    a. 10 – 20 minutes.
    b. 20–40 minutes.
    c. 40–60 minutes.
    d. > 60 minutes.

15. Number these emergency classification levels in the IAEA system in order of most severe (1) to least significant (3):
    a. General ____
    b. Alert ____
    c. Site area ____

16. You are the off-site decision maker near a nuclear power plant. The plant notifies you that they have lost the capability to keep the core cool. The appropriate actions are to *(circle all applicable)*:
    a. Begin pre-planned public protective actions immediately.
    b. Get an independent assessment of the reactor conditions at the plant.
    c. Perform a dose projection.
    d. Meet with local officials to decide on the best actions to be taken.

Release and Environmental Impact Characteristics

17. A severe release from the plant that is likely to cause health effects off site is likely to be monitored and so the start and magnitude of the release will be known *(circle one)*.
    a. True.
    b. False.

18. Which of the following characteristics of a release are likely to be known *early on,* when protective action decisions need to be made *(circle all applicable)*?
    a. Timing.
    b. Duration.
    c. Size.
    d. Composition.

19. The information provided early on in the emergency by monitoring teams will probably be *(circle all applicable)*:
    a. Inconsistent and conflicting.
    b. Very limited.
    c. Crucial for decision making.

20. For each of these types of monitoring, pick the length of time that previous experience has shown it takes before results are available that can be used as a basis for decision making after a release. *(Pick the best one from: 1) hours, 2) days, or 3) weeks.*
    a. Aerial surveys by fixed wing aircraft. ____
    b. Vehicle born surveys. ____
    c. Soil sampling. _____

21. Deposition is typically very uneven over a large area. What one factor tends to have the biggest influence on this *(circle one)*?
    a. Wind velocity.
    b. Ground topography.
    c. Rain.
    d. Cities.
    e. Trees.

22. Dose projection methods were used to decide the initial public protective actions to be taken during the emergency at the Fukushima nuclear power plant *(circle one)*.
    a. True.
    b. False.

Public and Media Response

23. Which of the following have been observed in the public's response to radiological emergencies *(circle all applicable)*.
    a. Taking official protective action recommendations at distances much further than had been advised.
    b. Not taking official protective action recommendations at all.
    c. Following advice given over the internet whether or not the source is credible.
    d. Responding to rumours in case they are true.

24. When communicating protective action recommendations, the public and media are most concerned that which of the following groups were considered *(circle all applicable)*.
    a. Old and infirm.
    b. Young children.
    c. Young couples.
    d. Pregnant women.
    e. Working men.

25. Who are the 'worried well' *(circle one)*?
    a. People who were well, but have become ill from worry.
    b. People who are well (and likely to remain so) yet still demand monitoring and medical assessment.
    c. People who have an illness, but are worried about being well again.

Protective Action Objectives, Generic and Operational Criteria

26. Which of the following are examples of urgent protective actions that should be taken within hours (U) and which are examples of early protective actions that should be taken within days to weeks (E)?
    a. Estimating the dose to those who were in the area to determine if medical follow up is warranted. ____
    b. Evacuating or providing substantial shelter. ____
    c. Sampling and restricting food, milk from animals grazing in the area and rainwater. ____
    d. Taking iodine thyroid blocking (ITB) agents. ____
    e. Reducing inadvertent ingestion. ____
    f. Stopping consumption/distribution of all local produce, milk from animals grazing in the area and rainwater. ____
    g. Identifying those needing a medical examination or counselling. ____
27. Match each term with the most relevant related description by drawing lines between them.

Emergency action level actions	International dose criteria warranting
Generic criteria	Abnormal facility conditions
Operational intervention level	Field and laboratory measurements

28. The international generic criterion requiring sheltering or evacuation is a projected total effective dose in seven days of *(circle one)*:
    a. 100 μSv
    b. 1 mSv
    c. 10 mSv
    d. 100 mSv
    e. 1 Sv

29. Which of the following exposure pathways is/are <u>most important</u> *during* a release *(circle all that apply)*?
    a. Inhaling radioactive material in the plume.
    b. External gamma radiation from radioactive material deposited on the ground, called ground shine.
    c. Inadvertent ingestion of soil or dirt.
    d. Ingestion of contaminated vegetables and milk.
    e. External beta radiation from radioactive material deposited on the skin.

30. Which of the following exposure pathways is/are <u>most important</u> *after* a release *(circle all that apply)*?
    a. Inhaling radioactive material in the plume.
    b. External gamma radiation from radioactive material deposited on the ground, called ground shine.
    c. Inadvertent ingestion of soil or dirt.
    d. Ingestion of contaminated vegetables and milk.
    e. External beta radiation from radioactive material deposited on the skin.

The Threat from a Severe Fission Product Release and Protective Action Effectiveness

31. All deterministic effects can be avoided if evacuation is conducted ______ release.

32. Sheltering should only be used for a short period (1 or 2 days). *(circle one)*.
    a. True.
    b. False.

33. Unsafe evacuations of critically ill patients has, in the past, endangered the lives of those being evacuated and resulted in deaths that may have been preventable. *(circle one)*.
    a. True.
    b. False.

34. Iodine thyroid blocking is only really effective if taken before or within ____ hours of the time the person inhales or ingests radioactive iodine.
    a. 2
    b. 5

c. 10
d. 100

35. On detection of conditions that will lead to damage to the fuel in the reactor core, a General Emergency would be declared and an immediate (speedy) evacuation should be started out to *(circle one)*:
    a. 3 km
    b. 15 km
    c. 30 km
    d. 50 km
    e. 300 km

36. Restrictions on consumption of food, milk and water may well be needed out to which distance, in the event of a release following damage to the fuel in the core of the reactor *(circle one)*.
    a. 10 km
    b. 20 km
    c. 50 km
    d. 100 km
    e. Beyond 300 km

37. Those responsible for protecting the public (i.e. usually the decision maker), may not have the knowledge or expertise in order to ensure this is done effectively unless prepared in advance *(circle one)*:
    a. True
    b. False

Overview of the IAEA publication

Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

Module 3

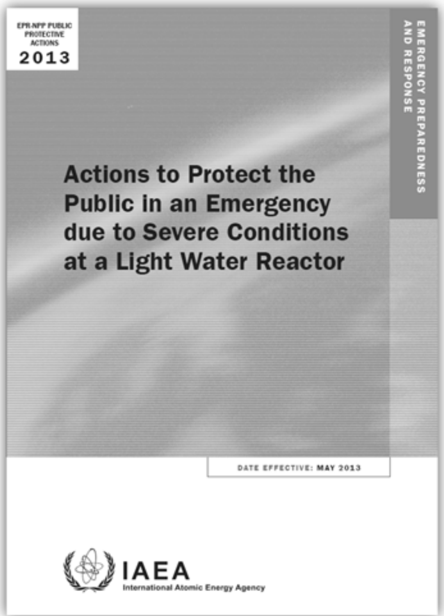
Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

IAEA

International Atomic Energy Agency

Lecture: L-03 Overview of the IAEA publication *Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor*
Purpose: To provide an overview and opportunity to use the IAEA publication: *Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor (EPR-NPP Public Protective Actions, 2013).*
Learning objectives: Upon completion of this lecture, the participants will: be familiar with the publication and have had an opportunity to use the publication during a questionnaire activity.
Duration: 1.5 hours

Please take out your document



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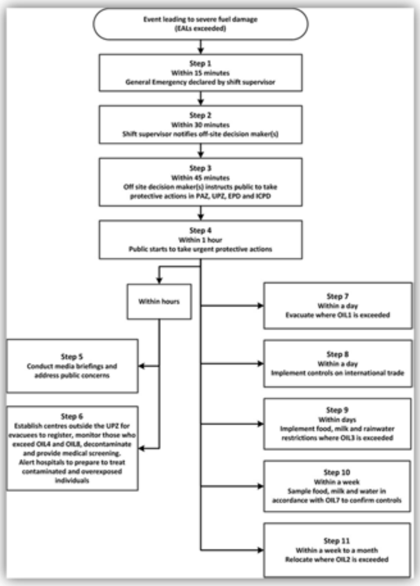
2. OVERALL CONCEPTS

- Concept of operations
- Summary of protective actions and other response actions
- Response actions for those potentially exposed
- Tools to support decision making
- Response to other emergencies



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3. EMERGENCY CLASSIFICATION SYSTEM

- Alert
- Facility Emergency
- Site Area Emergency
- General Emergency

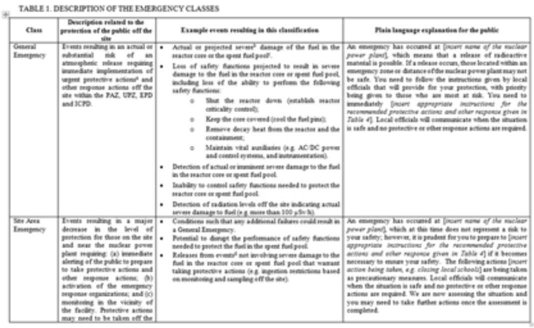

TABLE 1. DESCRIPTION OF THE EMERGENCY CLASSES

Class	Description related to the protection of the public off the site	Example events resulting in this classification	Plain language explanation for the public
General Emergency	Events resulting in an actual or substantial risk of an atmospheric release requiring immediate implementation of urgent protective actions[a] and other response actions off the site within the PAZ, UPZ, EPD and ICPD.	• Actual or projected severe[b] damage of the fuel in the reactor core or the spent fuel pool[c]. • Loss of safety functions projected to result in severe damage to the fuel in the reactor core or spent fuel pool, including loss of the ability to perform the following safety functions: ○ Shut the reactor down (establish reactor criticality control); ○ Keep the core covered (cool the fuel pins); ○ Remove decay heat from the reactor and the containment; ○ Maintain vital auxiliaries (e.g. AC/DC power and control systems, and instrumentation). • Detection of actual or imminent severe damage to the fuel in the reactor core or spent fuel pool. • Inability to control safety functions needed to protect the reactor core or spent fuel pool. • Detection of radiation levels off the site indicating actual severe damage to fuel (e.g. more than 100 μSv/h).	An emergency has occurred at [*insert name of the nuclear power plant*], which means that a release of radioactive material is possible. If a release occurs, those located within an emergency zone or distance of the nuclear power plant may not be safe. You need to follow the instructions given by local officials that will provide for your protection, with priority being given to those who are most at risk. You need to immediately [*insert appropriate instructions for the recommended protective actions and other response given in Table 4*]. Local officials will communicate when the situation is safe and no protective or other response actions are required.
Site Area Emergency	Events resulting in a major decrease in the level of protection for those on the site and near the nuclear power plant requiring: (a) immediate alerting of the public to prepare to take protective actions and other response actions; (b) activation of the emergency response organizations; and (c) monitoring in the vicinity of the facility. Protective actions may need to be taken off the	• Conditions such that any additional failures could result in a General Emergency. • Potential to disrupt the performance of safety functions needed to protect the fuel in the spent fuel pool. • Releases from events[d] not involving severe damage to the fuel in the reactor core or spent fuel pool that warrant taking protective actions (e.g. ingestion restrictions based on monitoring and sampling off the site).	An emergency has occurred at [*insert name of the nuclear power plant*], which at this time does not represent a risk to your safety; however, it is prudent for you to prepare to [*insert appropriate instructions for the recommended protective actions and other response given in Table 4*] if it becomes necessary to ensure your safety. The following actions [*insert action being taken, e.g. closing local schools*] are being taken as precautionary measures. Local officials will communicate when the situation is safe and no protective or other response actions are required. We are now assessing the situation and you may need to take further actions once the assessment is completed.

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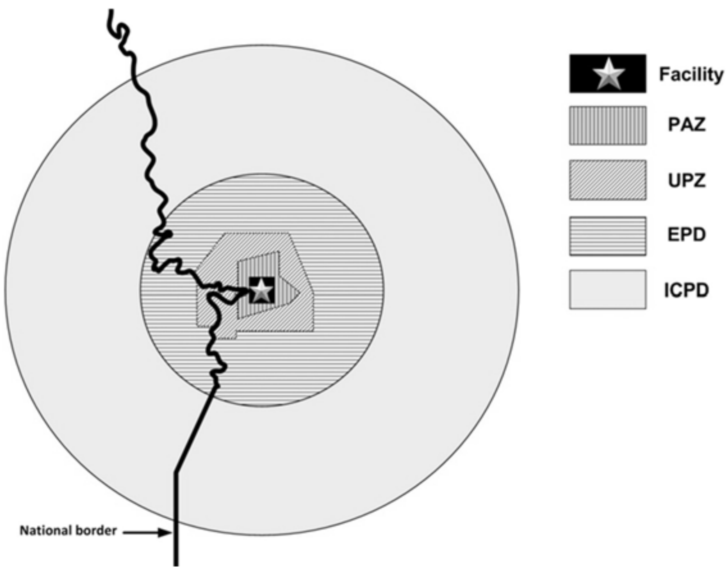
4. OFF-SITE EMERGENCY ZONES AND DISTANCES



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5. URGENT PROTECTIVE ACTIONS AND EARLY PROTECTIVE ACTIONS AND OTHER RESPONSE ACTIONS

- ITB
- Evacuation
- Sheltering
- Relocation
- Prevention of inadvertent ingestion
- Decontamination of individuals
- Food, milk and water restrictions
- Identification and management of exposed people
- Protection of international trade and commercial interests
- Stopping or relaxing response actions

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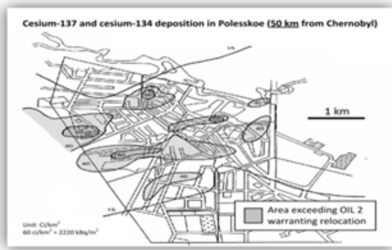
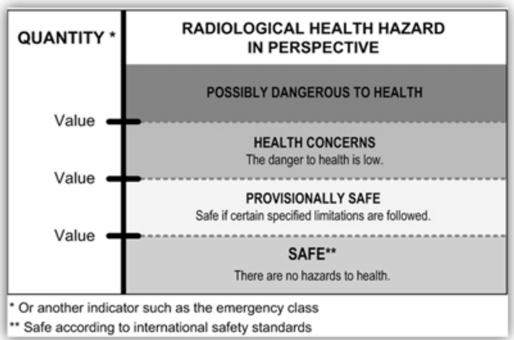
6. MONITORING AND COMPARISON WITH OPERATIONAL INTERVENTION LEVELS

- Operational intervention levels (OILs)
- Plain language explanations for OILs
- Contamination and hotspots
- Displaying monitoring results



7. COMMUNICATION WITH THE PUBLIC AND DECISION MAKERS

- Definition of ‘safe’
- Measured operational quantities in perspective in terms of the associated health hazard
- Common errors
- Doses in perspective in terms of the health hazard



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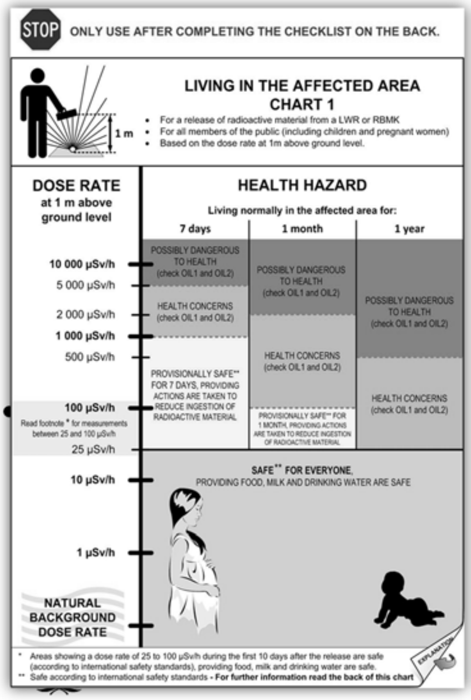

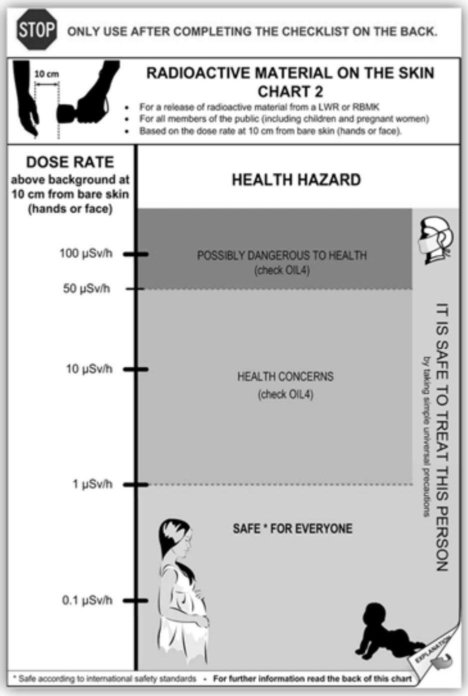

8. IMPLEMENTATION

- Interim implementation
- Minimum response capabilities checklist
- Changes in guidance compared to earlier publications

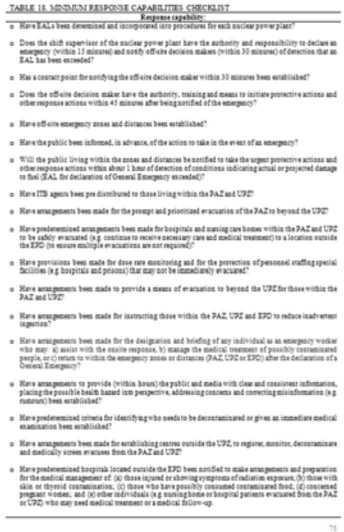

TABLE 18. MINIMUM RESPONSE CAPABILITIES CHECKLIST

Response capability:
◻ Have EALs been determined and incorporated into procedures for each nuclear power plant?
◻ Does the shift supervisor of the nuclear power plant have the authority and responsibility to declare an emergency (within 15 minutes) and notify off-site decision makers (within 30 minutes) of detection that an EAL has been exceeded?
◻ Has a contact point for notifying the off-site decision maker within 30 minutes been established?
◻ Does the off-site decision maker have the authority, training and means to initiate protective actions and other response actions within 45 minutes after being notified of the emergency?
◻ Have off-site emergency zones and distances been established?
◻ Have the public been informed, in advance, of the action to take in the event of an emergency?
◻ Will the public living within the zones and distances be notified to take the urgent protective actions and other response actions within about 1 hour of detection of conditions indicating actual or projected damage to fuel (EAL for declaration of General Emergency exceeded)?
◻ Have ITB agents been pre distributed to those living within the PAZ and UPZ?
◻ Have arrangements been made for the prompt and prioritized evacuation of the PAZ to beyond the UPZ?
◻ Have predetermined arrangements been made for hospitals and nursing care homes within the PAZ and UPZ to be safely evacuated (e.g. continue to receive necessary care and medical treatment) to a location outside the EPD (to ensure multiple evacuations are not required)?
◻ Have provisions been made for dose rate monitoring and for the protection of personnel staffing special facilities (e.g. hospitals and prisons) that may not be immediately evacuated?
◻ Have arrangements been made to provide a means of evacuation to beyond the UPZ for those within the PAZ and UPZ?
◻ Have arrangements been made for instructing those within the PAZ, UPZ and EPD to reduce inadvertent ingestion?
◻ Have arrangements been made for the designation and briefing of any individual as an emergency worker who may: a) assist with the onsite response, b) manage the medical treatment of possibly contaminated people, or c) return to within the emergency zones or distances (PAZ, UPZ or EPD) after the declaration of a General Emergency?
◻ Have arrangements to provide (within hours) the public and media with clear and consistent information, placing the possible health hazard into perspective, addressing concerns and correcting misinformation (e.g. rumours) been established?
◻ Have predetermined criteria for identifying who needs to be decontaminated or given an immediate medical examination been established?
◻ Have arrangements been made for establishing centres outside the UPZ, to register, monitor, decontaminate and medically screen evacuees from the PAZ and UPZ?
◻ Have predetermined hospitals located outside the EPD been notified to make arrangements and preparation for the medical management of: (a) those injured or showing symptoms of radiation exposure; (b) those with skin or thyroid contamination; (c) those who have possibly consumed contaminated food; (d) concerned pregnant women; and (e) other individuals (e.g. nursing home or hospital patients evacuated from the PAZ or UPZ) who may need medical treatment or a medical follow-up.

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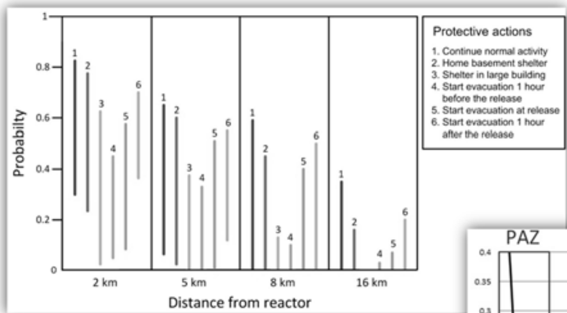
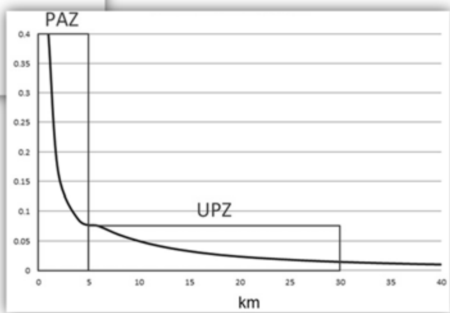
APPENDIX I – BASIS FOR THE SUGGESTED SIZE AND PROTECTIVE ACTIONS WITHIN THE EMERGENCY ZONES AND DISTANCES





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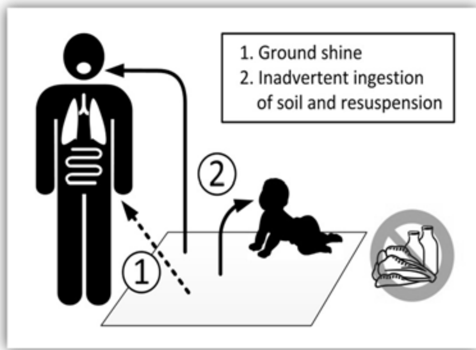
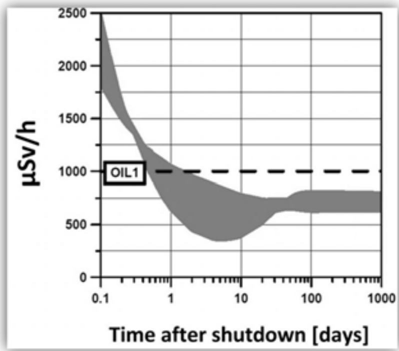
APPENDIX II – DESCRIPTION OF DEFAULT OPERATIONAL INTERVENTION LEVELS





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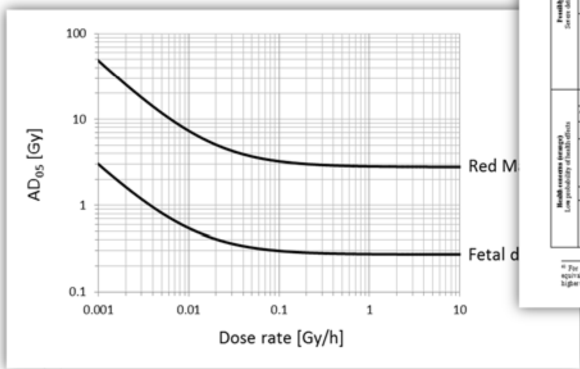
APPENDIX III – SYSTEM FOR PLACING THE RADIOLOGICAL HEALTH HAZARD IN PERSPECTIVE



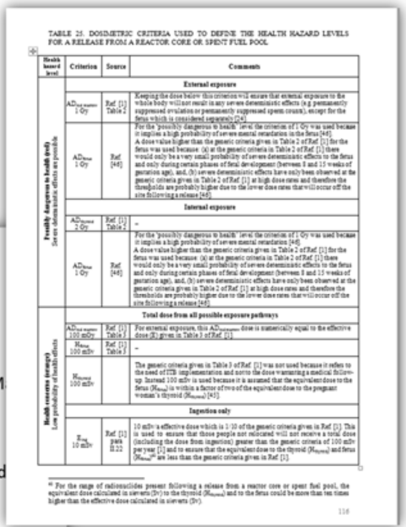


TABLE 25. DOSIMETRIC CRITERIA USED TO DEFINE THE HEALTH HAZARD LEVELS FOR A RELEASE FROM A REACTOR CORE OR SPENT FUEL POOL

Health hazard level	Criterion	Source	Comments
			External exposure
Possibly dangerous to health (red) Severe deterministic effects are possible	$AD_{red\ marrow}$ 1 Gy	Ref. [1] Table 2	Keeping the dose below this criterion will ensure that external exposure to the whole body will not result in any severe deterministic effects (e.g. permanently suppressed ovulation or permanently suppressed sperm count), except for the fetus which is considered separately [24].
	AD_{fetus} 1 Gy	Ref. [46]	For the 'possibly dangerous to health' level the criterion of 1 Gy was used because it implies a high probability of severe mental retardation in the fetus [46]. A dose value higher than the generic criteria given in Table 2 of Ref. [1] for the fetus was used because: (a) at the generic criteria in Table 2 of Ref. [1] there would only be a very small probability of severe deterministic effects to the fetus and only during certain phases of fetal development (between 8 and 15 weeks of gestation age), and, (b) severe deterministic effects have only been observed at the generic criteria given in Table 2 of Ref. [1] at high dose rates and therefore the thresholds are probably higher due to the lower dose rates that will occur off the site following a release [46].
			Internal exposure
	$AD_{thyroid}$ 2 Gy	Ref. [1] Table 2	–
	AD_{fetus} 1 Gy	Ref. [46]	For the 'possibly dangerous to health' level the criterion of 1 Gy was used because it implies a high probability of severe mental retardation [46]. A dose value higher than the generic criteria given in Table 2 of Ref. [1] for the fetus was used because: (a) at the generic criteria in Table 2 of Ref. [1] there would only be a very small probability of severe deterministic effects to the fetus and only during certain phases of fetal development (between 8 and 15 weeks of gestation age), and, (b) severe deterministic effects have only been observed at the generic criteria given in Table 2 of Ref. [1] at high dose rates and therefore the thresholds are probably higher due to the lower dose rates that will occur off the site following a release [46].
			Total dose from all possible exposure pathways
Health concerns (orange) Low probability of health effects	$AD_{red\ marrow}$ 100 mGy	Ref. [1] Table 3	For external exposure, this $AD_{red\ marrow}$ dose is numerically equal to the effective dose (E) given in Table 3 of Ref. [1].
	H_{fetus} 100 mSv	Ref. [1] Table 3	–
	$H_{thyroid}$ 100 mSv		The generic criteria given in Table 3 of Ref. [1] was not used because it refers to the need of ITB implementation and not to the dose warranting a medical follow-up. Instead 100 mSv is used because it is assumed that the equivalent dose to the fetus (H_{fetus}) is within a factor of two of the equivalent dose to the pregnant woman's thyroid ($H_{thyroid}$) [45].
			Ingestion only
	E_{ing} 10 mSv	Ref. [1] para. II.22	10 mSv is effective dose which is 1/10 of the generic criteria given in Ref. [1]. This is used to ensure that those people not relocated will not receive a total dose (including the dose from ingestion) greater than the generic criteria of 100 mSv per year [1] and to ensure that the equivalent dose to the thyroid ($H_{thyroid}$) and fetus (H_{fetus})[40] are less than the generic criteria given in Ref. [1].

[40] For the range of radionuclides present following a release from a reactor core or spent fuel pool, the equivalent dose calculated in sieverts (Sv) to the thyroid ($H_{thyroid}$) and to the fetus could be more than ten times higher than the effective dose calculated in sieverts (Sv).

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APPENDIX IV – REGISTRATION FORM

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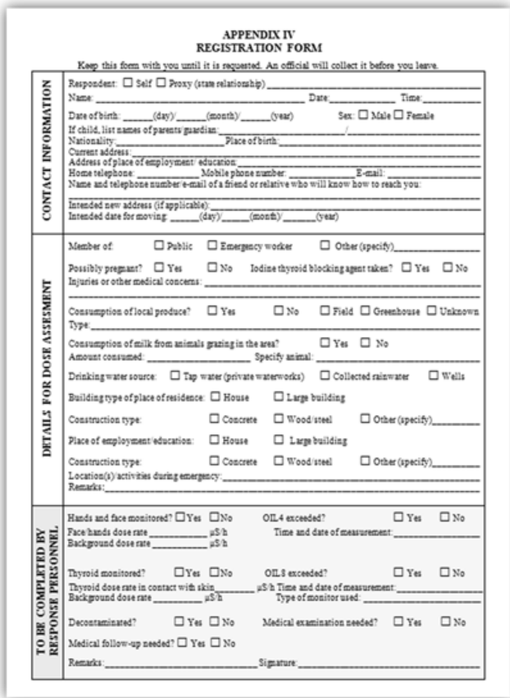

APPENDIX IV
REGISTRATION FORM

Keep this form with you until it is requested. An official will collect it before you leave.

CONTACT INFORMATION

Respondent: ☐ Self ☐ Proxy (state relationship) ____________
Name: ____________ Date: ________ Time: ________
Date of birth: ______(day)/______(month)/______(year) Sex: ☐ Male ☐ Female
If child, list names of parents/guardian: ____________ / ____________
Nationality: ____________ Place of birth: ____________
Current address: ____________
Address of place of employment/ education: ____________
Home telephone: ________ Mobile phone number: ________ E-mail: ________
Name and telephone number/e-mail of a friend or relative who will know how to reach you:
____
Intended new address (if applicable): ____________
Intended date for moving: ______(day)/______(month)/______(year)

DETAILS FOR DOSE ASSESMENT

Member of: ☐ Public ☐ Emergency worker ☐ Other (specify)________
Possibly pregnant? ☐ Yes ☐ No Iodine thyroid blocking agent taken? ☐ Yes ☐ No
Injuries or other medical concerns: ____________
____
Consumption of local produce? ☐ Yes ☐ No ☐ Field ☐ Greenhouse ☐ Unknown
Type: ____________
Consumption of milk from animals grazing in the area? ☐ Yes ☐ No
Amount consumed: ________ Specify animal: ________
Drinking water source: ☐ Tap water (private waterworks) ☐ Collected rainwater ☐ Wells
Building type of place of residence: ☐ House ☐ Large building
Construction type: ☐ Concrete ☐ Wood/steel ☐ Other (specify)________
Place of employment/education: ☐ House ☐ Large building
Construction type: ☐ Concrete ☐ Wood/steel ☐ Other (specify)________
Location(s)/activities during emergency: ____________
Remarks: ____________

TO BE COMPLETED BY RESPONSE PERSONNEL

Hands and face monitored? ☐ Yes ☐ No OIL4 exceeded? ☐ Yes ☐ No
Face/hands dose rate ________ µS/h Time and date of measurement: ________
Background dose rate ________ µS/h
Thyroid monitored? ☐ Yes ☐ No OIL8 exceeded? ☐ Yes ☐ No
Thyroid dose rate in contact with skin________ µS/h Time and date of measurement: ________
Background dose rate ________ µS/h Type of monitor used: ________
Decontaminated? ☐ Yes ☐ No Medical examination needed? ☐ Yes ☐ No
Medical follow-up needed? ☐ Yes ☐ No
Remarks: ____________ Signature: ____________

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APPENDIX V – TYPICAL QUESTIONS AND CONCERNS OF THE PUBLIC IN A NUCLEAR OR RADIOLOGICAL EMERGENCY

- Am I safe?
- Can children play outside?
- Should I take measures to decontaminate my home (such as remove all topsoil from my garden)?
- What does “radiation levels 20 times above normal” mean?
- What could be the consequences for my health?
- …

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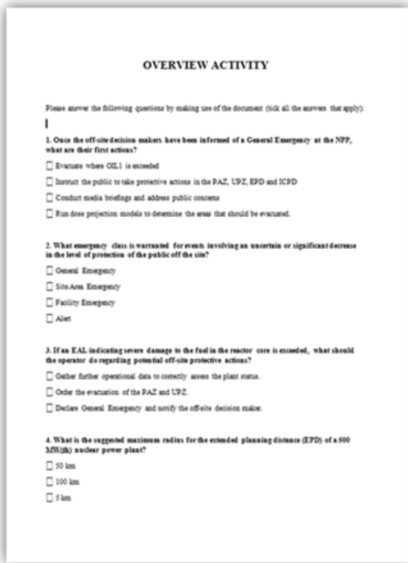
PLEASE ANSWER THE QUESTIONNAIRE (WITH THE AID OF THE PUBLICATION)

You will be asked to answer the questions in

45 minutes



OVERVIEW ACTIVITY

Please answer the following questions by making use of the document (tick all the answers that apply):

1. Once the off-site decision makers have been informed of a General Emergency at the NPP, what are their first actions?

- ☐ Evacuate where OIL1 is exceeded
- ☐ Instruct the public to take protective actions in the PAZ, UPZ, EPD and ICPD
- ☐ Conduct media briefings and address public concerns
- ☐ Run dose projection models to determine the areas that should be evacuated.

2. What emergency class is warranted for events involving an uncertain or significant decrease in the level of protection of the public off the site?

- ☐ General Emergency
- ☐ Site Area Emergency
- ☐ Facility Emergency
- ☐ Alert

3. If an EAL indicating severe damage to the fuel in the reactor core is exceeded, what should the operator do regarding potential off-site protective actions?

- ☐ Gather further operational data to correctly assess the plant status.
- ☐ Order the evacuation of the PAZ and UPZ.
- ☐ Declare General Emergency and notify the off-site decision maker.

4. What is the suggested maximum radius for the extended planning distance (EPD) of a 500 MW(th) nuclear power plant?

- ☐ 50 km
- ☐ 100 km
- ☐ 5 km

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OVERVIEW ACTIVITY

Please answer the following questions with the aid of the EPR-NPP Public Protective Actions document (tick all the answers that apply):

1. Once the off-site decision makers have been informed of a General Emergency at the nuclear power plant, what are their first actions?

- [ ] Evacuate where OIL1 is exceeded.
- [ ] Instruct the public to take protective actions in the PAZ, UPZ, EPD and ICPD.
- [ ] Conduct media briefings and address public concerns.
- [ ] Run dose projection models to determine the areas that should be evacuated.

2. What emergency class is warranted for events involving an uncertain or significant decrease in the level of protection of the public off the site?

- [ ] General Emergency
- [ ] Site Area Emergency
- [ ] Facility Emergency
- [ ] Alert

3. If an EAL indicating severe damage to the fuel in the reactor core is exceeded, what should the operator do regarding potential off-site protective actions?

- [ ] Gather further operational data to correctly assess the plant status.
- [ ] Order the evacuation of the PAZ and UPZ.
- [ ] Declare a General Emergency and notify the off-site decision maker.

4. What is the suggested maximum radius for the extended planning distance (EPD) of a 500 MW(th) nuclear power plant?

- [ ] 50 km
- [ ] 100 km
- [ ] 5 km

5. Patients from hospitals within the PAZ or UPZ should be evacuated to beyond the:

- [ ] PAZ
- [ ] UPZ
- [ ] EPD
- [ ] ICPD

6. In order to determine who needs subsequent medical follow-up, the doses should be estimated for:

- [ ] those within the PAZ and UPZ.
- [ ] those in areas where OIL1 or OIL2 was exceeded.
- [ ] those with a concentration of radioactive material on the skin exceeding OIL4.
- [ ] those with a dose rate from the thyroid exceeding OIL8.
- [ ] concerned pregnant women in the PAZ.
- [ ] those who may have consumed contaminated food, milk or water with concentrations exceeding OIL7.

7. Protective actions and other response actions can be taken immediately (without further assessment) based on quantities that are measured by a field monitoring instrument or determined by laboratory analysis. These quantities are called:

- [ ] Generic Criteria (GC)
- [ ] Emergency Action Levels (EALs)
- [ ] Operational Intervention Levels (OILs)

8. The Operational Intervention Level 3 is intended to be used for the:

- [ ] dose rate at 10 cm from skin
- [ ] dose rate at 1 m above ground
- [ ] radionuclide concentration

9. In an emergency, an object or person is to be referred to as contaminated only if the amount of radioactive material on or in that object or person is greater than:

- [ ] a predefined criterion, such as an OIL, which requires an action
- [ ] the standard amount of radioactive material usually found on that object or person

☐ zero.

10. When determining if and where protective actions and other response actions need to be taken based on environmental monitoring and sampling, decision makers need to consider characteristics such as:

☐ social conditions.

☐ the ability to define the area in a way understandable to the public.

☐ administrative and jurisdiction boundaries.

☐ the reliability of the measurement.

11. 0.01 mSv/h is being monitored at 1m above ground level in a certain district. Living normally in this area for 7 days is:

☐ possibly dangerous to health.

☐ there may be health concerns.

☐ provisionally safe, provided that actions are taken to reduce ingestion of radioactive material.

☐ safe for everyone, provided that food, milk and drinking water a safe.

12. Consuming milk with a concentration of 0.1 Bq/g of I-131 is:

☐ possibly dangerous to health.

☐ there may be health concerns.

☐ safe for everyone.

☐ cannot be assessed, more information is required.

13. The dose to the following organs needs to be assessed in order to determine the possible health hazard from radioactive material released from a reactor core or spent fuel pool:

☐ equivalent dose to the thyroid ($H_{thyroid,}$ mSv) from inhalation and ingestion.

☐ equivalent dose to the fetus ($H_{fetus,}$ mSv) from all exposure pathways.

☐ RBE weighted absorbed dose to the red marrow ($AD_{red\ marrow,}$ mGy) from external exposure.

14. An effective dose of 50 mSv:

☐ is not safe.

☐ is safe.

☐ may not be safe.

15. In developing OIL3 it was assumed that the members of the public most sensitive to radiation (e.g. children or pregnant women) would consume items for:

☐ 10 years

☐ 1 year

☐ 1 month

☐ 1 week

☐ 1 day

16. 'Hotspot' is defined as an area with ground deposition of radioactive material:

☐ higher than the standard deposition of radioactive material.

☐ resulting in an OIL or other predetermined criteria being exceeded.

☐ higher than the deposition of radioactive material of the surrounding areas.

17. 'EPD' stands for:

☐ emergency preparedness director.

☐ equivalent pulmonary dose.

☐ extended planning distance.

Quantities and Possible Health Effects Relevant for an Emergency at a Nuclear Power Plant

Module 4

Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

IAEA

International Atomic Energy Agency

Lecture:
L-04 Quantities and Possible Health Effects Relevant for an Emergency at a Nuclear Power Plant

Purpose:
To explain the quantities and possible health effects relevant for an emergency at a nuclear power plant.

Learning objectives: Upon completion of this lecture, the participants will:

- List and explain the primary terms used to describe radiation exposure and dose.
- Describe severe deterministic effects and stochastic effects and the potential for their occurrence following a release.
- State how the imprecise use of radiological quantities has caused confusion during emergencies.
- Explain why dose and other quantities are meaningless unless expressed in terms of health effects.

Author: Thomas MCKENNA **Revisions:** Phillip VILAR WELTER, Brian DODD, Eduardo LURASCHI

Duration: 1.5 hours

Learning objectives

- Upon completing this module, participants will be able to:
  - List and explain the primary terms used to describe radiation exposure and dose
  - Describe severe deterministic effects and stochastic effects and the potential for their occurrence following a release
  - State how the imprecise use of radiological quantities has caused confusion during emergencies
  - Explain why dose and other quantities are meaningless unless expressed in terms of health effects

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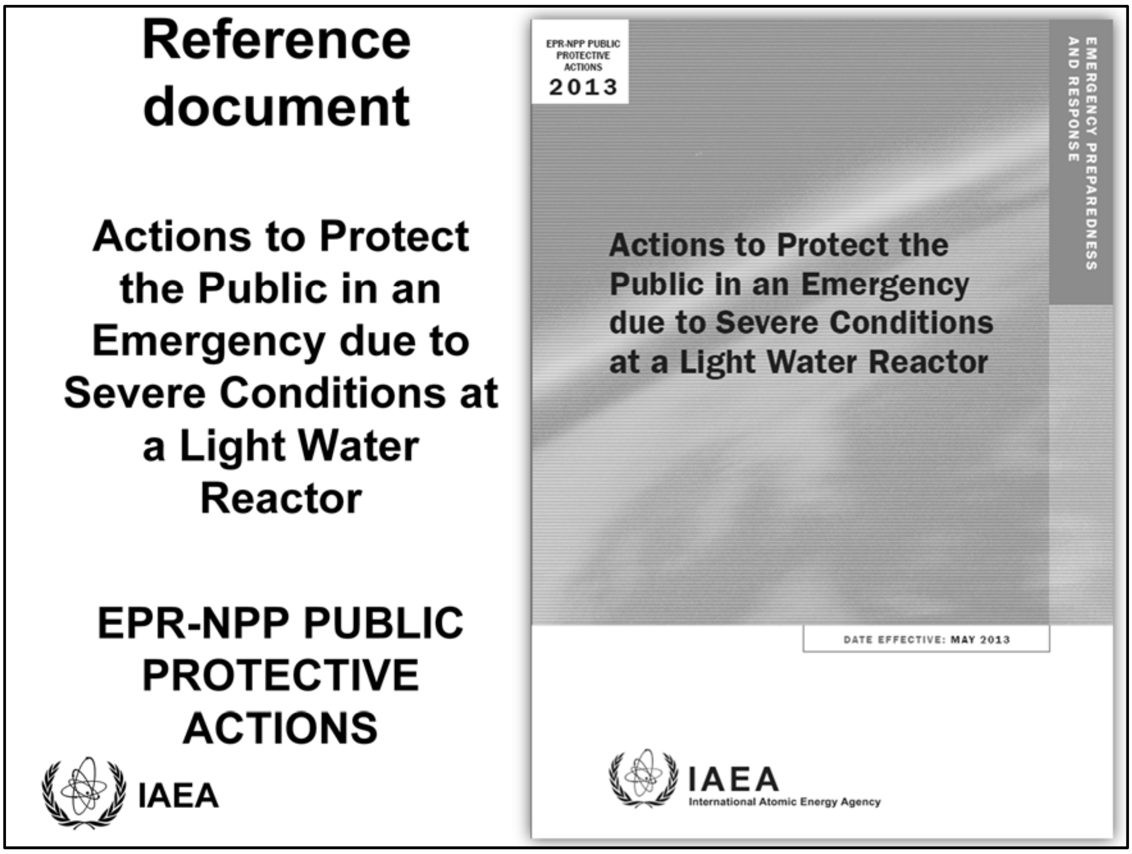

This presentation is based on the material contained in the EPR publication entitled Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor, EPR-NPP PUBLIC PROTECTIVE ACTIONS (2013).

References to pages tables figures in square brackets within this presentation are to this publication.

Radioactive Material, Radiation, Dose Quantities and Units, Health Effects

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Isotopes – radionuclides

- Elements can have many different isotopes, some of which are radioactive
  - These are called radioisotopes or radionuclides
  - Example: I-131, I-132, I-133, I-134, I-135
- Indicated by mass number in three different ways:

  ^{131}I, $^{131}_{53}I$, I-131
- The radiological hazard is different for each

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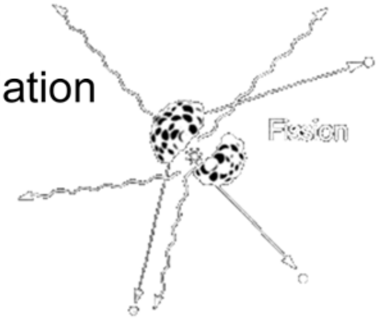
The same element can have different numbers of neutrons, these are called isotopes. If the isotope is unstable it is called a radioactive isotope (radioisotope) or radionuclide. The same element – for example iodine (symbol I) or cesium (symbol Cs) – can have many different radionuclides, some of which can be a significant radiological hazard and others are not. A radionuclide of an element is identified by its mass number. The mass number is the total number of protons and neutrons in the nucleus of the atom. A specific nuclide is represented normally in one of three ways:

– The chemical symbol with the mass number in superscript, e.g., ^{131}I,
– There may be a number below the mass number. This is the atomic number, which is the number of protons (53 for iodine) which identifies the element.
– The chemical symbol followed by the mass number, for example I-131.

This would be called iodine 131.

Fission products

- Atoms in reactor fuel are split to produce heat energy
- These fission products:
  - consist of hundreds of radionuclides
  - must be contained and cooled to protect the public and workers
  - give off different types of radiation



IAEA

Like a fossil-fuelled plant, a nuclear power plant (NPP) boils water to produce electricity. However, unlike a fossil-fuelled plant such as a coal fired plant, the nuclear plant's energy does not come from the burning of fuel but from a nuclear reaction involving the fission (or splitting) of fuel atoms. The result of this splitting produces hundreds of different radionuclides which are called fission products. Many fission products are unstable and undergo radioactive decay, producing hazardous radiation and heat. The fission products must be contained to protect the public and workers and cooled to prevent their release.

Ionizing radiation

- Harmful when it penetrates and causes damage to cells in the body
- Radiation of concern for emergencies with a reactor or spent fuel pool:
  - **Gamma rays (γ)** – hazardous from external exposure, i.e. radioactive material outside the body
  - **Beta particles (β)** – hazardous if radioactive material giving off the β is ingested or inhaled or if on the skin
    - Skin hazard is only a concern for those on-site

IAEA

Ionizing radiation is harmful when it penetrates the body and damages cells. How hazardous this radiation is depends on the type of radiation and type of exposure or where the material is positioned relative to the body. Ionizing radiation is given off when radioactive fission products that are produced in the reactor decay.

Radiation comes in several different forms, for example:

Alpha particles (α)
Beta particles (β)
X rays
Neutrons
Gamma rays (γ).

Only gamma radiation and beta radiation (particles) are a health hazard to the public for an emergency with a reactor or spent fuel pool :

- Gamma radiation (γ) is very penetrating and can deliver significant doses to internal organs from outside the body for example from radioactive fission products deposited on the ground;

- Beta (β) radiation does not normally penetrate beyond the top layer of skin and is hazardous if radioactive material enters the body by being inhaled or ingested or if very large amounts are in contact with the skin. However the skin is only a concern for those on the site of the reactor.

Activity…given in becquerels (Bq)

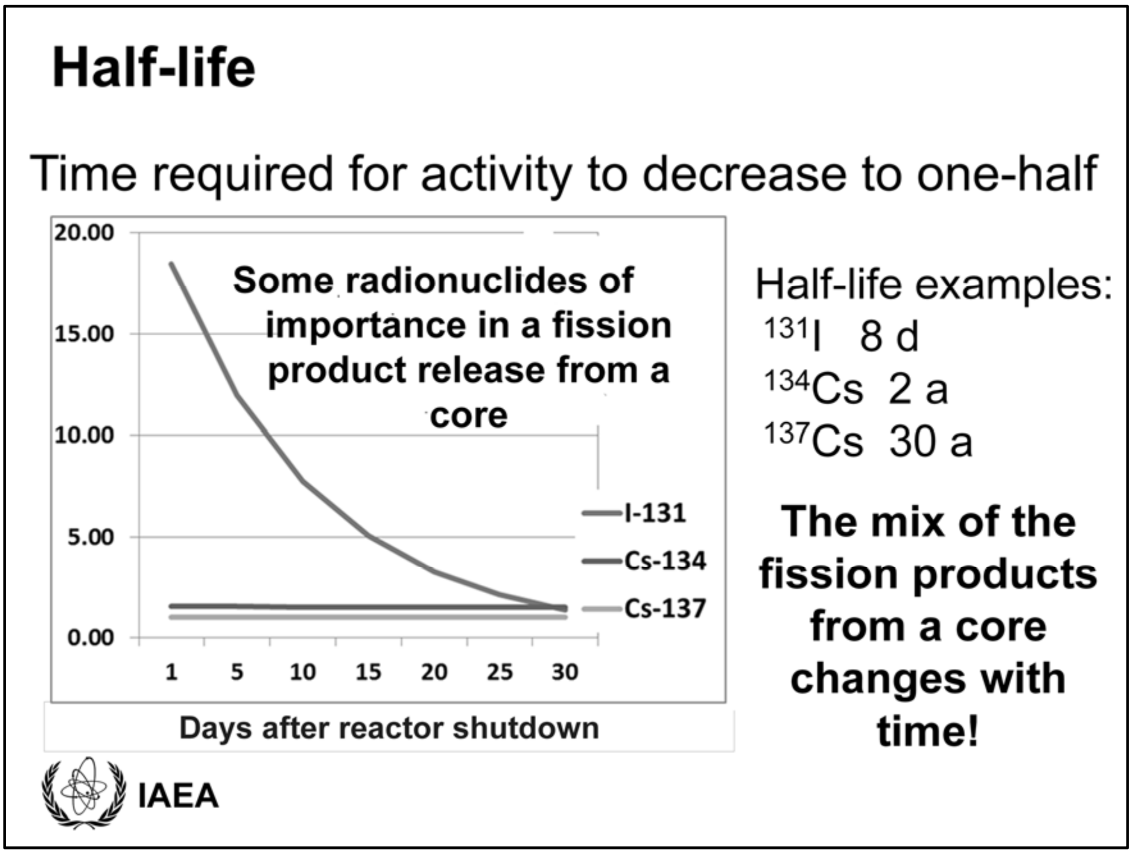
- Amount of radioactive material at a given time
- One Bq is one nucleus decay per second (possibly producing gamma rays or beta particles)
- Only useful when given with the radionuclide
  - e.g. 100 Bq, I-131
- Not a good indicator of the hazard
  - Example: activity ingested by a pregnant woman that warrants a medical examination

Isotope	Bq
^{131}I	100 000
^{137}Cs	10 000 000

IAEA

Activity is the amount of radioactive material present at a specific time and is given in becquerels (symbol Bq). One Bq is the quantity of radioactive material in which one nucleus decays per second. When the nuclei decay they can produce ionizing radiation such as gamma rays or beta particles. To be useful, the activity must be given for a radionuclide (or isotope) for example 100 Bq of I-131.

Activity by itself is not a good indicator of dose or the hazard posed by the radioactive material. As an example, this table shows the activity of iodine-131 and cesium-137 that must be ingested before a pregnant woman should see a doctor to assess the possible health effects to the fetus. A pregnant woman would have to eat 100 times more cesium-137 than iodine-131 before she should go see a doctor.



Each radionuclide decays or decreases in activity with time at its own unique rate. This rate of decrease is given in terms of the half-life of the radionuclide. The half-life is defined as the time required for the activity (Bq) of any particular radionuclide to decrease to half of its initial value.

This figure shows the relative activity of three radionuclides (fission products) that would probably be released early from the core of a reactor for different times after the reactor has shut down (after fissions stopped in the core). Iodine-131 is the most important radionuclide in terms of health effects early on and the cesium radionuclides become more important later. As you can see from the chart, iodine-131, which has a half-life of only eight days, is mostly gone within the first month; however, the activity of the cesium radionuclides, which have half-lives of years, remain relatively unchanged over the first month. This shows that the mixture (often called the mix) of the radionuclides released from a reactor core will change with time and this is important when assessing the consequences of an emergency. The change with time of the mixture of fission products released from a spent fuel pool is less dramatic because most of the fission products in the spent fuel will have reactively long half-lives.

Question Module 4-1:

The following quantities were measured in a deposition sample taken off-site during an emergency at an operating reactor.

What was the probable source of the release ?:

- reactor core
- spent fuel pool

	Bq/m^2
I-131	Non detected
Cs-137	1200
Cs-134	1345

IAEA

Answer Module 4 –1:

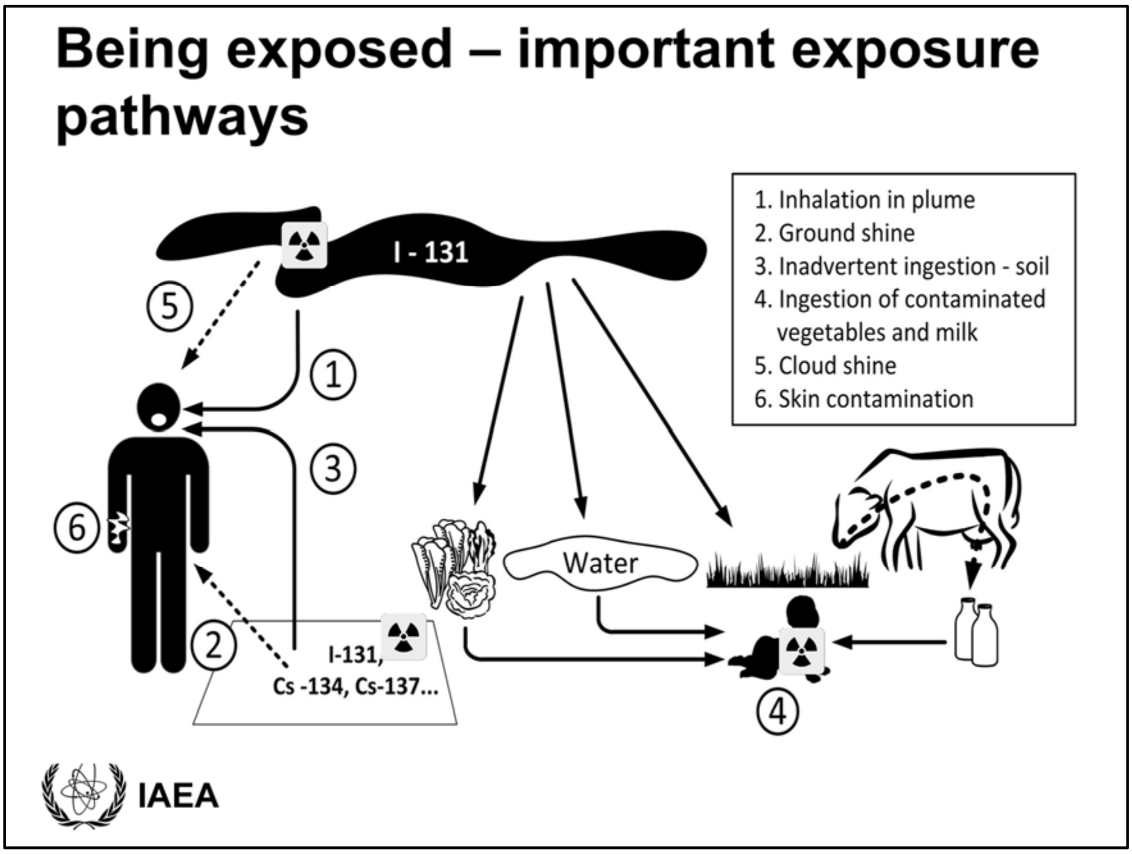
The following quantities were measured in a deposition sample taken off site during an emergency at an operating reactor

What was the probable source of the release?
The spent fuel pool because all the I-131 had decayed away

	Bq/m^2
I-131	Non detected
Cs-137	1200
Cs-134	1345

IAEA

The spent fuel pool was the probable source of the release because all the I-131 had decayed away. Any fuel in the spent fuel pool would not have been in an operating reactor within weeks or more.



Being exposed to radiation means that something, for example a person or instrument, is being hit by or influenced by radiation. This illustration shows the important exposure pathways (ways the public could be exposed) following the release of fission products from a reactor core or sent fuel pool.

External exposure comes from radioactive material outside the body. Radioactive material released from a nuclear reactor or spent fuel pool that is deposited on the ground (called ground shine – Item 2) or in the air (called cloud shine – Item 5) can be a source of external exposure because it emits gamma radiation which can travel considerable distances and can penetrate through the whole body.

Beta emitting radioactive material released from a nuclear power reactor or spent fuel pool that is deposited on the skin (Item 5) can cause external exposure that is limited principally to the skin; however, this is not a concern off-site.

Internal exposure comes from radioactive material inside the body. For a reactor emergency, this can result from breathing while in the plume from the power plant (Item 1 in the figure), inadvertent ingestion of soil containing radioactive material released from the plant (e.g. dirt on the hands, Item 3 in the figure) or ingesting contaminated food, water or milk (Item 4 in the figure).

Contamination – contaminated

[Section 6.3.1, EPR-NPP PPA]

- Often misused and a source of considerable confusion
- Meaningless unless stated in terms of a operational level or limit requiring a response action (e.g. restriction or decontamination)
- Only regard something as contaminated if a response action is needed

IAEA

During an emergency, the terms ‘contamination’ and ‘contaminated’ are often misused and a source of considerable confusion. As you know, we are all affected in some way by Chernobyl, the atmospheric bomb tests, etc. Therefore, unless the level of contamination exceeds some level requiring an action or is stated in terms of such levels, it is meaningless. In general, something should be referred to as being contaminated only if the amount of radioactive material present warrants some sort of response action. This is discussed in Section 6.3.1 of the publication EPR-NPP PUBLIC PROTECTIVE ACTIONS.

Prefixes – be careful:

- Leaving off the prefix or giving a wrong prefix results in an error of a 1000 or more
- Write M or m very clearly

Prefix	Symbol	10^n	Decimal
tera	T	10^{12}	1 000 000 000 000
mega	M	10^{6}	1 000 000
kilo	k	10^{3}	1000
			1
centi	c	10^{-2}	0.01
milli	m	10^{-3}	0.001
micro	µ	10^{-6}	0.000 001
pico	p	10^{-12}	0.000 000 000 001

IAEA

Prefixes are symbols used to show very large or very small numbers. You may see a prefix before the unit of activity, dose or dose rate. Without the prefix, the activity, dose or dose rate is meaningless. Leaving off a prefix or giving the wrong prefix could indicate to someone else that the amount of dose or activity is 1000 or more times larger or smaller than it actually is. Be particularly careful about writing M (for mega – × 1 000 000) and m (for milli – 1/1000).

Question Module 4-2: Convert

Example: $2\,\frac{\text{mSv}}{\text{h}} \times 1000\,\frac{\mu\text{Sv}}{\text{mSv}} = 2000\,\frac{\mu\text{Sv}}{\text{h}}$

Convert:

- 30 kBq/kg to ? Bq/kg
- 2 Sv/h to ? μSv/h

IAEA

Let the students calculate the corresponding values.

Answer Module 4 – 2: Convert

Example: $2\ \frac{\text{mSv}}{\text{h}} \times 1000\ \frac{\mu\text{Sv}}{\text{mSv}} = 2000\ \frac{\mu\text{Sv}}{\text{h}}$

30 kBq/kg = 30 000 Bq/kg
2 Sv/h = 2 000 000 µSv/h

IAEA

Dose

- Cause of much confusion during emergencies
- It can be a calculated or measured quantity
- Meaningless unless you know how it was calculated or measured

IAEA

Dose is a source of much confusion during emergencies. Dose can be a calculated or measured quantity and is only meaningful if you know how it was calculated or measured. In other words: what type of dose is it?

Dose quantities

Quantity	Symbol	Unit	Related to
RBE weighted absorbed dose in tissue T	AD_T	Gy	Severe deterministic health effects
Equivalent dose in tissue T	H_T	Sv	Cancer risk
Effective dose	E	Sv	Radiation protection

AD and H are used to assess the primary health hazard – not the effective dose

IAEA

This table shows the various dose quantities that are used for describing when you can expect various health effects and for developing criteria to prevent or reduce these effects. Note that two different dose quantities are designated in sieverts (Sv) but each of these doses is calculated differently.

Only RBE weighted dose and equivalent dose to particular organs can be used to assess the primary health hazard. Effective dose cannot be used as it does not apply to a specific organ.

Operational (measured) dose quantities

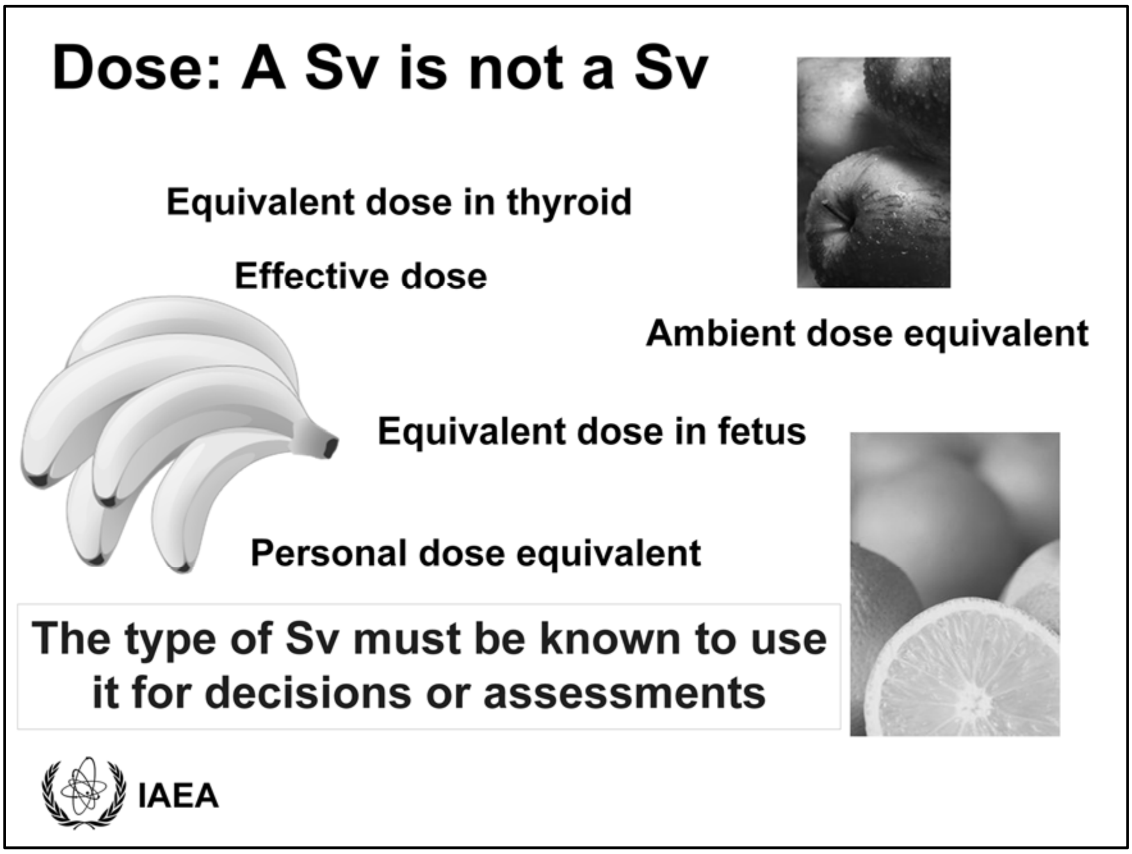
Quantity	Symbol	Unit	Monitoring
Personal dose equivalent	$H_p(10)$	Sv	External exposure of the individual (dosimeters)
Ambient dose equivalent	$H^*(10)$	Sv	Environment and public monitoring of external radiation field (dose rate)

More sieverts (Sv), we now have four different ones

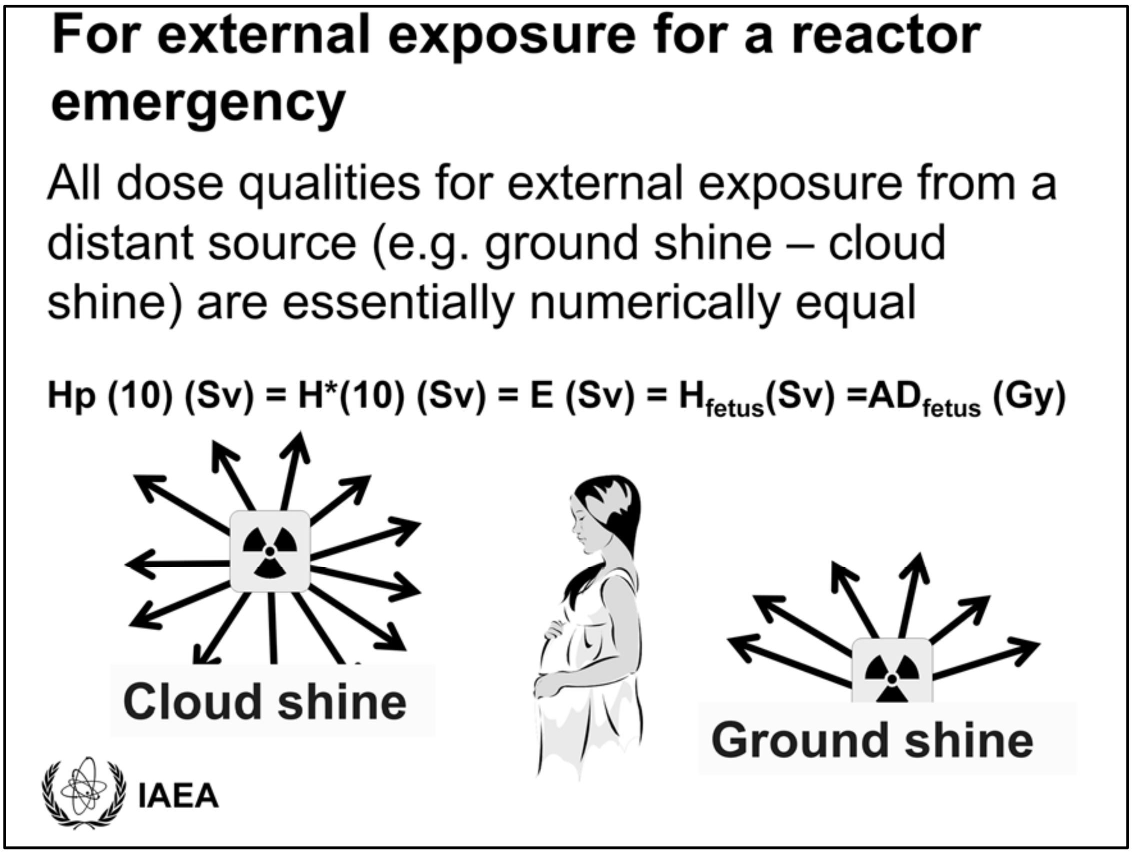
This slide shows quantities that are doses of external exposure as measured by monitoring instruments and personal dosimeters. Personal dose equivalent is measured by personal dosimeters typically used by emergency responders and workers inside a power plant. Ambient dose equivalent is the dose measured by dose rate monitoring instruments.

Note that these are also measured in sieverts (Sv): we now have a total of four different quantities measured in sieverts.

Image credits: IAEA booklet, Radiation, People and the Environment, IAEA, Vienna (2004)



During an emergency, dose is almost always given in sieverts (Sv). However, as we have seen, there are many different types of Sv and you must know what type of Sv you are dealing with before you can relate it to any health effects or use it with any criteria. You cannot add apples and oranges…or bananas.



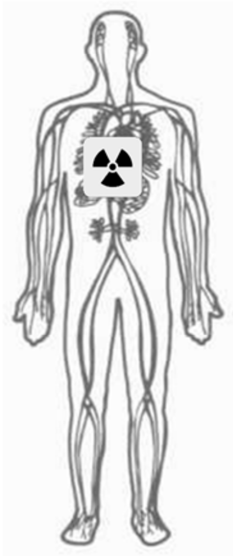
All dose qualities used for external exposure from a distant source (e.g. ground shine or cloud shine) are essentially numerically equal. **But this is not true for dose from intake (ingestion or inhalation).**

For intake, the dose quantities can be very different for the same intake

They are calculated differently

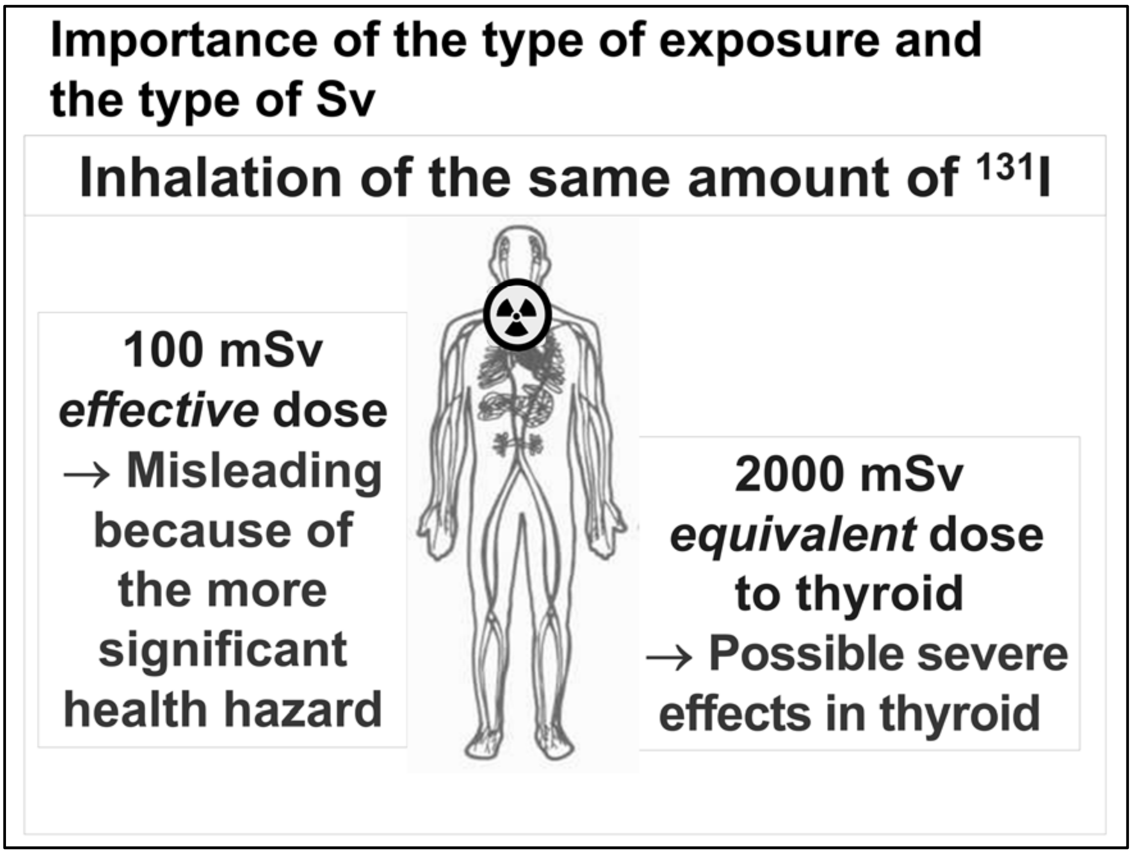
<u>Not equal</u>

E (Sv) ≠
H_{fetus}(Sv) ≠
Ad_{fetus} (Gy)



IAEA

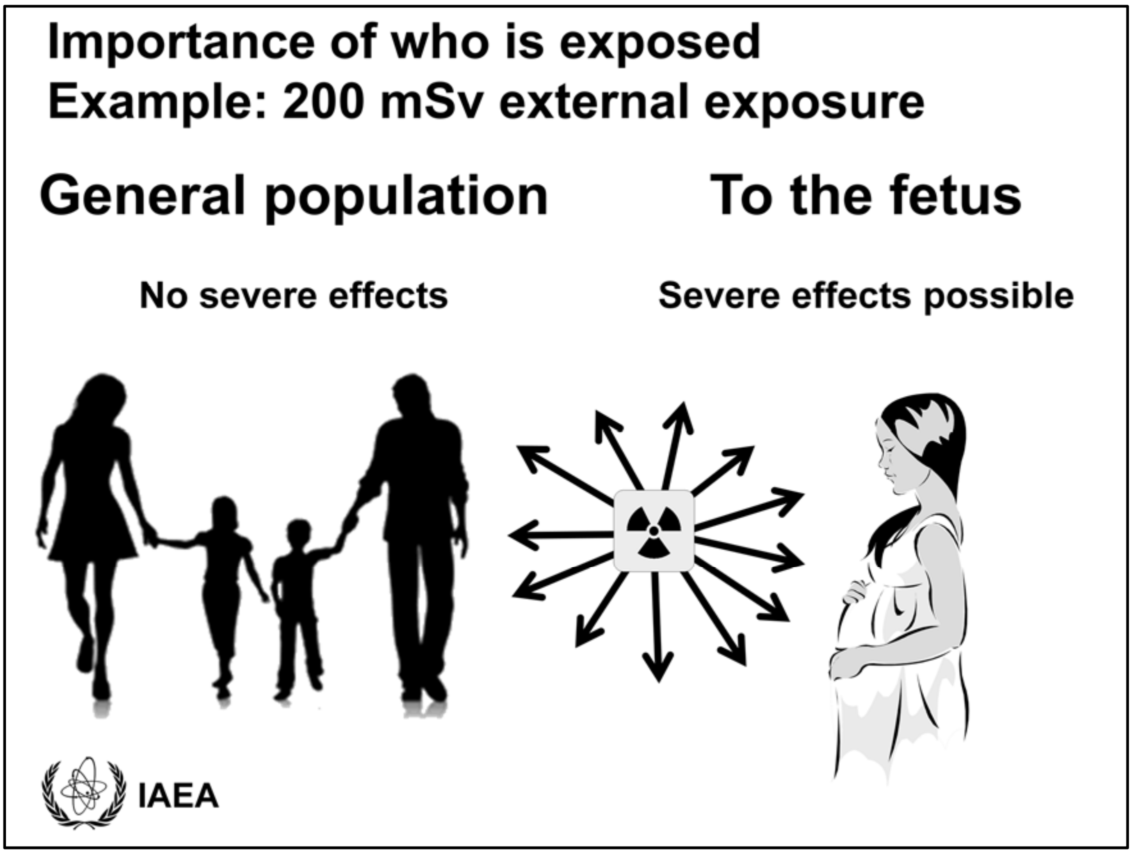
For intake of radioactive material, the different dose quantities are calculated in different ways and cannot be compared.



This shows the importance of knowing how someone was exposed and what type of Sv (dose) is calculated.

The inhalation of the same amount of I-131, a major component of a release from a reactor, that results in 100 mSv **effective dose** results in 2000 mSv of **equivalent dose** to the thyroid gland. Above 2000 mSv **equivalent dose** to the thyroid, severe effects may occur.

So saying someone has received 100 mSv **effective dose** ignores the more significant health risks to the thyroid.



In this example, showing who is exposed is also important. Here a group of people, one of whom is pregnant, receive an effective dose of 200 mSv from an external source.

At 200 mSv equivalent dose:

- the fetus may suffer severe health effects requiring a medical evaluation, but
- no severe health effects would be expected in the others.

In this case, knowing someone received 200 mSv effective dose does not indicate the risk until you know who was exposed.

Question Module 4-3:

It was reported that the population received 100 mSv in the first year. You are asked: “What is the health hazard?”

IAEA

Answer Module 4-3: "What is the health hazard?"

- Meaningless in terms of health hazard
- Need to know:
  - What was the quantity calculated (i.e. what type of Sv is it)?
  - How were they exposed (e.g. external exposure or internal intake)?
  - Who was exposed (pregnant women)?
  - To what were they exposed (e.g. I-131, Cs-137)?

IAEA

Answer: Saying a person has received 100 mSv does not tell you anything about the associated health hazard unless you know:

- What was the quantity calculated (what type of Sv is it)?
- How were they exposed (e.g. external or internal)?
- Who was exposed?
- To what they were exposed (e.g. I-131, Cs-137)?

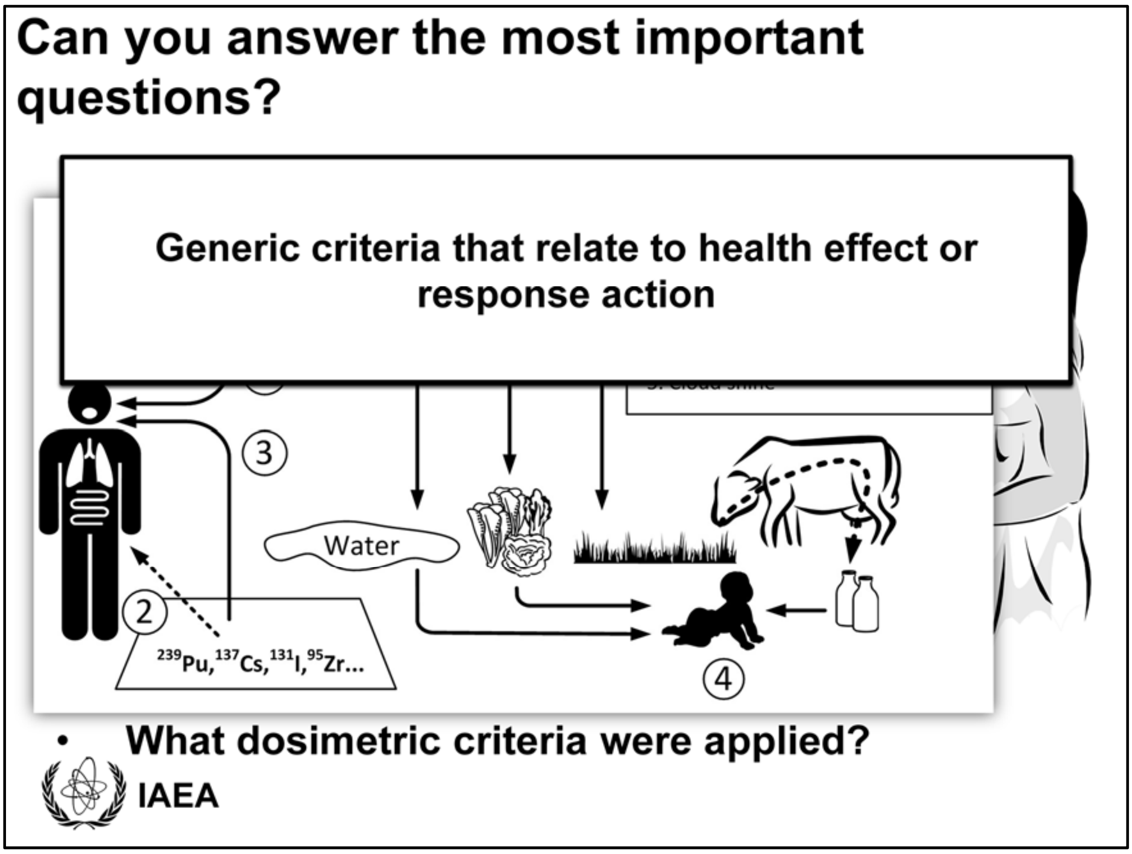
Doses

- Are meaningless and cannot be related to health effects or response actions unless the following questions are answered:
  - What was calculated (type of dose)?
  - How was the person exposed, i.e. what was the exposure scenario?
  - Who is exposed?
  - How dose it relate to a health effect or criteria calling for an action?

IAEA

We have just seen that dose and other quantities are meaningless unless you know the answer to these questions:

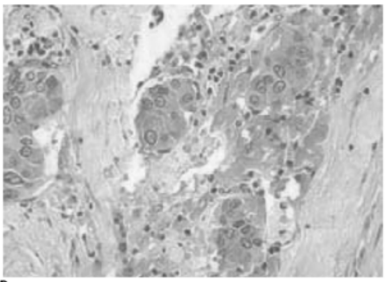
- What was calculated (type of dose)?
- How was the person exposed (what was the exposure scenario)?
- Who was exposed?
- How does it relate to a health effect or criteria calling for an action?



Animation summarizing the questions that need to be answered when interpreting a calculated dose.

Types of health effects

- Severe deterministic health effects
- Stochastic effects
  - cancers



IAEA

There are two types of health effects of concern that can result from a severe reactor or spent fuel pool emergency:

- severe deterministic health effects – these are health effects which are either fatal or reduce the quality of life;
- stochastic effects – which in fact can just be considered as cancers.

On the right is a picture of a fire fighter, day 40 after the Chernobyl accident who received severe beta radiation burns while inside the plant because standard firefighting clothing did not provide adequate protection from beta emitters (I-131) in contaminated water. These burns are a severe deterministic effect and were major contributors to some of the fatalities to on-site responders at Chernobyl. Such burns would not be expected off-site.

Image credits:

1. Severe multiple necrotic-ulcerative radiation burns in

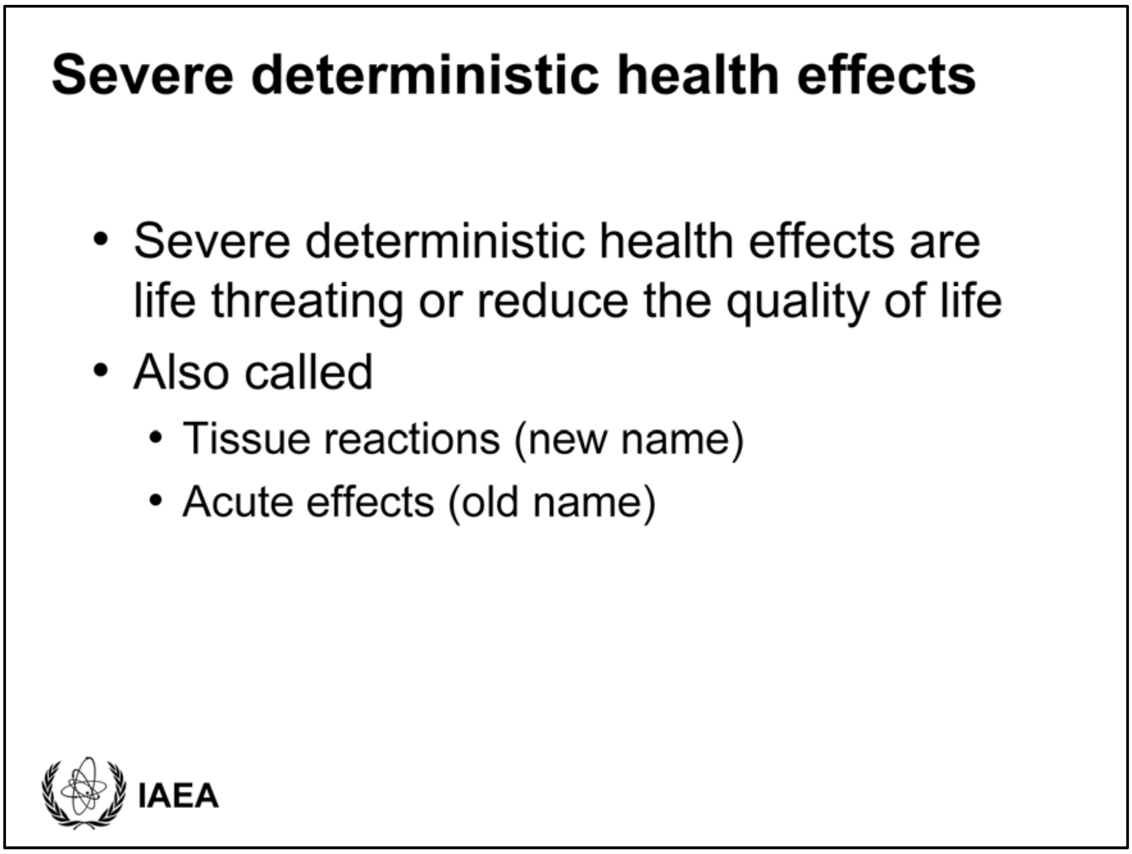
(Source: IAEA, Health consequences and lessons learned from medical response to selected radiation accidents – Module XIX Chernobyl, ppt-Presentation)

2. Carcinoma of thyroid; Radiation, People and the Environment, IAEA, Vienna (2004).

Severe Deterministic Effects and the Generic Criteria Used as a Basis to Avoid These

IAEA

International Atomic Energy Agency



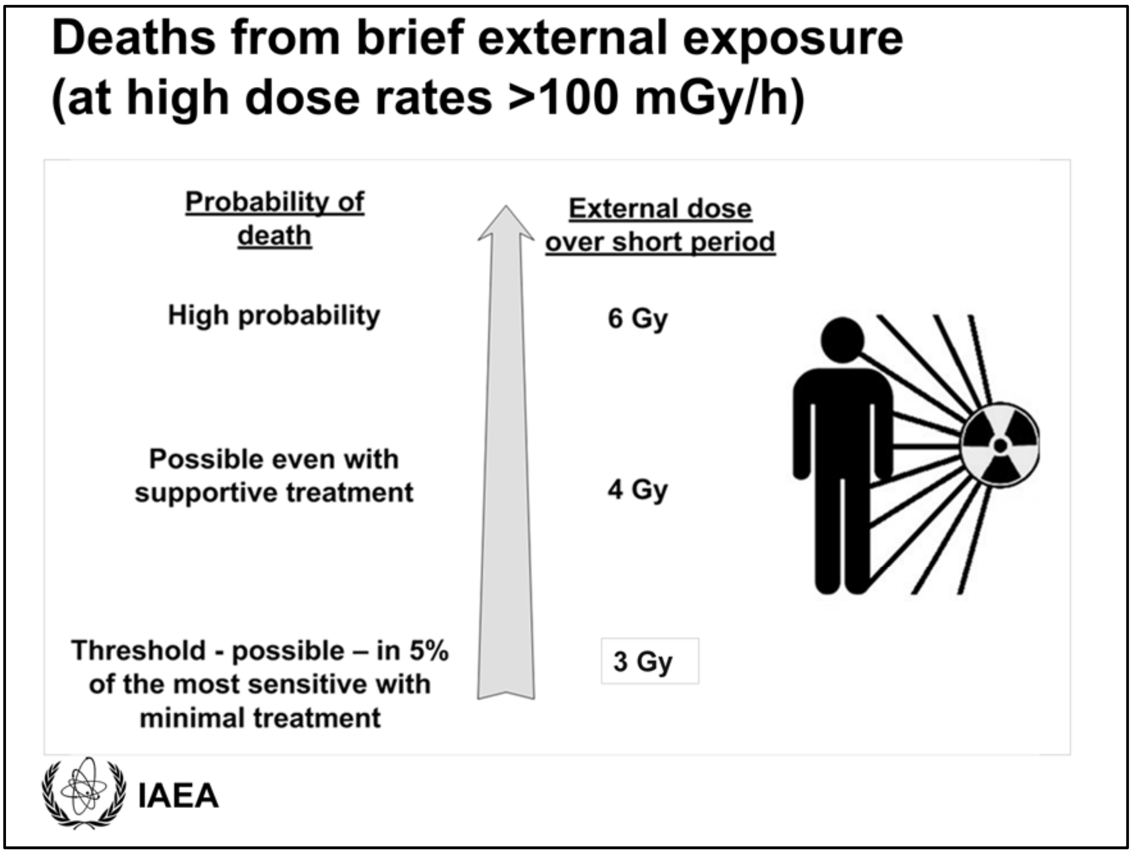
Severe deterministic health effects are effects that are fatal or reduce the quality of life. They are also sometimes called tissue reactions or acute effects.

Severe deterministic health effects

- Occur shortly after exposure (week – months)
- Effects worse for bigger doses
- Occur above a RBE-weighted (AD_T) threshold dose (Gy) in an organ T (e.g. bone marrow)
- The threshold dose for development of severe deterministic health effects depends on factors such as dose rate, medical treatment, age and health of the affected person, and how he or she was exposed
- Threshold dose for severe deterministic effects is when 5% would suffer the effect

IAEA

Severe deterministic health effects would be expected to occur within days or months of exposure. The magnitude of the effect is greater with greater doses. These health effects are seen above a certain dose called the threshold dose given in Gy. The dose at which an individual would suffer the effect (threshold) depends on factors such as the dose rate, medical treatment, age and health of the exposed individual, and how the person was exposed.



As an example of the severe health effects, this shows the probability of death from a brief (<10 hours) exposure to gamma radiation from an external source. At about 3 Gy there is a small possibility of death after exposure in the most sensitive people (e.g. sick) if they receive only a minimal amount of treatment. But above 6 Gy there is a high probability of death, regardless of who was exposed or the quality of their medical treatment.

Most important severe off-site deterministic health effects (with threshold in AD_T)

Fatal effects		
Effect	**Organ**	**Threshold AD_T (mGy)**
Haematopoetic syndrome	Red marrow	3000
Non-fatal severe health effects		
Hypothyroidism	Thyroid	2000
Permanently suppressed ovulation – sperm counts	Ovum/Testes	1000
Verifiable reduction in IQ	Fetus	100
High probability of severe mental retardation	Fetus	1000

Threshold – 5% of those exposed may suffer the effect

IAEA

This shows the threshold dose for developing severe deterministic effects that are most likely to occur off-site from a fission product release from a nuclear power plant or spent fuel pool. The threshold doses for these effects are also shown in mGy (RBE weighted dose to a tissue or organ).

- **Fatal effects:** Dose to the red bone marrow is used to indicate when fatalities are possible. This is because the red bone marrow has the lowest lethal dose threshold for any organ; however, deaths from radiation are ultimately the result of multi-organ failure and depend on factors such as medical treatment, age and health of the exposed individual, and the received dose rates.
- **Non-fatal severe deterministic effects** reduce the quality of life but are not fatal. The most important severe deterministic effects for a reactor release are those to the fetus, thyroid and the reproductive organs. At 100 mGy there would only be a very small probability of severe deterministic effects to the fetus and only during certain phases of fetal development (between 8 and 15 weeks of gestation age) and these effects have only been observed at high dose rates. Depending on the stage of development at 1 Gy implies a high probability of severe mental retardation in the fetus.

Sources:

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Pregnancy and Medical Radiation, ICRP Publication No. 84, Ann ICRP Vol. 30 No. 1, Pergamon Press, Oxford (2000).

INTERNATIONAL ATOMIC ENERGY AGENCY, Development of an Extended Framework for Emergency Response Criteria: Interim Report for Comments, IAEA-TECDOC-1432, Vienna (2005).

INTERNATIONAL ATOMIC ENERGY AGENCY, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency, Standards Series No. GSG-2, IAEA, Vienna (2011).

UNITED NATIONS, Sources and Effects of Ionizing Radiation (Report to the General Assembly), Volume 1: Sources, Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), UN, New York (2000).

INTERNATIONAL ATOMIC ENERGY AGENCY, Dangerous Quantities of Radioactive Material (D-Values), EPR-D-Values, IAEA, Vienna (2006).

Generic criteria (GC) expressed in terms of dose [IAEA GSG-2]

- Avoid severe deterministic effects
  - Take urgent actions (e.g. evacuation)
- Reduce the risk of stochastic effects
  - Take urgent actions
  - Take early actions (e.g. relocation)
- Provide medical treatment and follow-up for received dose

IAEA

International generic criteria (GC) expressed in terms of dose are provided in IAEA Standards Series No. GSG-2. These GC establish at what dose levels urgent actions, early protective actions and other actions are to be taken if certain doses are projected, and provide for medical actions if the doses are received.

The protective and other actions recommended based on the generic criteria will be discussed later.

Source:

INTERNATIONAL ATOMIC ENERGY AGENCY, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency, Safety Standards Series No. GSG-2, IAEA, Vienna (2011).

GC are for the most sensitive person

- Carrying on normal activities
- Ensures protection of all

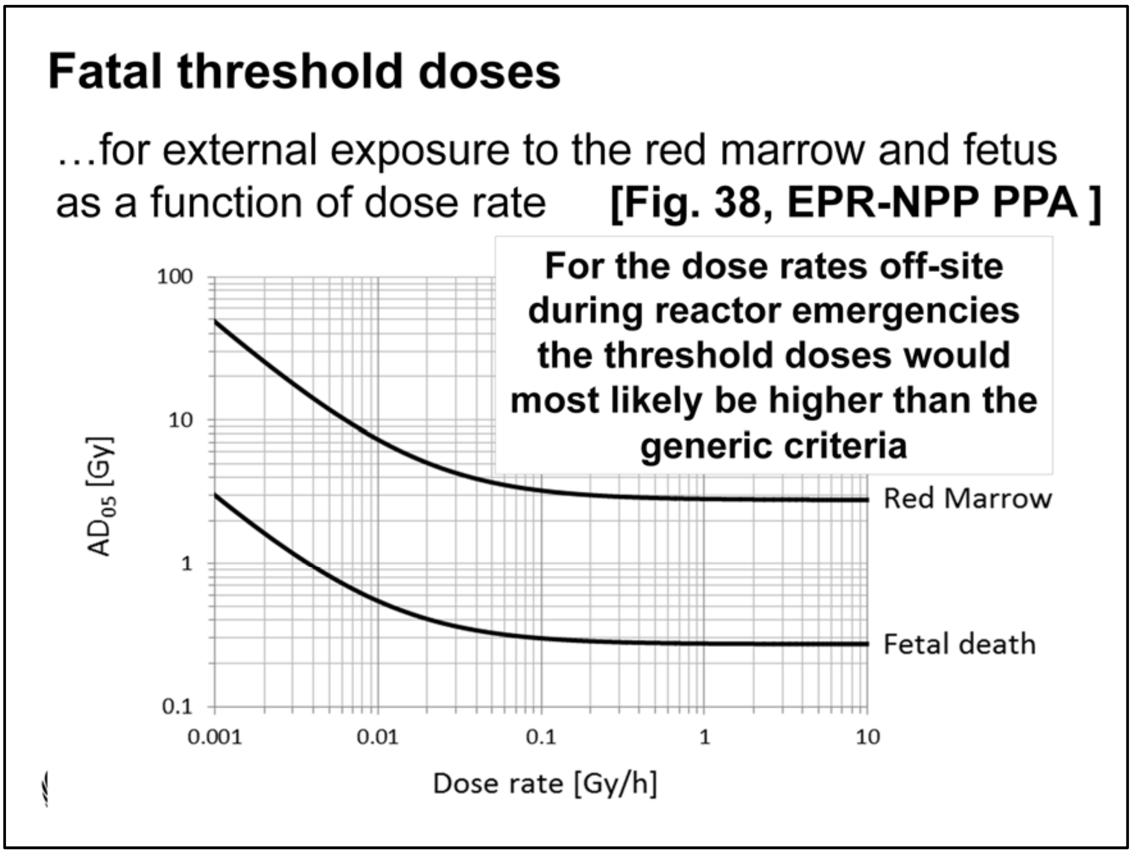
IAEA

The GC have been determined assuming the most sensitive person is exposed. In most cases this is a child or pregnant woman (fetus). This ensures that all members of the public will be protected.

Generic criteria (GC) to avoid or treat severe deterministic effects [IAEA GSG-2]

RBE weighted dose (AD tissue)	Criteria and action	
Red marrow	**1 Gy**	**Projected:** urgent protective action **Received:** immediate medical examination
Fetus	**0.1 Gy**	
Thyroid	**2 Gy**	

These are the GC (Table 2 of GSG-2) at which urgent protective actions would be taken under any circumstances to avoid these doses and to treat the person if the dose is received. The goal here is to prevent or treat severe deterministic effects. Note that these are the threshold doses of most important health effects arising from a reactor emergency. Reproductive organs are not mentioned because keeping the red bone marrow dose below 1 Gy will prevent severe deterministic effects to these organs.



The thresholds for severe deterministic effects are often a function of dose rate, as shown in Fig. 38 of the publication EPR-NPP PUBLIC PROTECTIVE ACTIONS. For the external dose rates expected off-site during a reactor emergency (e.g. less than 0.01 Gy/h), the thresholds for severe deterministic effects from external exposure most likely would be higher than the GC used to avoid severe determinist effects.

Summary: GC to avoid or treat severe deterministic effects

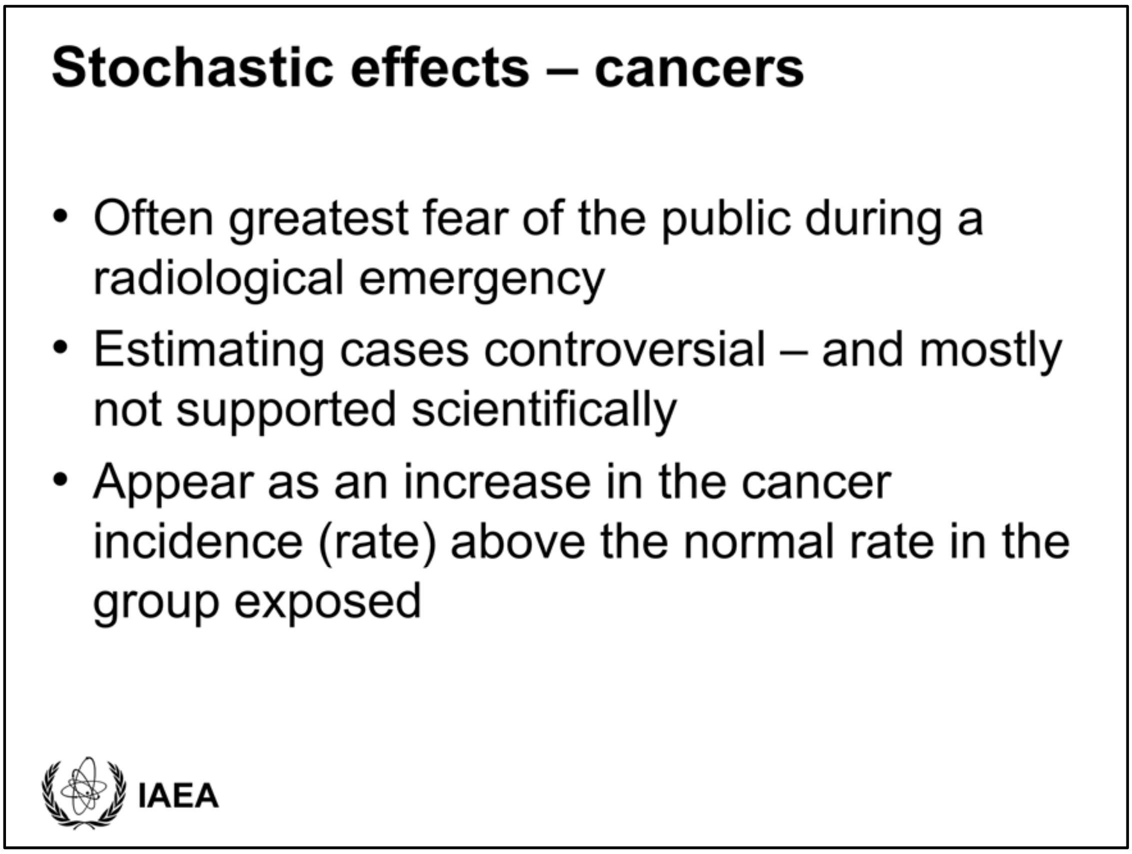
- Lowest dose in an organ at which severe deterministic health effects may occur
- A few people may suffer severe health effects (about 5%)
- The threshold dose for severe deterministic effects will most likely be higher for a reactor emergency than the generic criteria

IAEA

Stochastic Effects and the Generic Criteria used as a Basis to Reduce their Risk of Occurrence

IAEA

International Atomic Energy Agency

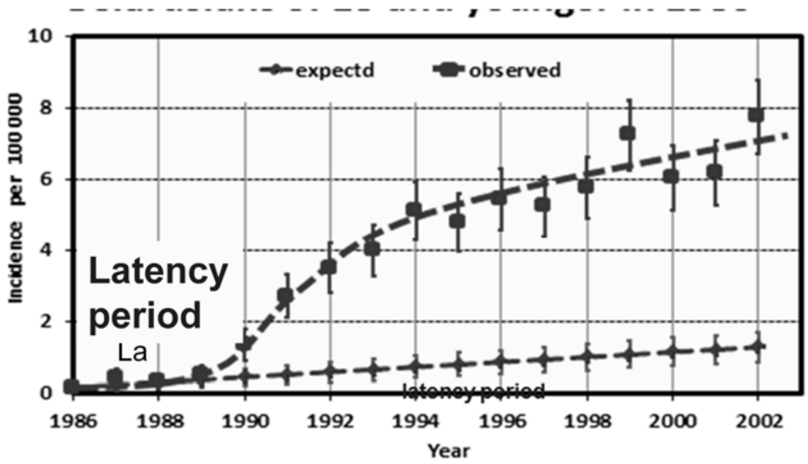


Risk of cancer is one of the greatest fears of the public during a radiological emergency.

Estimating the potential of radiation exposure to cause an increase in the incidence of cancer is a complicated and controversial issue, and in most cases not scientifically supported. In part, this is because a cancer in a particular person cannot be definitely attributed to the exposure unless possibly if the normal rate is very low. Therefore, cancer risk is discussed in terms of an increase in the cancer incidence (rate) above the normal rate in the group that was exposed.

Thyroid cancer is the concern for a reactor release. For Chernobyl –

- An increase in thyroid cancers was easily observed due to low background
- No increase in others cancers seen in public



IAEA

Thyroid cancers are by far the greatest cancer concern following a release from a nuclear power plant. This is because of the large amount of iodine that may be released, which can then concentrate in the thyroid, giving it very high doses.

It is unlikely that you will see any increase in any other type of radiation induced cancers in the public following a nuclear power plant or spent fuel pool emergency. An increase in other cancers would only be expected if very large numbers of people are exposed to very high doses. To date, no increase in the cancer rate amongst the public, apart from thyroid cancers, has been clearly demonstrated around Chernobyl.

This graph shows the increase in the incidence of cancers among children following the Chernobyl accident in Belarus. This increase was due to high thyroid doses resulting from drinking milk from cows grazing on grass contaminated with radioactive iodine. This increase was easily seen because of the low background rates of thyroid cancers. This figure shows the rapid increase in the cancer incidence rate among Belarusians of 18 years old and younger in 1988. The increase was seen after the latency period of about three to four years following the accident.

Source:

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, OFFICE FOR THE COORDINATION OF HUMANITARIAN AFFAIRS, UNITED NATIONS DEVELOPMENT PROGRAMME, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD BANK GROUP, WORLD HEALTH ORGANIZATION, Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts; Recommendations to the Governments of Belarus, the Russian Federation and Ukraine, The Chernobyl Forum: 2003–2005, IAEA, Second Revised Version, IAEA, Vienna (2006).

Question Module 4-4:

Data from the study of the atomic bomb survivors in Japan are the primary basis for our estimates of the cancer risk from exposure to radiation

Question: How many cancers were attributed to the exposure from the bombs?

IAEA

In discussing cancer risk, we have to be careful to distinguish between the risk of *getting* cancer and the risk of *dying* from cancer. Some cancers, such as pancreatic cancer, are almost always fatal, while others, such as thyroid cancer, are hardly ever fatal.

Answer Module 4-4: Cancer risk is small

Atomic bombs in Japan caused:

- 200 000 deaths – due to blast, fire and severe deterministic effects
- Less than 500 deaths due to cancer (9% increase over the normal rate in those exposed)

IAEA

The risk of getting cancer from radiation exposure is very small. As an example, consider the consequences of the atomic bombs dropped on Japan. There were less than 500 extra cancer deaths detected due to radiation exposure from the bombs, this is about a 9% increase in the normal fatality rate for cancer.
It must be remembered that cancer is normal. While discussing these numbers, compare with ~20–25% probability of fatal spontaneous cancer in a lifetime. Normally in the USA for example, approximately 1 in 2 men and 1 in 3 women will get some form of cancer in their lifetime from natural sources and about 1 in 4 people will die from it. Look around the room and count the total number of people in the room and divide by 2 or 3 to see how many people in the room statistically will get cancer and divide by 4 to see how many will die from it.

47 years of follow-up (1950-1997)
Observed: 9335 fatal cases of solid cancer
Expected: ~8895 fatal cases of solid cancer
    i.e. ~440 fatal cancers (5%) attributable to radiation

The above numbers summarize data from 47 years follow-up of the atomic bomb survivors (source: Preston, D.L., et al., *Radiat Res* 160:381–407, (2003)).

Among these people, the leukaemia incidence started to increase two years after exposure and then gradually faded. The maximum increase occurred less than ten years after exposure. In contrast, the incidence for solid tumours started to increase later, about 5 years after exposure, but the increase is still going on and seems to continue to the end of life. It is actually accentuated when the exposed population gets older and natural cancer incidence increases.

Detectable increase in cancer incidence

- Appears years after exposure (latency period)
- Only expected if large numbers of people were exposed to high doses
- There is a dose below which no increase can be detected above normal incidence
  - Possibly because the increase is too small relative to the normal rate
  - Below this dose, it will be unknown if any cancers will have been caused by the emergency

IAEA

The increase in the cancer incidence or rate due to radiation exposure from an emergency will potentially be seen years after the exposure, this is called the latency period.

An observable increase in cancer incidence would only be expected if large numbers of people were exposed to high doses. In addition, there will be a dose below which no increase in cancer rate will be seen. This may be because any increase is too low to be seen when compared to the cancer rate for normal background. However, below this dose, it is unknown if any cancers will have been caused by the emergency.

Normal cancer incidence rates

Cancers per 100 000			
Canada		Belarus	
Number	Rate	Number	Rate
All cancers			
31 500	32%	19 000	19%
Thyroid (0–19 year olds)			
330	0.3%	120	0.1%

Much easier to see excess thyroid cancers thanks to the low background

IAEA

This table shows the normal cancer incidence rates (not including those from an emergency) for all cancers and thyroid cancers for two States. Note that the normal cancer rates are higher in Canada than in Belarus. Also note that for all cancers, the background rate is about 20–30%, but the background rate for thyroid cancers is very low (less than 1%). (Source: INTERNATIONAL ATOMIC ENERGY AGENCY, Development of an Extended Framework for Emergency Response Criteria: Interim Report for Comments, IAEA-TECDOC-1432, Vienna (2005))

Therefore, it would be much easier to see any excess thyroid cancers resulting from a reactor emergency than an increase in all cancers.

According to the US National Cancer Institute, the latest (2010) projected lifetime risk of developing cancer in the USA is 45% for men and 38% for women. (http://seer.cancer.gov/statfacts/html/all.html), with the fatality risk being about 23%.

Detectable increase – minimum dose

Organ	Dose at which excess incidence may be seen	Number of people needed to be studied to see excess
Whole body: external exposure (all cancers)	E > 100 mSv (effective dose)	>100 000
Thyroid: intake of ^{131}I	$H_{thyroid}$ > 50 mSv (equivalent dose)	> 10 000

IAEA

This shows the lowest dose at which an excess incidence in the cancer rate would be expected and the number of people who would need to be carefully studied in order to detect any increase. You would not expect to see any increase in the incidence rate when the doses received were less than those indicated.

UNSCEAR 2010

- Observations are frequently **unable to reveal clear evidence of increased incidence of radiation-induced health effects** at low doses (less than 200 mGy) or low dose rates (less than 0.1 mGy/h).

IAEA

Source:

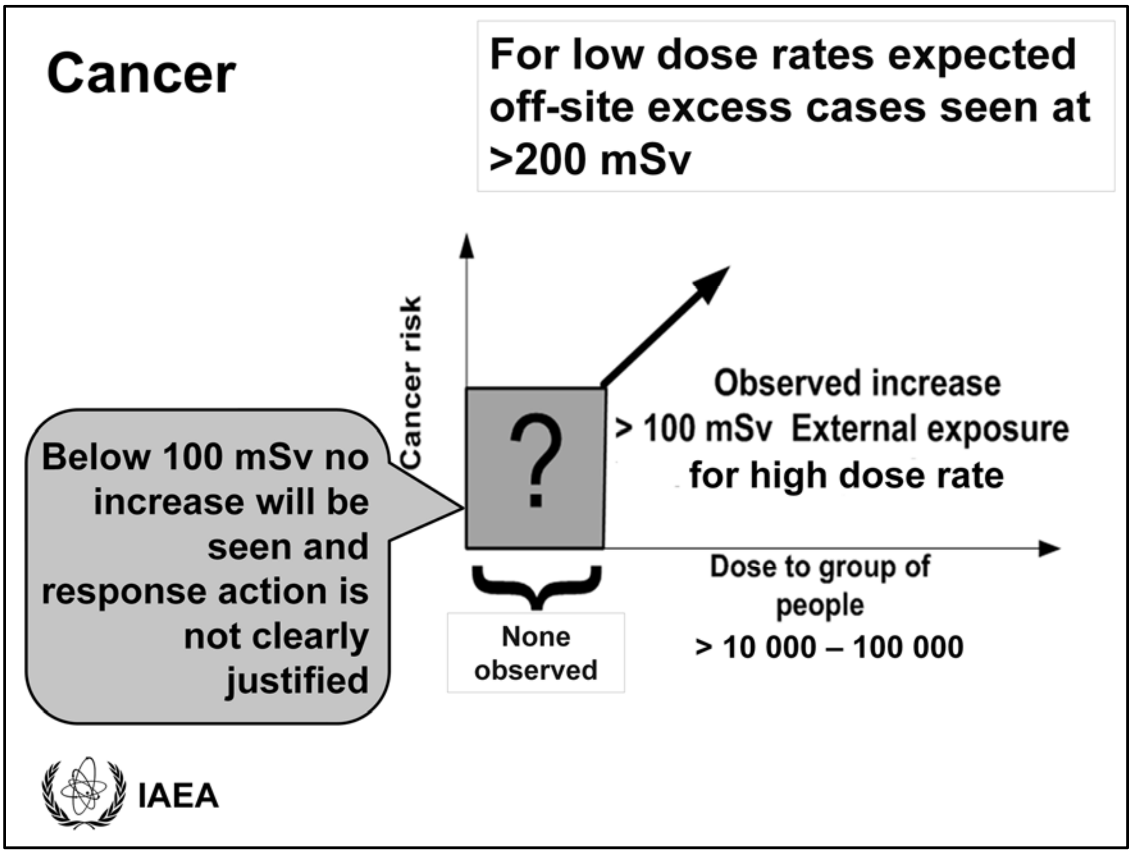
UNITED NATIONS, Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR 2010 Report, UN, New York (2011).

ICRP 103

- ICRP 103 – states that it is not appropriate to calculate the hypothetical number of cases of cancers that might be associated with very small radiation doses received by large numbers of people over very long periods.

IAEA

Based on: INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Recommendations of the International Commission on Radiological Protection, ICRP Publication No. 103, Ann. ICRP, Vol. 37 (2-3), Pergamon Press, Oxford (2007).



Therefore, there will be a dose below which an increase in cancers cannot be observed. This may be because any increase is too low to be seen when compared to the cancer rate for normal background. However, below this dose it is unknown if any cancers would have been caused by the emergency.

As shown in the figure, an increase in the total cancer incidence has only been observed when large numbers of people (>10 000 to 1000 000) have received an effective dose from external radiation to their whole bodies or equivalent dose to their organs at levels greater than about 100 mSv. This is based on data from high dose rates. For the lower dose rates that will occur off the site following a release of radioactive material from a reactor core or spent fuel pool, a comparable level of radiation induced cancer risk may occur at a dose two or more times higher.

Below the dose at which health effects would be seen, protective and other response actions are not clearly justified.

Generic criteria (GC) to reduce the risk of stochastic effects [Table 3, GSG-2]

	Urgent actions	Early actions
Effective (E)	100 mSv, 7 days	100 mSv, 1 year
Fetus: equivalent (H_{fetus})		
Thyroid: equivalent ($H_{thyroid}$)	50 mSv (ITB only)	

Below the GC, an increase in the cancer rate would be not seen even for high doses rates

IAEA

These are the GC (Table 3 of publication GSG-2) that if projected, call for taking urgent actions with the goal of reasonably reducing the risk of stochastic effects (cancers). The GC have been established at doses at which an increase in the cancer incidence would not be seen even for emergencies involving large numbers of people being exposed to high dose rates.

Abbreviation:

ITB – iodine thyroid blocking

Generic criteria (GC) to reduce the risk of stochastic effects [Appendix III, EPR-NPP PPA]

- Below these doses:
  - an increase in the cancer rate is undetectable
  - the risk of cancers is too low to justify taking any actions such as a medical screening
- These generic criteria may be conservative for an actual emergency because for a reactor release, the dose for a comparable level of risk would probably be two or more times higher than the GC

IAEA

As discussed in Appendix III of EPR-NPP PUBLIC PROTECTIVE ACTIONS, the GC for reducing the risk of stochastic effects (cancers) are established at doses below which an increase in the cancer incidence rate due to radiation induced cases is uncertain and will not be detectable. Therefore the risk of radiation induced cancers for doses below the criteria is too low to justify taking any actions, such as a medical screening.

The criteria were established for exposures at high dose rates. For the lower dose rates that will occur off the site following a reactor core or spent fuel pool release, a comparable level of radiation induced cancer risk would probably occur at a dose two or more times higher.

Problems with the Projection of Cancers and Other Effects during an Emergency

IAEA

International Atomic Energy Agency

Cancer predictions for low doses

- Unjustified and not supported scientifically
- Can do more harm than good
- Result in undue public concern and unjustified actions (for example):
  - abortions
  - medical examinations
  - compensation schemes
- Do not provide a basis for justified response actions
- But…be prepared to address concerns raised

IAEA

Making predictions of excess cancers at low doses is unjustified and not supported scientifically.

However, these predictions are likely be made after any severe emergency and result in undue public concern and unwarranted actions such as abortions, medical examinations and compensation payments. These predictions do more harm than good and do not provide a justified basis for any response actions.

It will be impossible to prevent experts from making such predictions; therefore, preparation should be made to address public concerns resulting from such predictions.

Chernobyl – cancer predictions (non-thyroid)

Chernobyl – cancer deaths among the public worldwide over the next 50 years	
Newspapers – experts – IAEA, WHO, UNDP projections	4000 – 500 000
Actual excess, above normal rate, expected to be attributed to Chernobyl	≈ 0

"Cancer death toll from Fukushima could exceed 10 000"

IAEA

This slide shows that the number of excess cancer deaths projected to result from Chernobyl by experts was anywhere from about 4000 to over 500 000. These projections appeared in newspapers and were attributed to various experts and international organizations. However, the actual number of excess cancers above the normal rate of cancers that we expect to be attributed to the Chernobyl accident over the next 50 years is near zero. Projections of cancer deaths are already being made for Fukushima: "The death toll from Fukushima could exceed 10 000."

Sources:

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, OFFICE FOR THE COORDINATION OF HUMANITARIAN AFFAIRS, UNITED NATIONS DEVELOPMENT PROGRAMME, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD BANK GROUP, WORLD HEALTH ORGANIZATION, Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts; Recommendations to the Governments of Belarus, the Russian Federation and Ukraine, The Chernobyl Forum: 2003–2005, IAEA, Second Revised Version, IAEA, Vienna (2006).

INTERNATIONAL ATOMIC ENERGY AGENCY, Development of an Extended Framework for Emergency Response Criteria: Interim Report for Comments, IAEA-TECDOC-1432, Vienna (2005).

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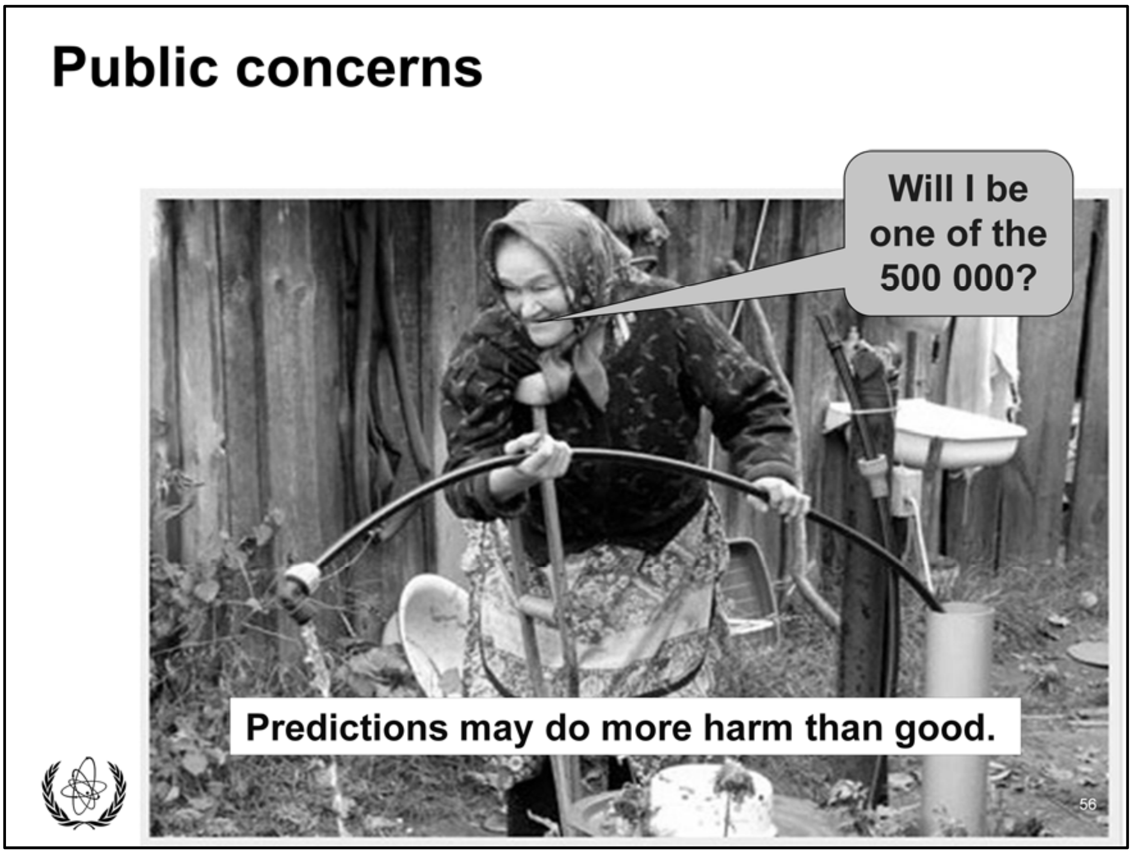


Predictions of cancers may do more harm than good.

Picture by: *Dana Sacchetti and Gill Tudor*
http://www.iaea.org/newscenter/focus/chernobyl/25years/

Cannot reasonably predict cancers for low dose [Section 7.4, EPR-NPP PPA]

- To detect excess cancers, experts must study cancer statistics for the population affected over a period of many years
- ICRP says: <u>do not use</u> ICRP's risk coefficient to predict cancers
- Linear-non-threshold (LNT) model <u>should not be used</u> to project cancers at low doses (<100 mSv)

IAEA

Section 7.4 of EPR-NPP PUBLIC PROTECTIVE ACTIONS discusses the common errors committed when assessing the health impact of an emergency to include projecting excess cancers based on the use of the fatal risk coefficient (deaths per sievert of collective effective dose) given by the International Commission on Radiation Protection (ICRP). This coefficient is based on the linear-non-threshold (LNT) model and was intended to be used for the purposes of radiological protection only. ICRP clearly states that its use for projecting health consequences was never intended because of the uncertainty of health effects at low doses.

Source:

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Recommendations of the International Commission on Radiological Protection, ICRP Publication No. 103, Ann. ICRP, Vol. 37 (2-3), Pergamon Press, Oxford (2007).

Information wanted vs. that provided

Is my baby safe ?
Am I safe?
Is my family safe?

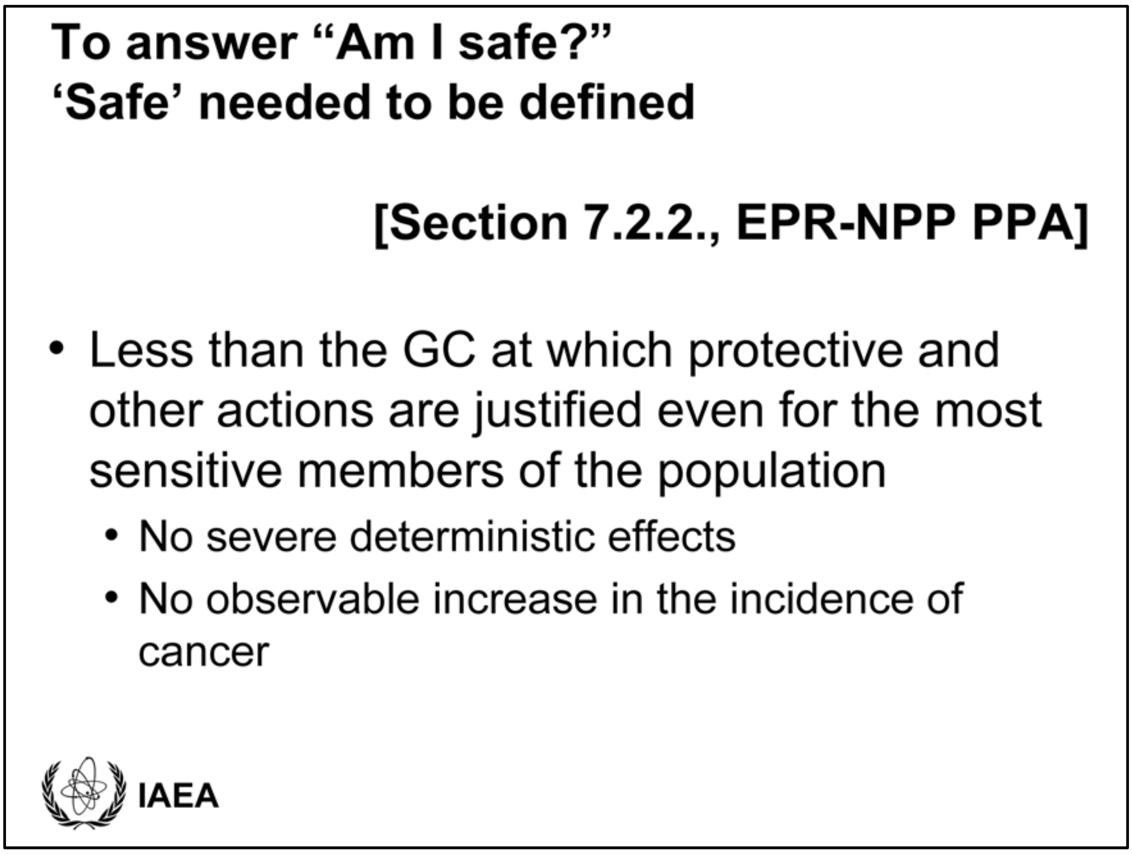
During emergencies:

- Not answered
- When answered the answers were
  - incorrect
  - conflicting
  - confusing

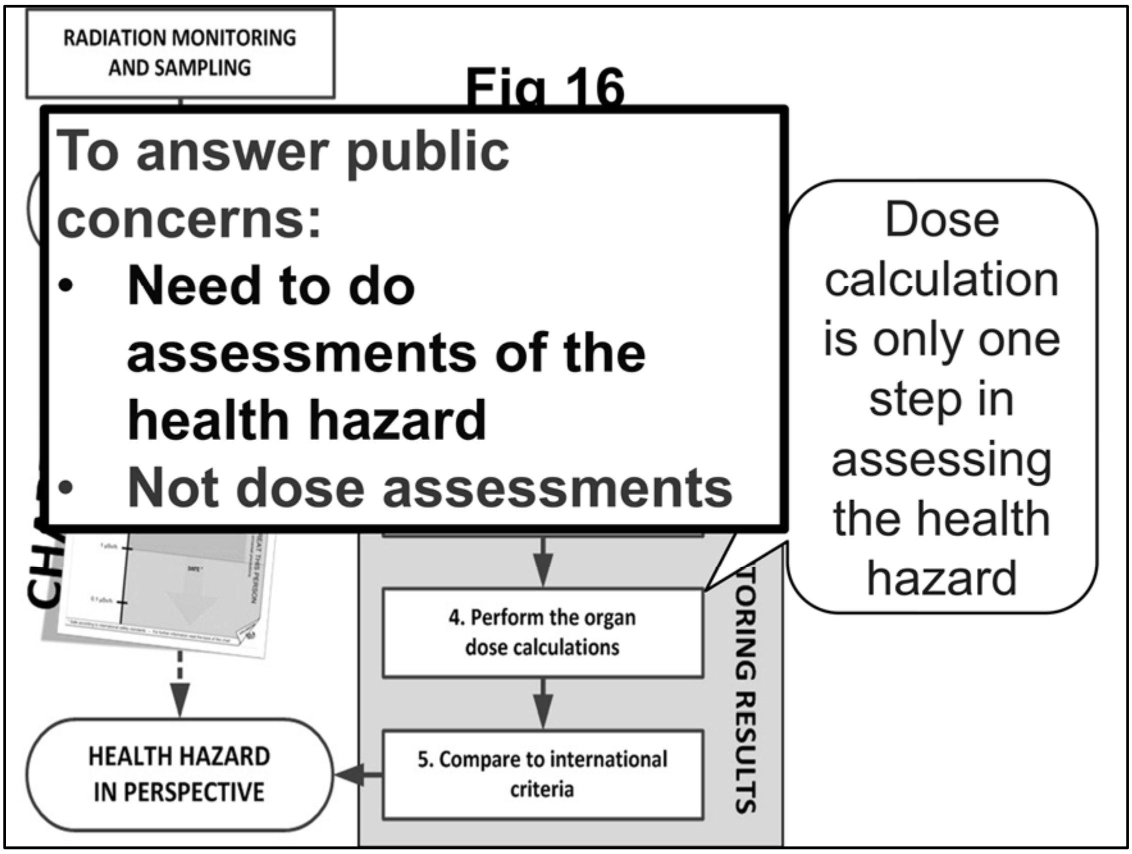
Result: confusion and mistrust

IAEA

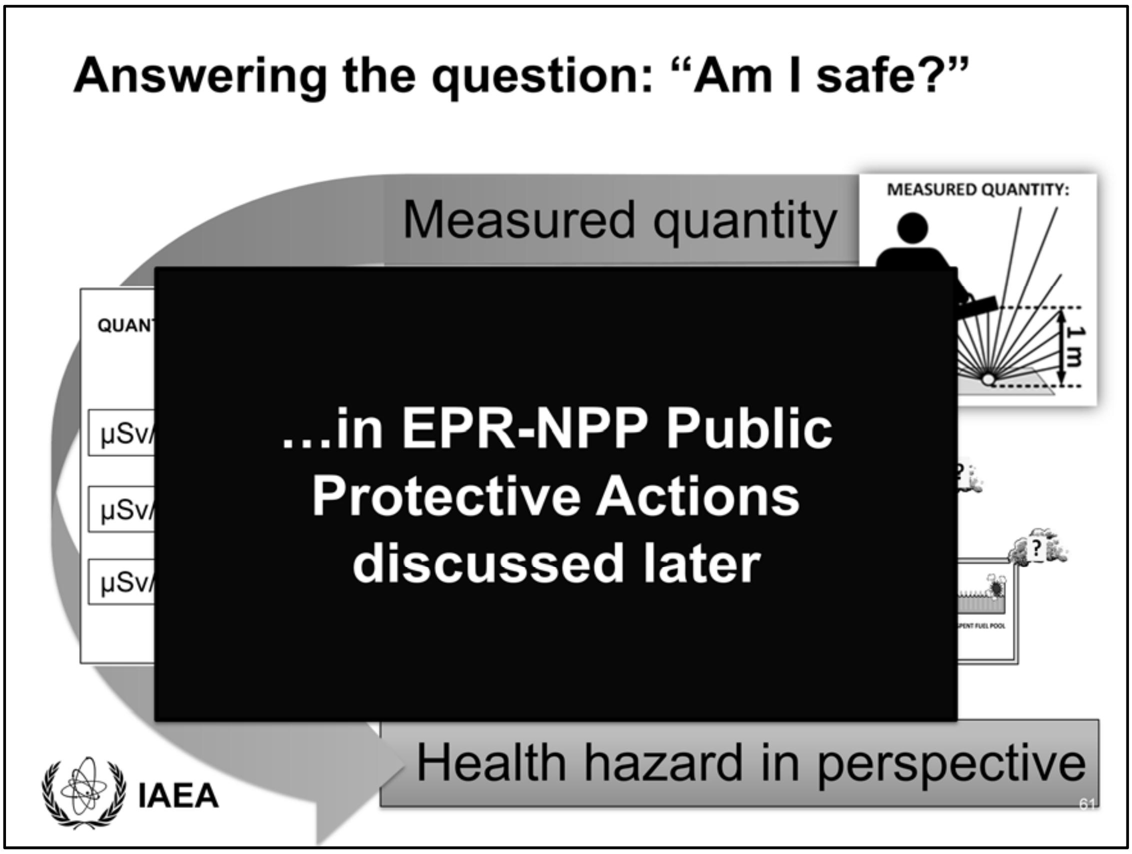
In most cases, the answers to these questions were not given when numbers in various units and quantities were reported in the media during past reactor emergencies. When the media did use these units and quantities to answer these questions, the answers were often incorrect, conflicting or confusing. The result was confusion and, sometimes, inappropriate actions being taken by the public.



To respond to the fundamental question "Am I safe?" that the public will ask, 'safe' is defined as keeping the dose below the GC for which no protective or other response actions need to be taken, in accordance with section 7.2.2 of EPR-NPP PUBLIC PROTECTIVE ACTIONS. This also means that no severe deterministic effects nor increase in the incidence of cancer will arise, even among the most sensitive members of the population such as pregnant women and children.



Calculating a dose is just part of the process of determining the health hazard, as shown in Fig. 16 of the publication EPR-NPP PUBLIC PROTECTIVE ACTIONS. During an emergency, specialists need to do assessments of the health hazard, not dose assessments.



To answer the question “Am I safe?” the publication EPR-NPP PUBLIC PROTECTIVE ACTIONS provides charts that show for measured quantities (e.g. dose rate above contaminated ground) the potential heath hazard for exposure scenarios important during a reactor emergency (e.g. living on contaminated ground). These figures will be discussed later.

Questions Module 4-5 and 4-6:

5. Which questions should be asked in order to determine the health effects of a dose?

6. Why would you not expect to see any increase in the incidence rate of cancer when the dose is less than the Generic Criteria (GC) to reduce the risk of stochastic effects?

IAEA

Answers Module 4-5 and 4-6:

5. Which questions should be asked in order to determine the health effects of a dose?

How was the exposure received, who was exposed, how was the dose calculated, what were the criteria used to establish the onset of the effect?

6. Why would you not expect to see any increase in the incidence rate of cancer when the dose is less than the generic criteria to reduce the risk of stochastic effects?

Any increase is too low to be seen when compared to normal background cancer rate. Below this dose a cancer cannot be attributed to the doses received.

IAEA

Questions Module 4-6 and 4-7:

6. Which cancer is of most concern from a fission product release?

7. How does ICRP say that you should use their risk coefficient when projecting cancers amongst the public following a release from a nuclear power plant such as occurred at Fukushima?

IAEA

Answers Module 4-6 and 4-7:

6. Which cancer arising from a fission product release is of most concern?

   Cancer of the thyroid

7. How does ICRP say that you should use their risk coefficient when projecting cancers amongst the public following a release from a nuclear power plant such as occurred at Fukushima?

   ICRP says that it is inappropriate to make such projections

IAEA

Timeline of Events During the Emergency at the TEPCO Fukushima Daiichi NPP

Module 5

Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

IAEA

International Atomic Energy Agency

Lecture: L-05 Timeline of Events During the Emergency at the TEPCO Fukushima Daiichi NPP
Purpose: To provide an overview of the emergency that began on 11 March 2011 at the TEPCO Fukushima Daiichi nuclear power plant in Japan.
Learning objectives: Upon completion of this lecture, the participants will: know the main events of the emergency and will have identified the main lessons to be learned on emergency preparedness and response.
Duration: 1 hour

To do

- Update Timeline handout

IAEA

Learning objectives

- Upon completion of this module participants will:
  - have an overview of the key events in the Fukushima emergency
  - know the main lessons to be learned in emergency preparedness and response (EPR) for this emergency

IAEA

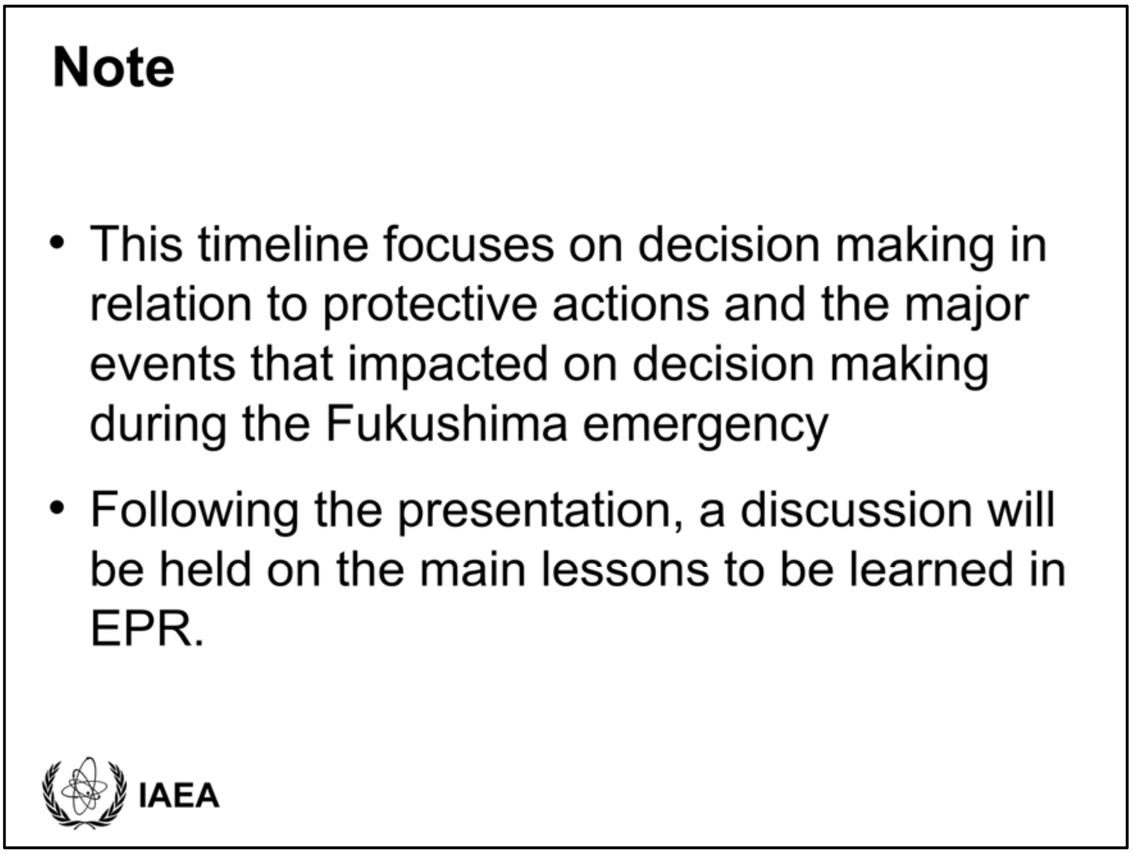
Upon completion of this module participants will:
- have an overview of the key events in the Fukushima emergency
- know the main lessons to be learned in emergency preparedness and response (EPR) for this emergency.

Introduction

- This presentation will provide participants with an overview of the emergency that began on 11 March 2011 at the TEPCO Fukushima Daiichi nuclear power plant in Japan.

IAEA

This presentation will provide participants with an overview of the emergency that began on 11 March 2011 at the TEPCO Fukushima Daiichi nuclear power plant in Japan.



This timeline focuses on decision making in relation to protective actions and the major events that impacted on decision making during the Fukushima emergency.

Following the presentation, a discussion will be held on the main lessons to be learned in EPR.

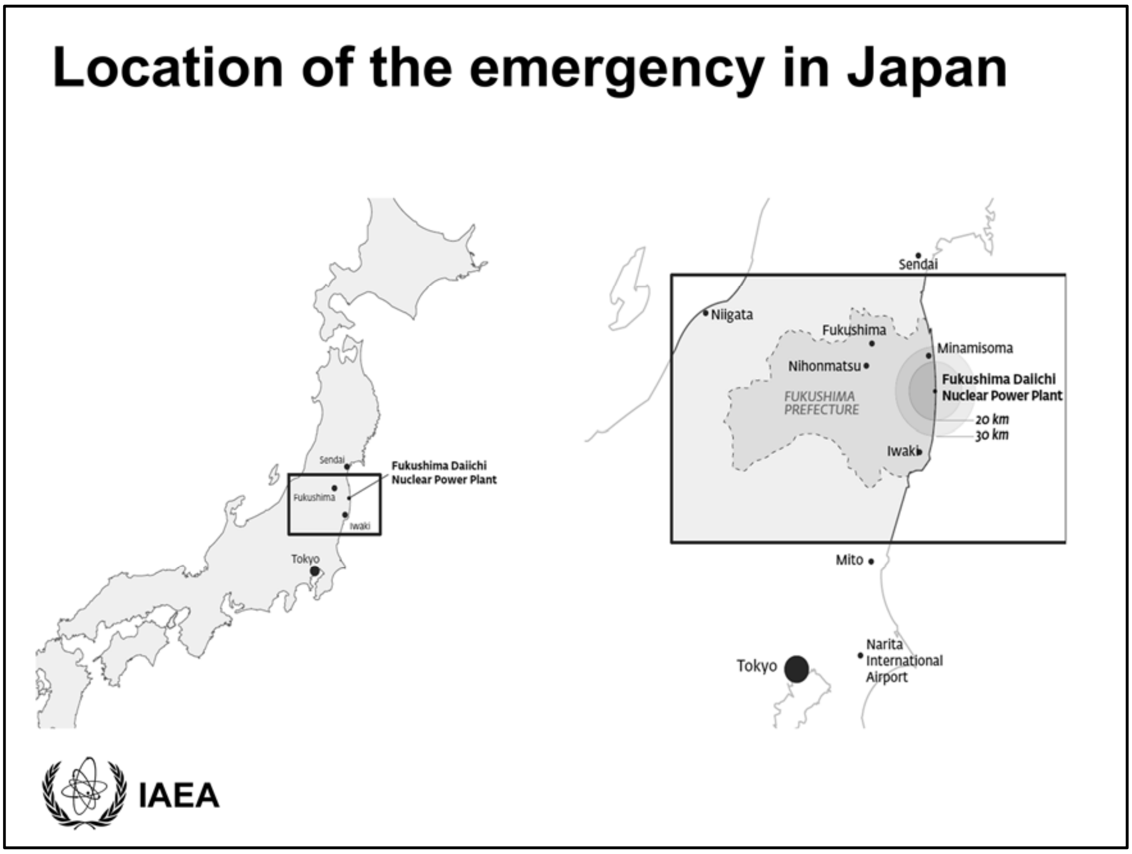
The next few slides provide an outline of the EPR system established in Japan at the time of the emergency: the main features relevant to response will be highlighted.

Overview – context

- The magnitude 9.0 Tohoku Great East Japan Earthquake and Tsunami of 11 March 2011 caused the deaths of some 15 000 people.
- Japan's EPR system was responding at the same time to both a natural disaster and the nuclear emergency at the TEPCO Daiichi nuclear power plant in Fukushima Prefecture.

IAEA

On 11 March 2011 the Tohoku Great East Japan Earthquake with a magnitude 9.0 and subsequent tsunami caused the deaths of some 15 000 people.
Japan's EPR system was responding at the same time to both this natural disaster and the nuclear emergency at the TEPCO Daiichi nuclear power plant in Fukushima Prefecture.



This slide shows the geographical location of the TEPCO Fukushima Daiichi nuclear power plant on the east coast of Japan.

Source of figure: THE NATIONAL DIET OF JAPAN FUKUSHIMA NUCLEAR ACCIDENT INDEPENDENT INVESTIGATION COMMISSION, The official report of The Fukushima Nuclear Accident Independent Investigation Commission, Executive summary, The National Diet of Japan, Tokyo (2012).

Overview – context (cont.)

- Approximately 150 000 people were evacuated or relocated due to the accident (Diet report, 2012)
- To date, there have been no health effects from radiation exposure among the public (UNSCEAR 2012)

IAEA

Approximately 150 000 people were evacuated or relocated due to the accident (Diet report, 2012).
To date, there have been no health effects from radiation exposure among the public (UNSCEAR 2012).

Source: THE NATIONAL DIET OF JAPAN FUKUSHIMA NUCLEAR ACCIDENT INDEPENDENT INVESTIGATION COMMISSION, The official report of The Fukushima Nuclear Accident Independent Investigation Commission, Executive summary, The National Diet of Japan, Tokyo (2012).
http://warp.da.ndl.go.jp/info:ndljp/pid/3856371/naiic.go.jp/en/report/

Source: United Nations Scientific Committee on the Effects of Atomic Radiation, Report of United Nations Scientific Committee on the Effects of Atomic Radiation, Fifty-Ninth session, General Assembly Sixty-Seventh session, Supplement No. 46, United Nations, New York (2012).

Authority to evacuate

- Basic law – Countermeasures for Disasters Law (Disaster Act)
  - Local government authority to advise evacuation
- Act on Special Measures Concerning Nuclear Emergency Preparedness (Nuclear Act)
  - The Prime Minister (PM) has the authority to advise evacuation
  - The response is launched after the PM declares an emergency

Japan’s EPR framework for the response to a nuclear emergency includes:
- Basic law – Countermeasures for Disasters Law (Disaster Act); and
- Act on Special Measures Concerning Nuclear Emergency Preparedness (Nuclear Act) – passed in 1999 after the Tokaimura criticality accident.

The authority to evacuate is specified in both the Disaster Act for the local government and the Nuclear Act for the Prime Minister. In addition, the response is launched after the Prime Minister declares an emergency.

Drills and exercises

- Conducted at the local level for instructing the public located within 2 km to evacuate following notification by the operator
- Prime Minister had participated in drills and exercises once a year.

IAEA

Prior to the emergency, regular nuclear emergency drills and exercises had been conducted at the local level for instructing the public located within 2 km to evacuate following notification by the operator.
The Prime Minister had participated in drills and exercises once a year.

EPR arrangements in Japan for a nuclear emergency

- Decision making to initiate off-site protective actions relied heavily on computer-based prediction systems and were used in drills and exercises
- Criteria for long term protective actions (e.g. temporary relocation) and termination criteria had not been established prior to the emergency

[redacted]

Prior to the accident, the EPR arrangements in Japan for a nuclear emergency had been established so that decision making to initiate off-site protective actions relied heavily on computer-based prediction systems.
However, criteria for long term protective actions such as temporary relocation and termination criteria had not been established prior to the emergency.

Timeline

IAEA

The main events of the Fukushima emergency are presented in the form of a timeline in the following slides.

11 March

- 14:46 Earthquake:
- All reactors in operation automatically shut down (SCRAM)
- Loss of off-site AC power for all units
- Emergency diesel generators (EDGs) began operation

IAEA

On 11 March 2011 at 14:46 the Tohoku Great East Japan Earthquake with a magnitude 9.0 caused:

– All reactors in operation were automatically shut down (SCRAM)
– Loss of off-site AC power for all units
– Emergency Diesel Generators (EDGs) began operation.

11 March

- 15:37 Impact of the first wave of the tsunami at the TEPCO Fukushima Daiichi nuclear power plant
- All EDGs in operation (except that of Unit 6) shut down, causing loss of all AC power: station blackout

IAEA

At 15:36 the first tsunami wave impacted the NPP. As a result, all EDGs in operation (except that of Unit 6) shut down, causing the loss of all AC power: station blackout.
Source: Fukushima Nuclear Accident Analysis Report, June 20, 2012, TEPCO
http://www.tepco.co.jp/en/press/corp-com/release/betu12_e/images/120620e0104.pdf

11 March

- 15:42 the operator notified off-site officials of the loss of AC/DC power at all units

- 16:36 the operator notified off-site officials of the inability to inject water into the reactor using any of the emergency core cooling systems

IAEA

Two notifications were sent from the operator to the off-site officials:

1) First notification of the loss of AC/DC power at all units was sent at 15:42
2) The second notification of the inability to inject water into the reactor using any of the emergency core cooling systems was sent at 16:36.

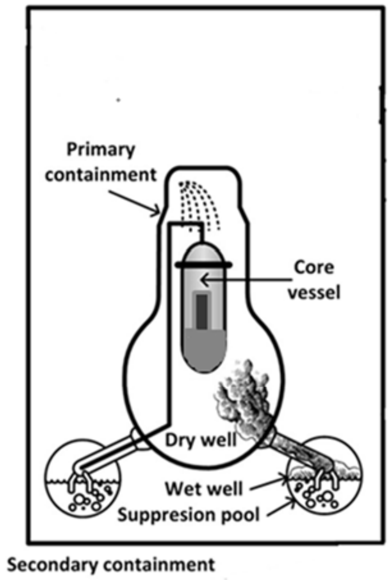
This was done in accordance with the criteria for notification established prior to the accident under the Nuclear Act.

The inability to inject water into the reactor meant that damage to the fuel will take place shortly.

The fuel of a reactor must always be kept covered with water for cooling otherwise it will overheat and fail, releasing radioactive material (IAEA 1997). The inability to inject water into the reactor at the Fukushima Daiichi NPP meant that damage to the fuel would take place shortly and radioactive material will be released into the atmosphere if the containment fails. The containment could have failed at any time and it was impossible to predict when this would happen. Thus, following damage to the fuel in the core, there is always the possibility of an unpredictable release of radioactive material to the atmosphere (IAEA 2013). In the most severe emergencies, this plume of radioactive material that is released can possibly result in injuries and deaths within hours for those located within about 2 to 5 km of the NPP if protective actions are not taken.

11 March

- 18:10 the core of Unit 1 became uncovered – severe release to the atmosphere was possible at any moment



IAEA

11 March

- 19:03 Declaration of a ‘State of Nuclear Emergency’ and launch of the emergency response
- ‘State of Nuclear Emergency’ is equivalent to a General Emergency under IAEA guidance

IAEA

11 March

- 20:50 The local government decided to issue an evacuation order directed at persons within a 2 km radius of the plant (notification of the public begins soon thereafter).

IAEA

11 March

- 21:23 The National Government decided to issue an evacuation order within a 3 km radius and advised sheltering within a 10 km radius.

  Press conference on decision was held at 21:52.

  (Evacuation out to 3 km completed at around 01:45 o'clock on 12 March).

IAEA

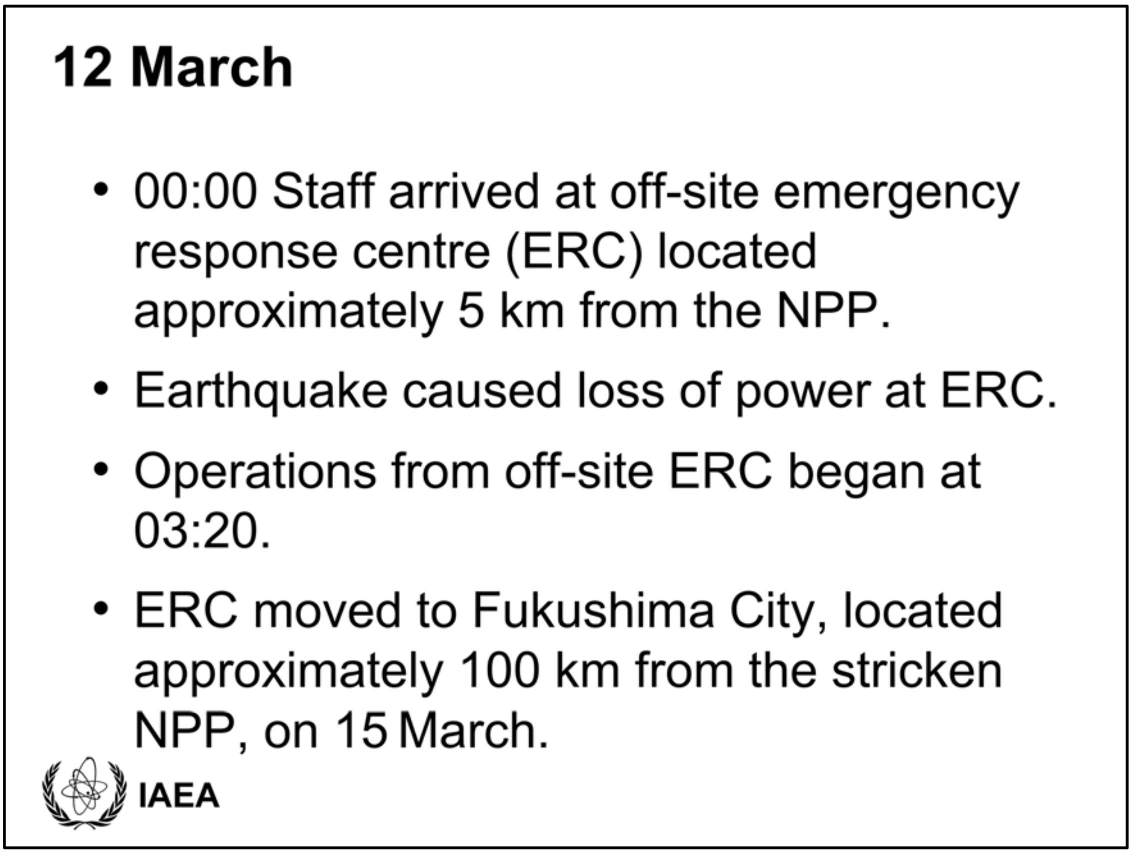
11 March – 25 April

- Independent press conferences held by:
  - Government
  - Regulator
  - Local emergency response organizations
  - Local government
  - TEPCO

IAEA

During the emergency information was provided to the media and public from five different official sources. This information was uncoordinated until arrangements were established on 25 April for joint press conferences to be held involving all response organizations.

Having several official sources of information caused messages provided to the media and the public to be inconsistent. In some cases, conflicting opinions were presented at press conferences by staff of the same official source.



At 00:00 on 12 March staff arrived at the emergency response centre (ERC) located at a distance of approximately 5 km from the NPP.
The purpose of the ERC was for operations related to the emergency response measures (e.g. evacuation) to be coordinated from this location. However, the earthquake caused loss of power at the ERC and its emergency diesel generators failed to function. This meant that operations from the off-site ERC did not begin until 03:20.

In addition, the ERC moved to Fukushima City, located approximately 100 km from the stricken NPP, on 15 March. This was because the ERC was located within the evacuation zone:
– the ERC did not have filters or a ventilation system for protection against a release of radioactive material
– the ERC encountered problems in obtaining necessary supplies (e.g. food, water and fuel).

12 March

- 00:06 Preparations for the venting of Unit 1 began.

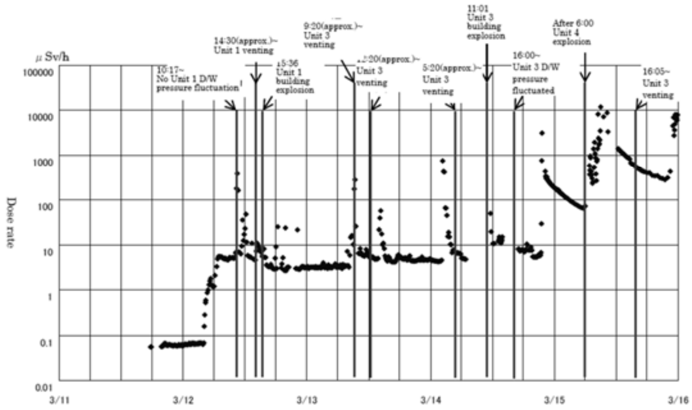
IAEA

At 00:06 preparations for the venting of Unit 1 of Fukushima Daiichi began.

12 March

- 04:00 Dose rate increase at the main gate.

  Believed to be the result of radioactive material released owing to damage to the reactor core of Unit 1.



Dose rate in vicinity of Fukushima Daiichi NPS main gate

At 04:00 an increase in the dose rate was measured at the main gate of the site.
The increase in dose rate at the main gain is thought to be the result of radioactive material released owing to damage to the reactor core of Unit 1.
Source: Fukushima Nuclear Accident Analysis Report, June 20, 2012, TEPCO: http://www.tepco.co.jp/en/press/corp-com/release/betu12_e/images/120620e0104.pdf

12 March

- 05:44 the National Government decides to issue an evacuation order for all individuals within a 10 km radius. A majority of the public were notified by approximately 09:00.

IAEA

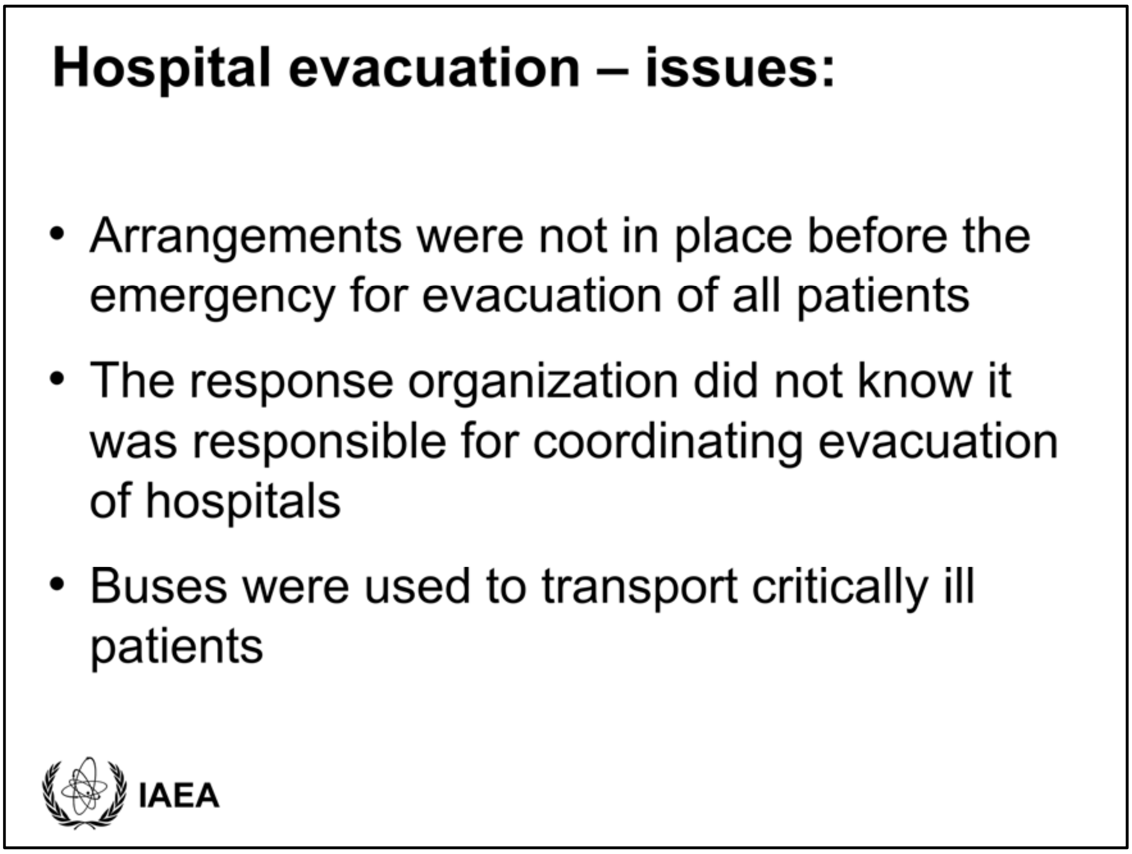
At 05:44 the National Government decided to issue an evacuation order for all individuals within a 10 km radius.
The majority of the public were notified by approximately 09:00.

12 March

- 14:00 Evacuation of a hospital (5 km from the NPP) began.
- Three members of staff remained with 228 bedridden patients.

IAEA

Evacuation of a hospital (located approximately 5 km from the NPP) began.
Three members of staff remained with 228 bedridden patients.
There were shortages of both daily commodities and medical supplies, and there were only candles for lighting.



The next two slides list some of the issues arising from the evacuation of the hospital:

- Arrangements were not in place before the emergency for the evacuation of all patients
- The response organization did not know it was responsible for coordinating the evacuation of hospitals
- Buses were used to transport critically ill patients (and as a result, necessary medical care could not be continued during transport).

Hospital evacuation – issues:

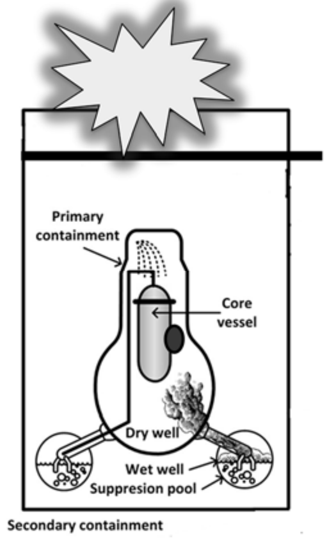
- Multiple, uncoordinated evacuations (no communication systems were working)
- Rescue teams aborted a rescue mission (had not been trained as emergency workers)
- Screening and decontamination was a condition for accepting patients at evacuation shelter (continuation of necessary medical care should have been the priority)

IAEA

There were multiple, uncoordinated evacuations by different response organizations (no communication systems were working).
Rescue teams aborted a rescue mission (they had not been trained as emergency workers).
Screening and decontamination was a condition for accepting patients at the evacuation shelter (continuation of necessary medical care should have been the priority).

12 March

- 14:30 Venting of Unit 1 completed.
- 15:36 Hydrogen explosion at Unit 1.



IAEA

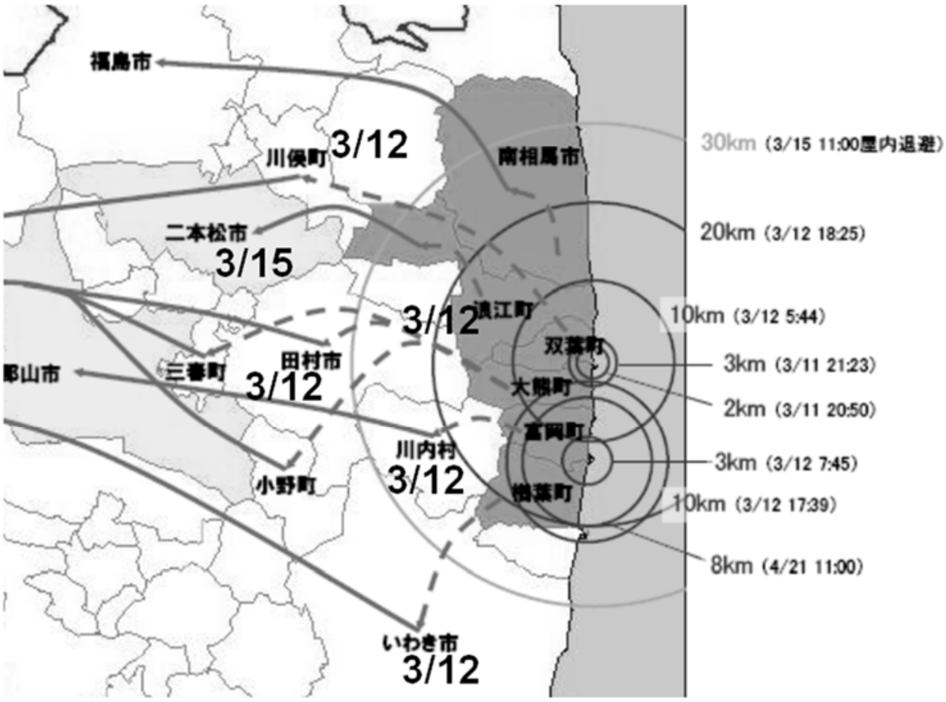
12 March

- 18:25 National Government decided to issue evacuation order for all individuals within a 20 km radius.

  The majority of local governments located in the area learned of the order via the media. The notification of the public and implementation of the evacuation varied.

IAEA

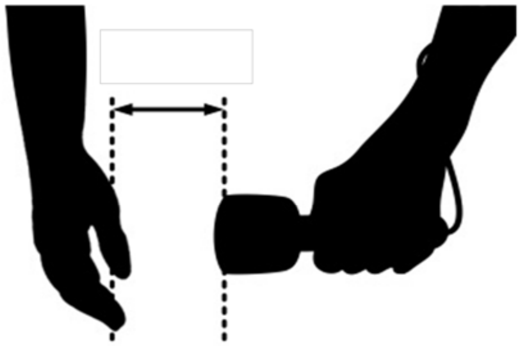
Map showing times and dates of evacuation orders



(Source: Council of local governments at all nuclear power plant sites)

12 March

- Monitoring of the public begins – criterion used: 13 000 cpm



IAEA

13 000 cpm was selected by the response organisation responsible for implementing screening based on the criterion of 40 Bq/cm^2 specified in Japan's nuclear emergency response manual (published in 2004).

13 March

- 05:10 Loss of ability to inject water into the core at Unit 3. Damage to the fuel will take place shortly.

IAEA

At 05:10 the ability to inject water into the core at Unit 3 was lost. Damage to the fuel will take place shortly.

14 March

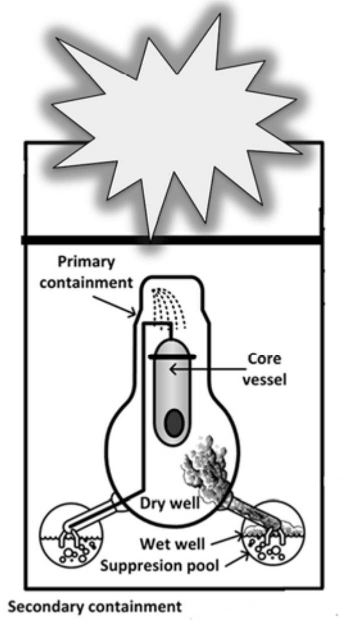
- Regulatory body holds a press conference. Different/conflicting explanations are provided by members of staff of the regulatory body.

IAEA

Prior to the holding of joint press conferences involving all response organizations as of 25 April 2011, uncoordinated information emanating from several official sources created inconsistencies in the messages provided to the media and the public. In some cases, conflicting opinions were presented at press conferences from staff of the same official source.

14 March

- 11:01 Hydrogen explosion at Unit 3.



IAEA

At 11:01 there was a hydrogen explosion at Unit 3.

14 March

- 13:25 Loss of the ability to inject water into the core of Unit 2. Damage to the fuel will take place within hours.

IAEA

At 13:25 the ability to inject water into the core was lost at Unit 2. Damage to the fuel will take place within hours.

14 March

- Monitoring of the public – criterion changed to 100 000 cpm (from 13 000 cpm).

IAEA

However, during screening and decontamination 13, 000 cpm was found to be unsuitable due to the increase from background levels of radiation and the conditions for decontamination measures (no showering facilities, no spare clothes and low temperatures making removal of outer garments unsuitable). Implementation of the new operational criterion of 100, 000 cpm was put into effect on 14 March – two days after screening had begun with 13, 000 cpm.

14 March

- An ambulance driver refused to transport three workers injured on-site, as hospitals were unwilling to accept contaminated patients.

IAEA

An ambulance driver refused to transport three workers who had been injured on-site, as hospitals were unwilling to accept contaminated patients.

15 March

- ≈ 00:00–04:00 Confusion over possible decision to evacuate all on-site staff.
- 05:30 A joint response organization (involving the operator and the Government) was established in Tokyo.

IAEA

Between 00:00 and 04:00 confusion took place over a possible decision to evacuate all on-site staff. This was a consequence of a misunderstanding between the operator and Government as to whether all on-site staff responding to the emergency would fully withdraw.

At 05:30 a joint response organization (involving the operator and Government) was established in Tokyo.

15 March

- 06:14 Explosion at the Unit 4 building.

IAEA

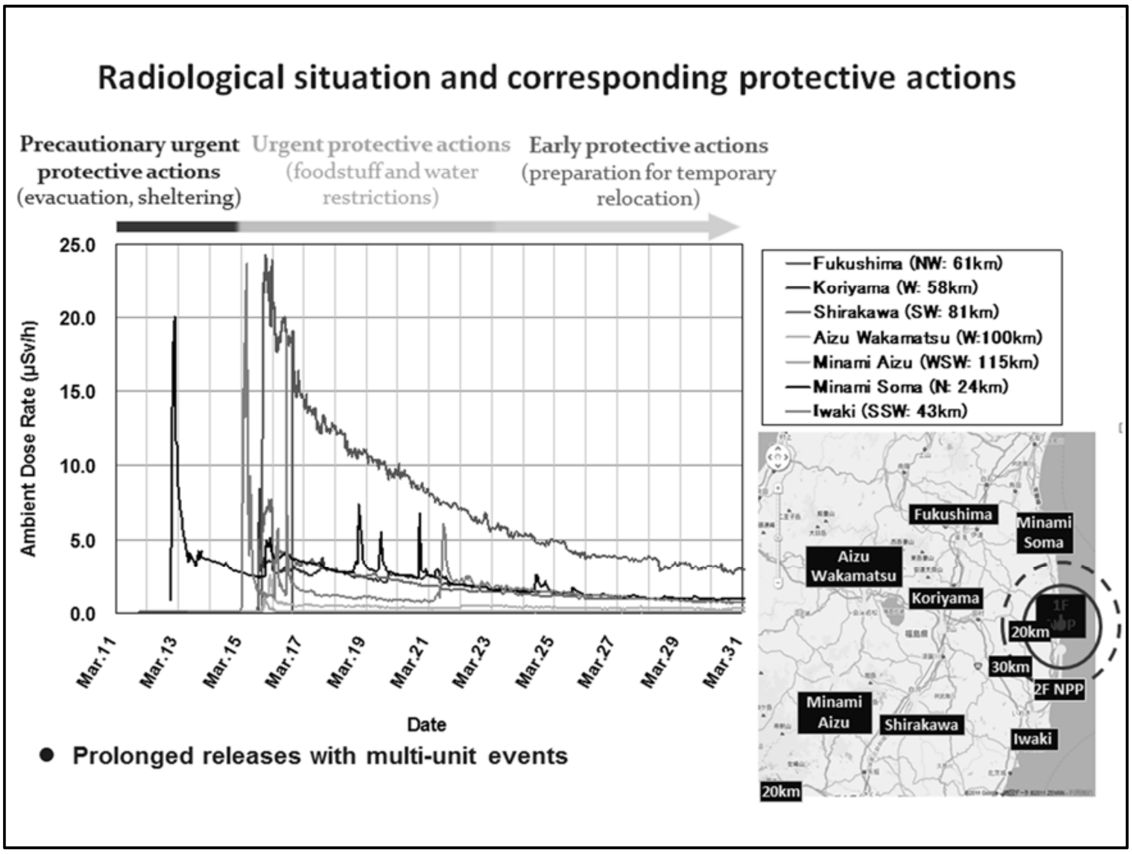
At 06:14 there was an explosion at the Unit 4 building.

15 March

- 11:00 Sheltering advised within 20–30 km zone.

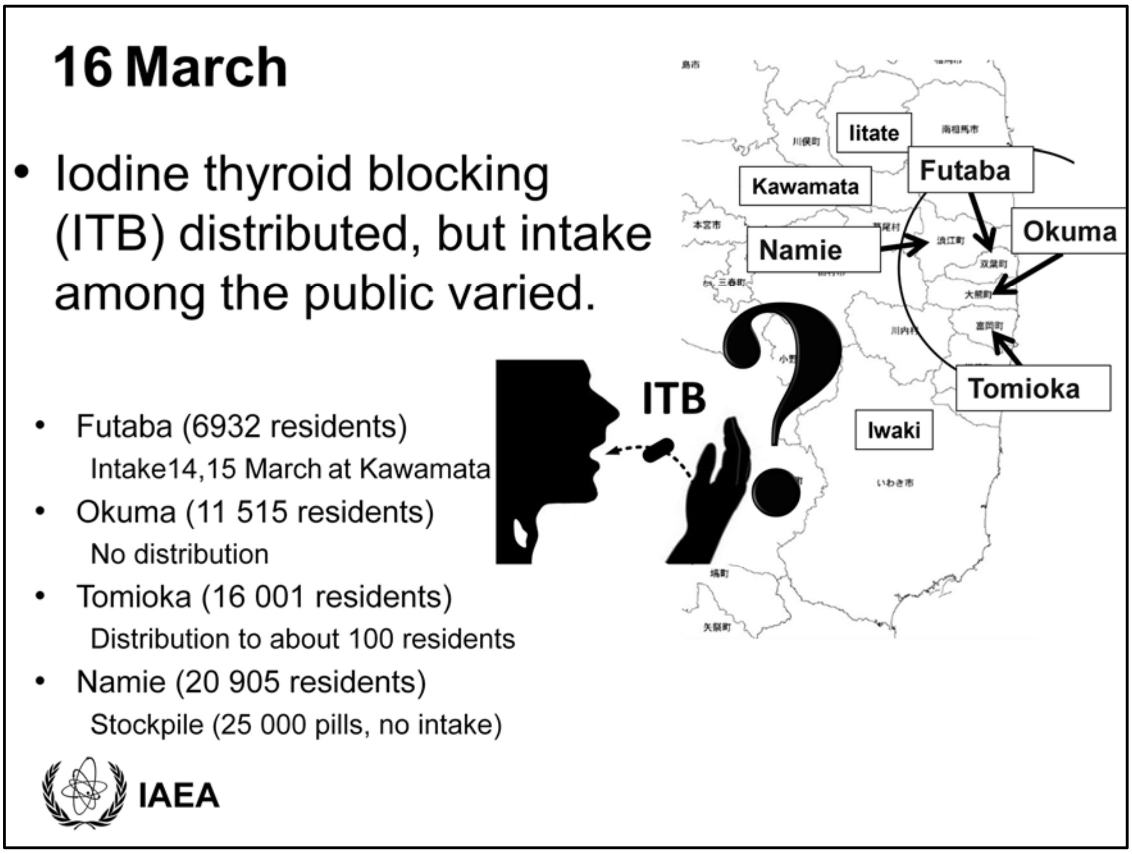
IAEA

At 11:00 sheltering was advised for all individuals within a distance of between 20 km and 30 km from the plant.



This graph shows the protective action phases (precautionary, urgent and early) implemented between 11 and 31 March 2011 in relation to the measured ambient dose rates.

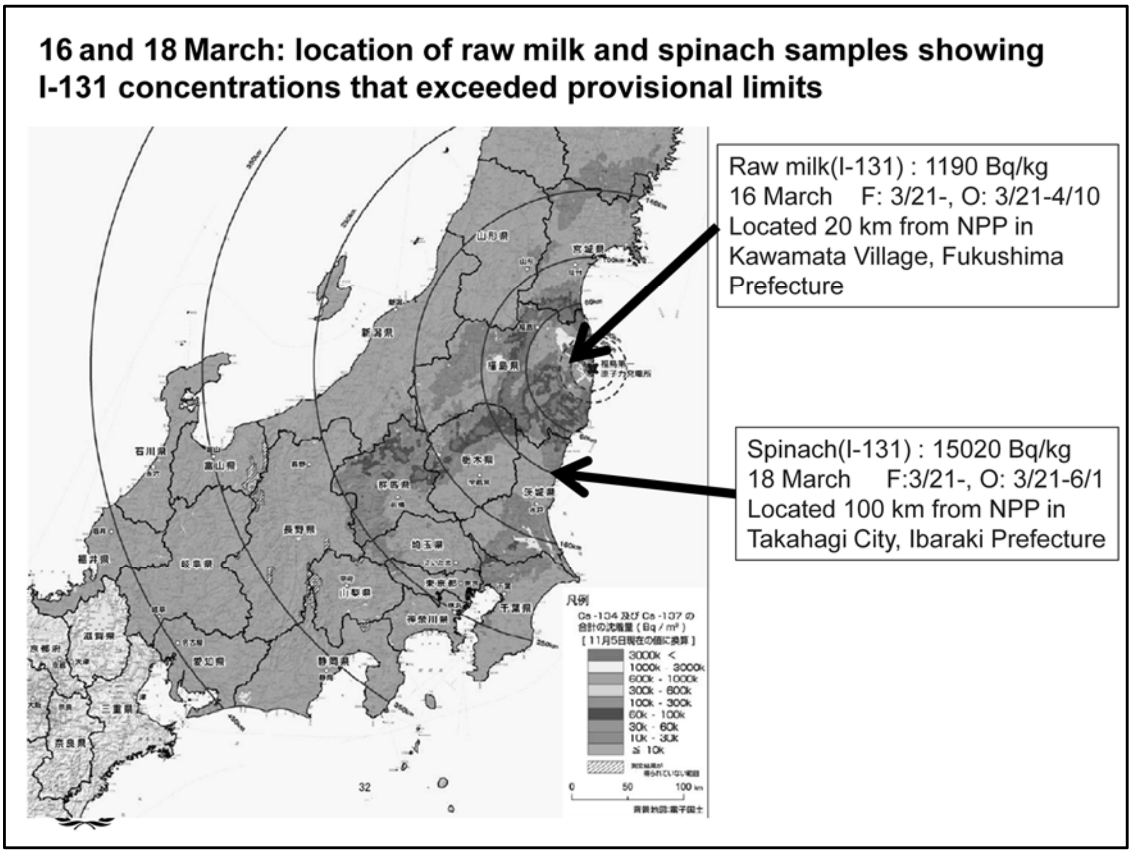
The image to the right shows the locations where the ambient dose rates were measured.



On 16 March iodine thyroid blocking (ITB) tablets were distributed, but intake among the public varied.

Four villages that are located within 20 km of the site are shown on this slide: Futaba, Okuma, Tomioka and Namie.

- Futaba (6932 residents) intake on 14, 15 March at Kawamata
- Okuma (11 515 residents) no distribution
- Tomioka (16 001 residents) distribution to about 100 residents
- Namie (20 905 residents) stockpile (25 000 pills, no intake).



This slide presents the locations of raw milk and spinach samples that showed I-131 concentrations exceeding 'provisional limits'.
Provisional limits are the criteria for applying or removing food restrictions, which were adopted by the Government on 17 March.

Raw milk – 16 March, located 20 km from the NPP in Kawamata Village, Fukushima.
Spinach – 18 March, located 100 km from the NPP in Takahagi City, Ibaraki Prefecture.

17 March

- The Ministry of Health, Labour and Welfare (MHLW) , which is responsible for food safety in Japan, decided to adopt NSC's criteria for food concentration levels (Bq/kg).

IAEA

On 17 March the Ministry of Health, Labour and Welfare (MHLW) – the governmental department that is responsible for food safety in Japan, decided to adopt NSC's criteria for food concentration levels (Bq/kg).

17 March

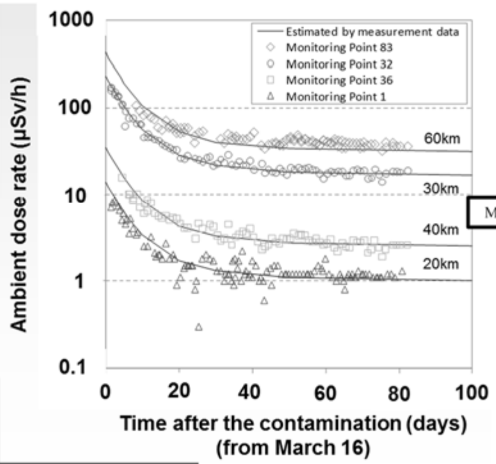
- The U.S. Embassy in Tokyo issued instructions for American citizens within 80 km to evacuate.

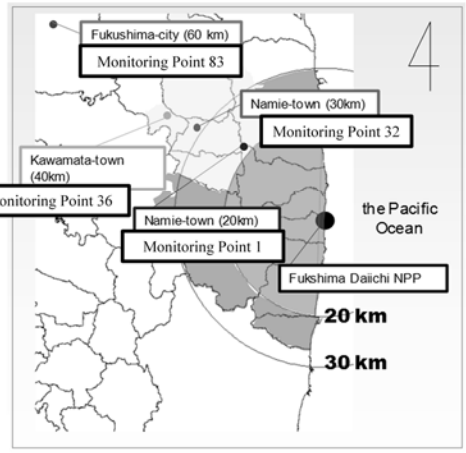
IAEA

On 17 March, the U.S. Embassy in Tokyo issued instructions for American citizens within 80 km of the NPP to evacuate.
http://japan.usembassy.gov/e/p/tp-20110317-01.html

17 and 18 March

- 17 March: 170 μSv/h measured (Monitoring Point 32, 30 km north-west)
- 18 March: NSC requested NISA to check the existence of houses around the monitoring point where the measurement was made





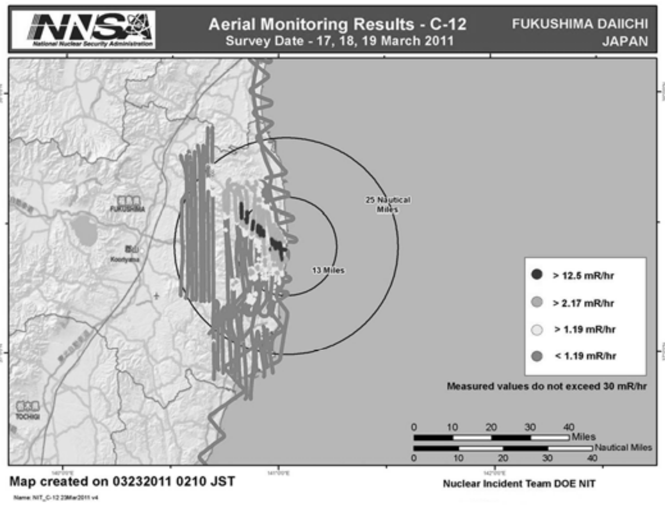
The graph on the left presents the ambient dose rate (μSv/h) readings measured from 16 March 2011 onwards at the monitoring point locations indicated in the image on the right.

17 March: 170 μSv/h measured (Monitoring Point 32, 30 km north-west) – as indicated on the graph on the left of this slide (red – 30 km 'Monitoring Point 32') – location Naime-town (indicated in the image on the right).

18 March: NSC requested NISA to check the existence of houses around the monitoring point where the measurement was made.

17–19 March

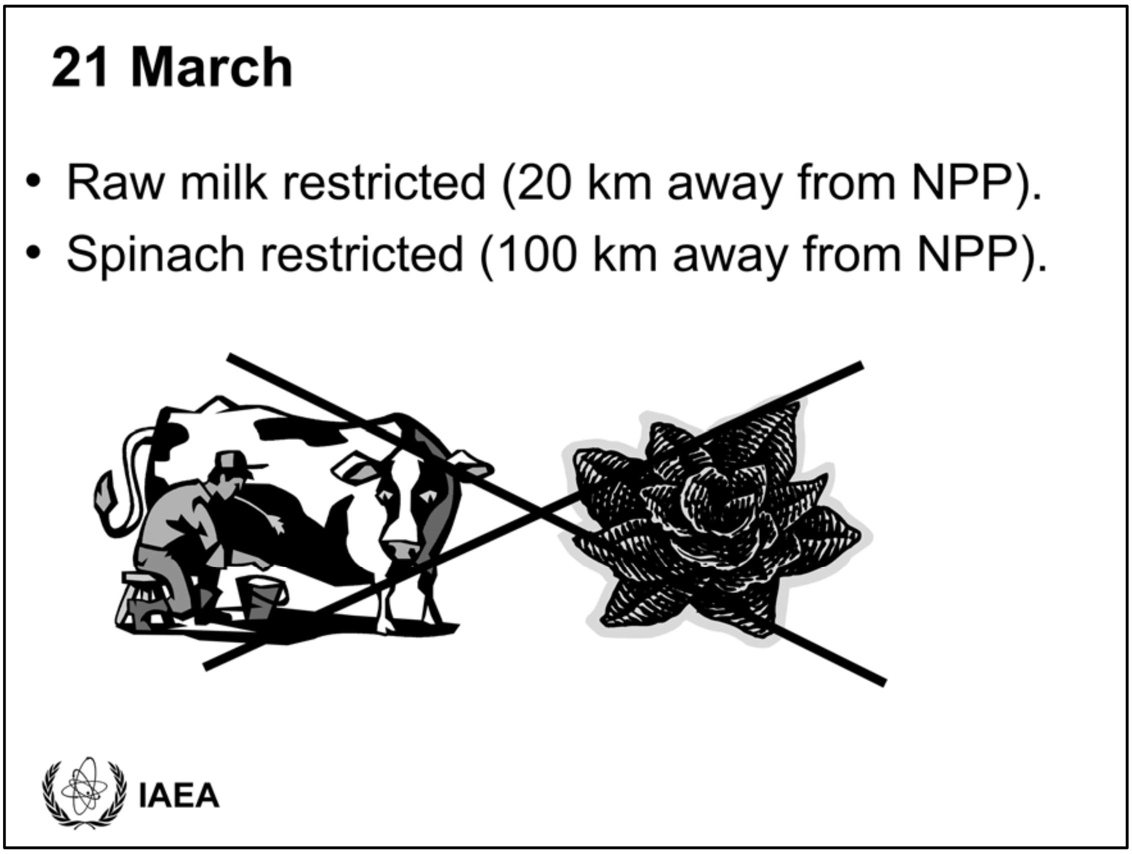
- U.S. Department of Energy conducts aerial monitoring.
- Identified locations outside area evacuated that exceed IAEA OIL for evacuation (in area that was later established as 'deliberate evacuation area' on 22 April).



IAEA

The U.S. Department of Energy conducted aerial radiological monitoring of the plant and surrounding areas.
The monitoring results identified locations outside the area evacuated that exceeded the IAEA operational intervention level (OIL) for evacuation (this was in an area that was established as 'deliberate evacuation area' on 22 April).

No formal procedures were in place for receiving data from foreign assistance.

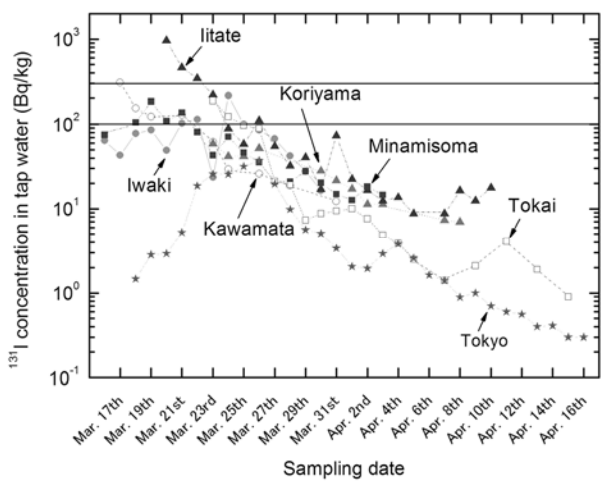


Restrictions on the distribution of raw milk began on 21 March – food sampling results for concentration of I-131 in raw milk were first obtained on 16 March (at a location 20 km away from the NPP in Kawamata Village, Fukushima Prefecture).
Restrictions on the distribution of spinach began on 21 March – food sampling results for concentration of I-131 in spinach were first obtained on 18 March (at a location 100 km away from the NPP in Takahagi City, Ibaraki Prefecture).

21 March

- Drinking water restricted (at locations up to 250 km away from the NPP).

Concentration of ^{131}I in tap water

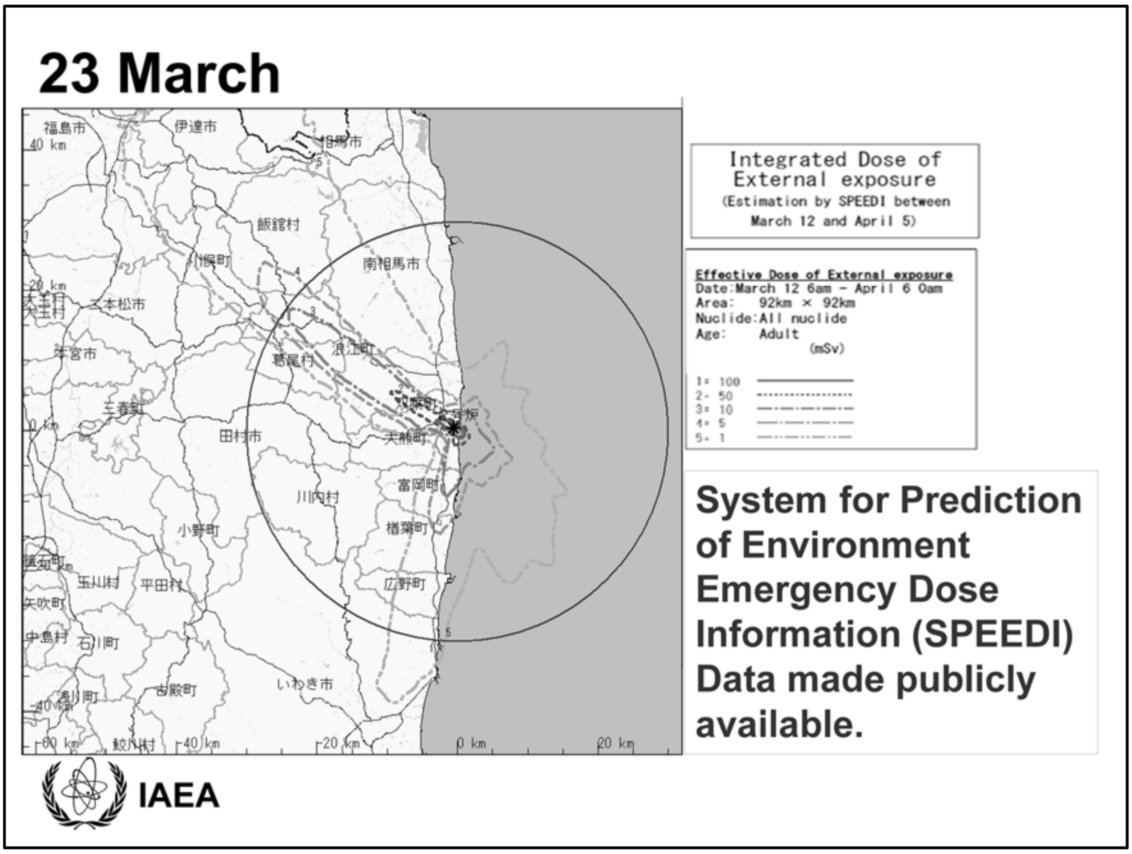


IAEA

On 21 March drinking water was restricted (at locations up to 250 km away from the NPP).

Distribution of bottled water in the Tokyo Metropolitan area took place over 2 days – some 240 000 bottles were distributed.

Source: (S. Kinase et al., Trans. A. Energy Soc. Japan, 10(3) 149, 2011)



The System for Prediction of Environment Emergency Dose Information (SPEEDI) is a computer-based decision support system for dose assessments.
The estimation of radioactivity of the plume provided by SPEEDI was a reverse analysis based on results from environmental monitoring that was conducted from 16 March onwards. The SPEEDI data was made publicly available on 23 March.

Residents of evacuated areas believed that a delay in making the data publicly available caused them to evacuate to areas with high air dose rates (Diet Report, 2012). However, the projections did not exist at the time when the evacuation orders were given on 11 and 12 March.

This gave rise to a misunderstanding and belief that the government could have prevented residents' exposure to radiation had the results been disclosed promptly and SPEEDI been effectively utilized in making decisions on the initial evacuation orders (Diet Report, 2012).

25 March

- Voluntary evacuations within 20–30 km sheltering zone advised.

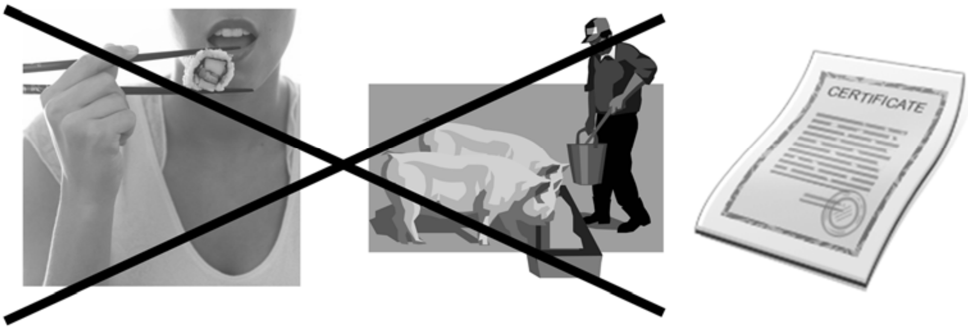
  The public had already begun to evacuate spontaneously.

IAEA

On 25 March voluntary evacuations were advised within the 20–30 km sheltering zone. Voluntary evacuation meant that those persons who were located in the 20–30 km zone could choose whether or not to evacuate. However, this proved to be problematic as the public were uncertain as how to decide. In addition, before this advice had been given, the public had already begun to evacuate spontaneously.

27 March

- European Union restricted food and animal feed from Japan and requires confirmation of monitoring/analysis or certificate of origin.

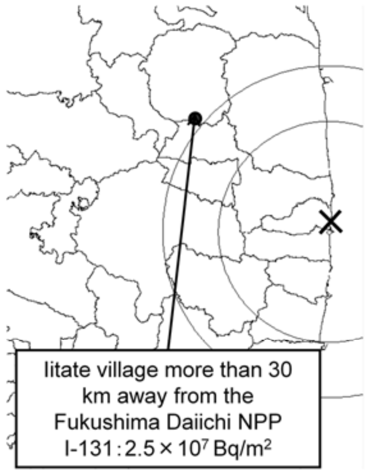


IAEA

The European Union restricted food and animal feed from Japan and required confirmation of monitoring/analysis or a certificate of origin.

30 March

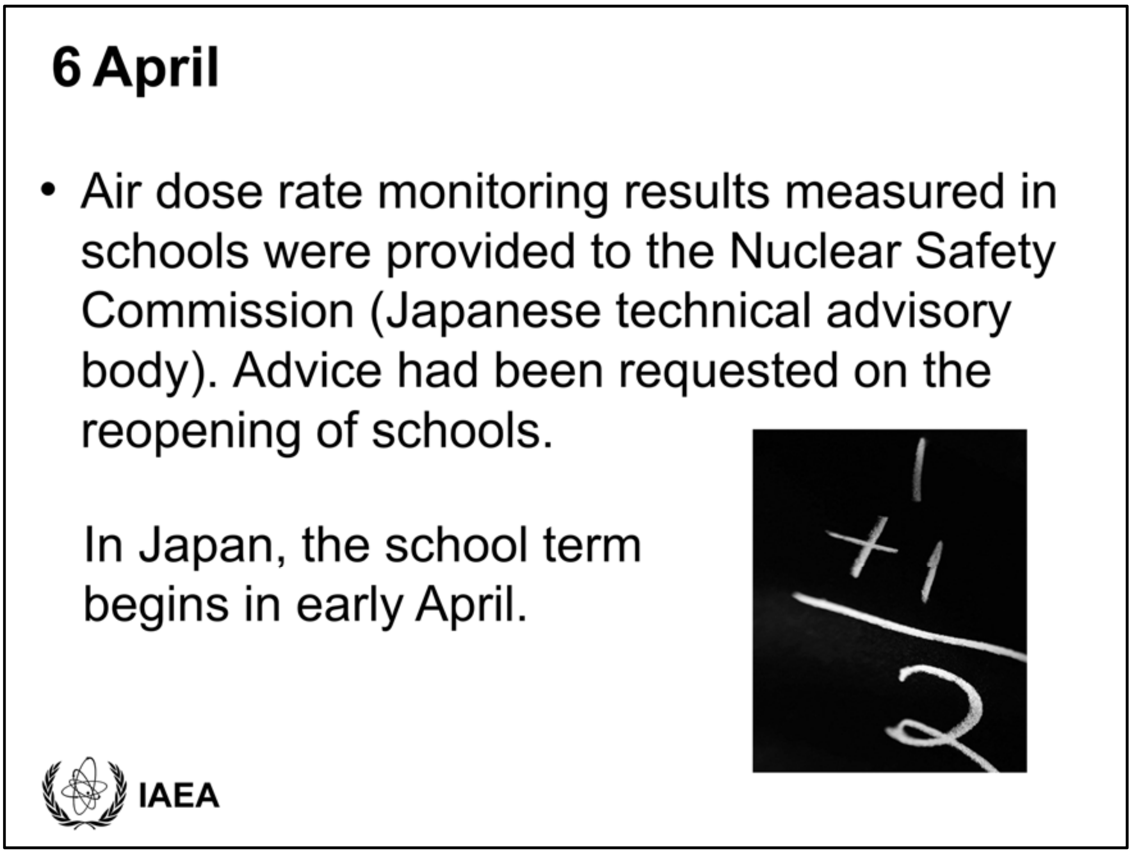
- The IAEA advised the Government of Japan to carefully assess the situation.
- One of the IAEA operational criteria for evacuation was exceeded in Iitate village.
  - The total deposition of I-131 and Cs-137 had been calculated based on measurements in soil sampled from 18 to 26 March.
  - I-131: 0.2–**25×10^6 Bq/m^2**, Cs-137 : 0.02–3.7 × 10^6 Bq/m^2.



OIL	Default OIL[1)]	Relevant OIL for Fukushima[2)]
OIL1	1000 μSv/h	200 μSv/h
		Cs-137 : 5×10^6 Bq/m^2 I-131 : 1×10^7 Bq/m^2
OIL2	100 μSv/h	100 μSv/h
		Cs-137 : 1×10^6 Bq/m^2 I-131 : 1×10^6 Bq/m^2

IAEA

On 30 March the IAEA advised the Government of Japan to carefully assess the situation. One of the IAEA operational criteria for evacuation was exceeded in Iitate village.
The total deposition of I-131 and Cs-137 had been calculated based on measurements in soil sampled from 18 to 26 March. I-131 : 0.2–25 × 106 Bq/m^2, Cs-137 : 0.02–3.7 × 106 Bq/m^2.



On 6 April air dose rate monitoring results measured in schools were provided to the Nuclear Safety Commission (Japanese technical advisory body). Advice had been requested on the re-opening of schools. The school term in Japan begins in early April.

8 April

The Ministry of Agriculture provided instructions on the restriction criteria (contamination levels of soil) for planting rice.

Rice planting season is end of April-beginning of May.

IAEA

On 8 April the Ministry of Agriculture provided instructions on the restriction criteria (contamination levels of soil) for planting rice.
Rice planting season in Japan is end of April/ beginning of May.

10 April

- The Nuclear Safety Commission recommended temporary relocation and provided criteria. Discussions with stakeholders were held on the 'deliberate evacuation area'.

IAEA

On 10 April the Nuclear Safety Commission recommended temporary relocation and provided criteria. Discussions with stakeholders were held on the 'deliberate evacuation area'.

19 April

- The Government established the criterion of 20 mSv for re-opening schools. Outdoor activities at schools restricted for air dose rate measurements above 3.8 µSv/h.

IAEA

On 19 April the government established the criterion of 20 mSv for re-opening schools. Outdoor activities at schools were restricted for air dose rate measurements above 3.8 µSv/h.

22 April

- The ‘deliberate evacuation area’ was established using the criterion of 20 mSv (deliberate evacuation is called relocation under IAEA guidance).

IAEA

On 22 April the ‘deliberate evacuation area’ was established using the criterion of 20 mSv (deliberate evacuation is called relocation under IAEA guidance).

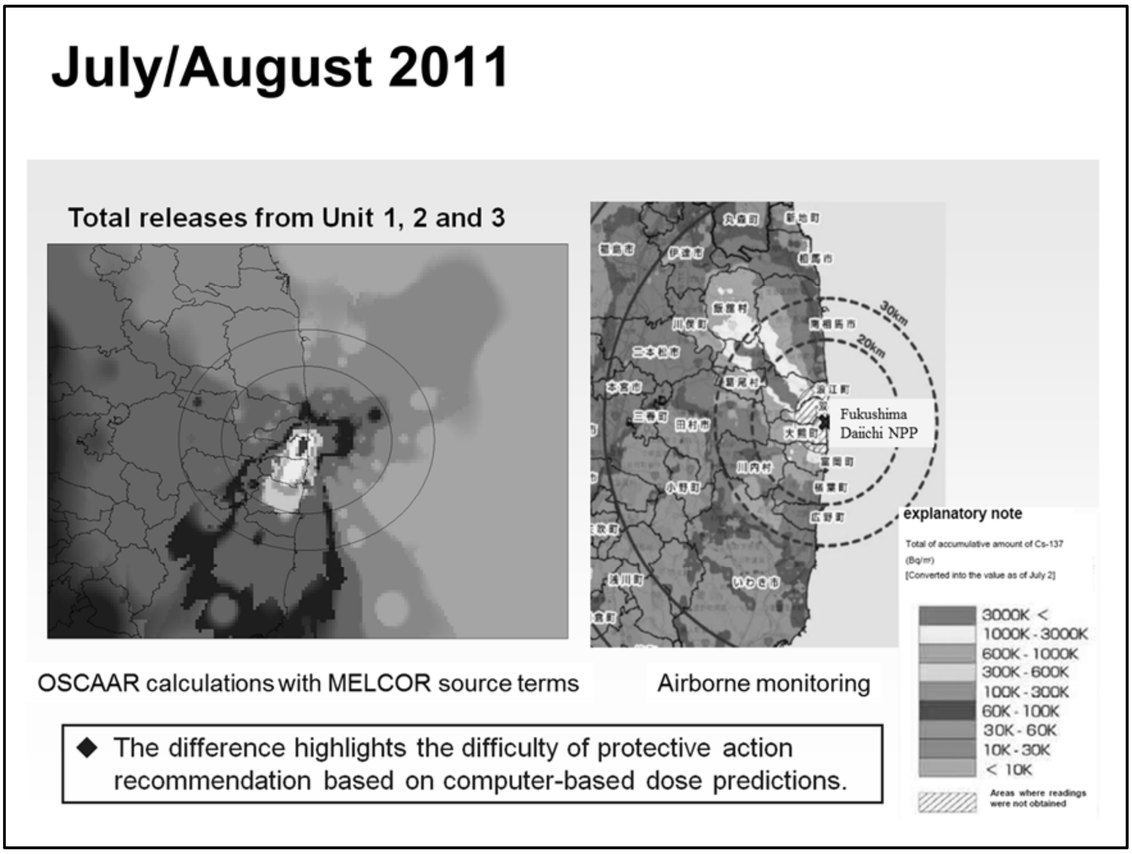
The decision to establish the deliberate evacuation area took 12 days owing to negotiations with stakeholders.

25 April – onwards

- Joint press conferences were held involving all response organisations.

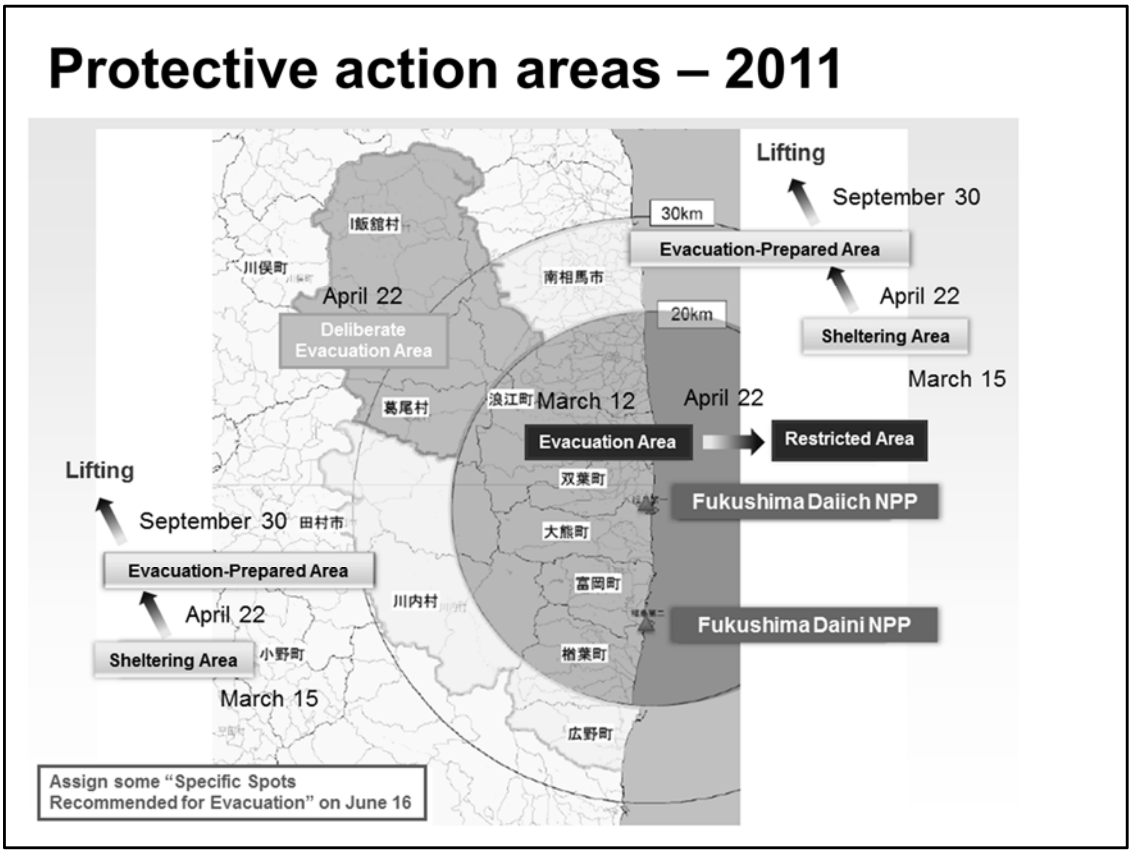
IAEA

From 25 April onwards joint press conferences were held involving all response organisations.

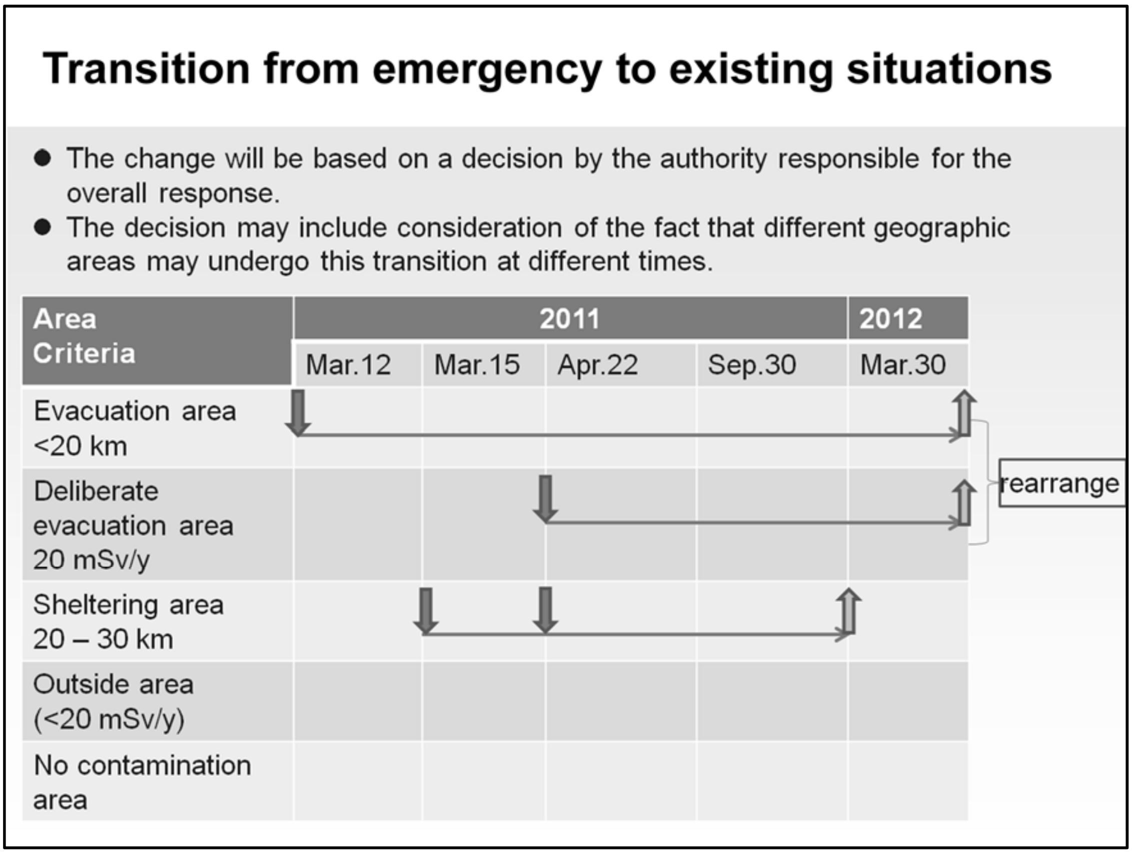


The image to the left of the slide is a projection that was made after the accident in July/August 2011. Assumptions made on the timing of the release were wrong because of the leakage route that had been assumed: when the pressure dropped from Unit 1 – the wind was mostly blowing to the south.

The image to the right of the slide shows the airborne monitoring results that were made publicly available in May 2011. It took approximately 23 days to obtain these results.



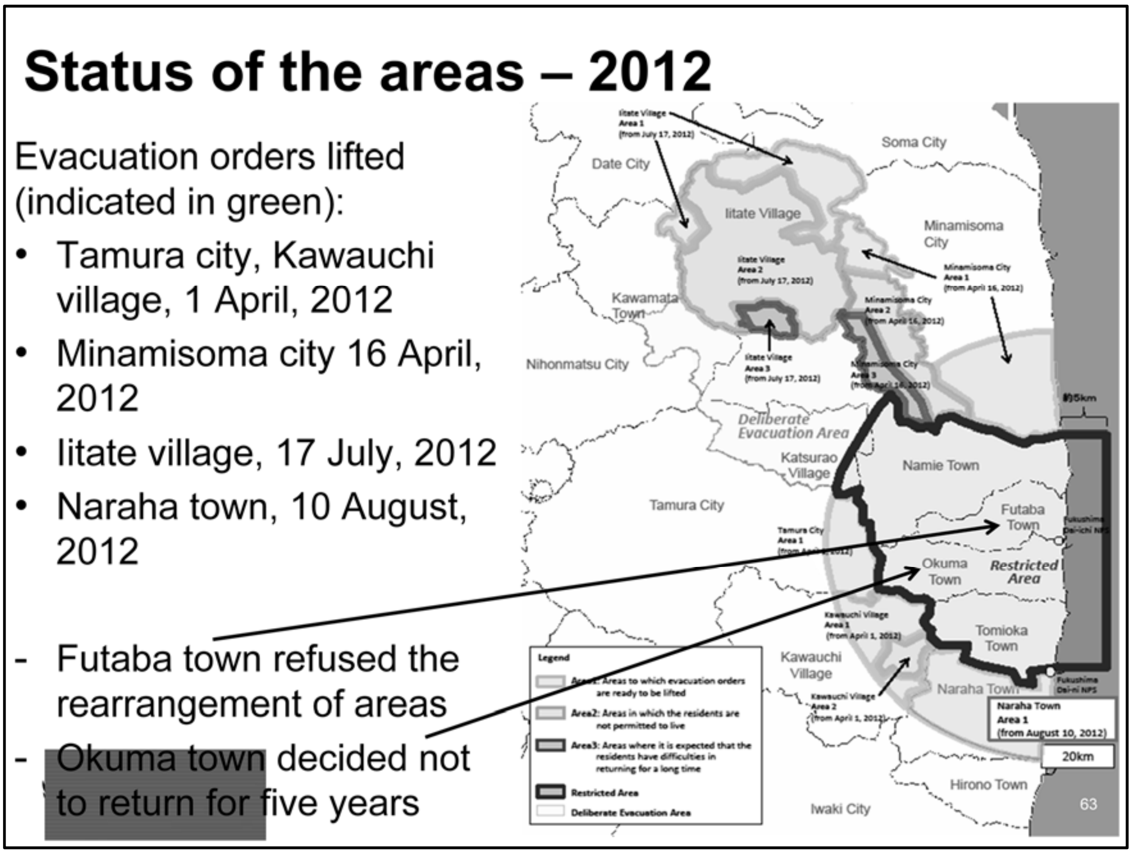
This slide presents the status of the protective actions areas for 2011.



This slide presents the scheduling of transition from emergency to existing exposure situations over the period March 2011–March 2012.

The change will be based on a decision by the authority responsible for the overall response.

The decision may include consideration of the fact that different geographic areas may undergo this transition at different times.



Area 1 – indicated in green in the image on the right represents areas where evacuation orders were lifted.
Area 2 – (orange), are areas in which residents are not permitted to live.
Area 3 – (pink), are area where it is expected that the residents will have difficulties in returning for a long time.
The restricted area is shown in red and the ‘deliberate evacuation area’ is shown in yellow.

Evacuation orders lifted (indicated in green):
- Tamura city, Kawauchi village, 1 April, 2012
- Minamisoma city 16 April, 2012
- Iitate village, 17 July, 2012
- Naraha town, 10 August, 2012

-Futaba town refused the rearrangement of areas
-Okuma town decided not to return for five years

Activity

- A printed copy of the timeline that was just presented is now being distributed.
- Working in groups, discuss the events of the timeline and identify the main lessons to be learned on emergency preparedness and response.
- Write a list of the lessons your group identified.
- We will share the lessons among the whole group after 20 minutes discussion.

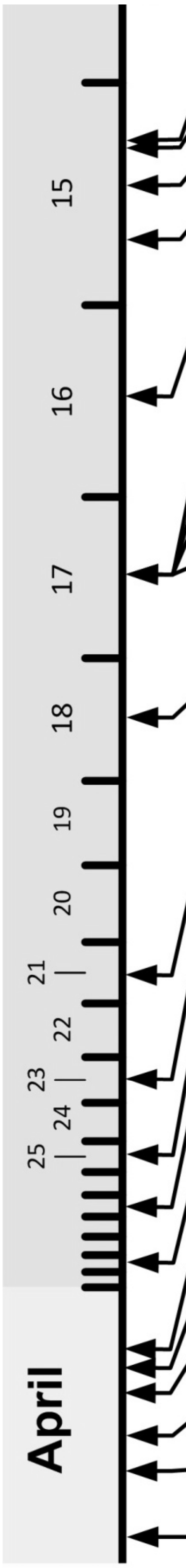
IAEA

Note to lecturer:

Distribute a printed copy of the timeline.
Explain to participants that they should work in groups, discuss the events of the timeline and identify the main lessons to be learned on emergency preparedness and response. They should write a list of the lessons identified in their group.

After 20 minutes, the lessons will be shared among the whole group.

	Time or date*	Event
	14:46	Earthquake: all reactors in operation were automatically shut down (SCRAM), loss of offsite AC power for all units, emergency diesel generators (EDGs) began operation.
	15:37	Impact of first wave at NPP. All EDGs in operation (except Unit 6) shut down, causing loss of all AC power (station black out).
	15:42	First notification sent by operator to the off-site officials: loss of AC/DC power at all units.
	16:36	Second notification sent to off-site officials: inability to inject water into the reactor using any of the emergency core cooling systems.
	18:10	Unit 1 core uncovered - severe release to the atmosphere is possible at any moment.
11	19:03	Declaration of 'State of Nuclear Emergency' and the emergency response launched.
	20:50	Local government decides to issue evacuation order directed at persons within 2 km radius (notification of public begins soon after).
	21:23	National government decides to issue evacuation order within 3 km radius and advise sheltering within a 10 km radius.
	21:52	Press conference on evacuation.
	00:06	Preparation of Unit 1 venting began.
	03:20	Operations from offsite emergency response centre (ERC) began.
	04:00	Increase in dose rate at the main gate. Believed to be the result of radioactive materials released owing to damage of the reactor core of Unit 1.
	05:44	National government decides to issue evacuation order within 10 km radius. Majority of public notified by approximately 09:00.
12	14:00	Evacuation of a hospital began (located 5 km from NPP). Three members of staff remained with 228 bedridden patients.
	14:30	Venting of Unit 1 completed.
	15:36	Hydrogen explosion at Unit 1
	18:25	National government decides to issue evacuation order within 20 km radius. Majority of local governments located in area learned of order via media. Notification of the public and implementation of evacuation varied.
	12th	Monitoring of the public begins – criteria 13, 000 cpm.
13	05:10	Loss of ability to inject water into the core of Unit 3.
	09:15	Regulatory body held a press conference. Conflicting explanations are provided by members of staff.
March	11:01	Hydrogen explosion at Unit 3.
	13:25	Loss of ability to inject water into the core of Unit 2.
	14th	Monitoring of the public - criteria changed from 13, 000 cpm to 100, 000 cpm.
14	14th	Ambulance refuses to transport three emergency workers injured onsite as the hospital was unwilling to accept contaminated patients.



05:30 — Joint response organization (between operator and government) established in Tokyo.

06:14 — Explosion at building of Unit 4.

11:00 — Sheltering advised within 20-30 km zone.

15th — Offsite ERC relocated approximately 100 km from NPP.

16th — Iodine thyroid blocking (ITB) distributed but intake among the public varied. Raw milk samples measuring I-131 concentrations that exceeded provisional limits (located 20 km from NPP).

17th — Ministry of Health, Labour and Welfare (MHLW) adopted criteria for food concentration levels provided by the Nuclear Safety Commission (NSC) - Japanese technical advisory body.

17th — 170 μSv/h measured at location 'Monitoring Point 32', 30 km north west of the NPP.

17th — U.S. embassy in Tokyo issues instructions for American citizens within 80 km to evacuate.

17th - 19th — U.S. Department of Energy conducts aerial monitoring. Identifies locations outside area evacuated that exceed IAEA OIL for evacuation (in area that was later established as 'deliberate evacuation zone' on 22nd April).

18th — NSC requested NISA to check the existence of houses around Monitoring Point 32 where 170 μSv/h was measured. Spinach samples measuring I-131 concentrations that exceeded provisional limits (located 100 km from NPP).

21st — Drinking water restricted due to I-131 concentrations in samples (at locations up to 250 km from NPP). Restriction of distribution of raw milk (20 km from NPP) and spinach (100 km from NPP).

23rd — Dose projections using SPEEDI data made publicly available.

25th — Voluntary evacuations within 20–30 km sheltering zone advised. Public had already begun to evacuate spontaneously.

27th — European Union restricts food and animal feed from Japan and requires confirmation of monitoring/analysis or certificate of origin.

30th — IAEA operational intervention level (OIL) for evacuation exceeded in a location more than 30 km from NPP. IAEA advised Japanese Government to carefully assess the situation.

6th — Air dose rate monitoring results for schools submitted and NSC's advice requested on reopening of schools.

8th — Ministry of Agriculture provided instructions on the restriction criteria (contamination levels of soil) for planting rice.

10th — NSC recommends temporary relocation and provides criteria. Discussion with stakeholders take place.

19th — Government established criteria of 20mSv for re-opening of schools.

22nd — 'Deliberate evacuation area' using criteria of 20mSv established (deliberate evacuation is called relocation under IAEA guidance).

25th — Joint press conferences between all response organisations held.

* The time is not provided in some cases as it was not specified in the official reports.

Overview of Emergencies at a Nuclear Power Plant

Module 6

Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

IAEA

International Atomic Energy Agency

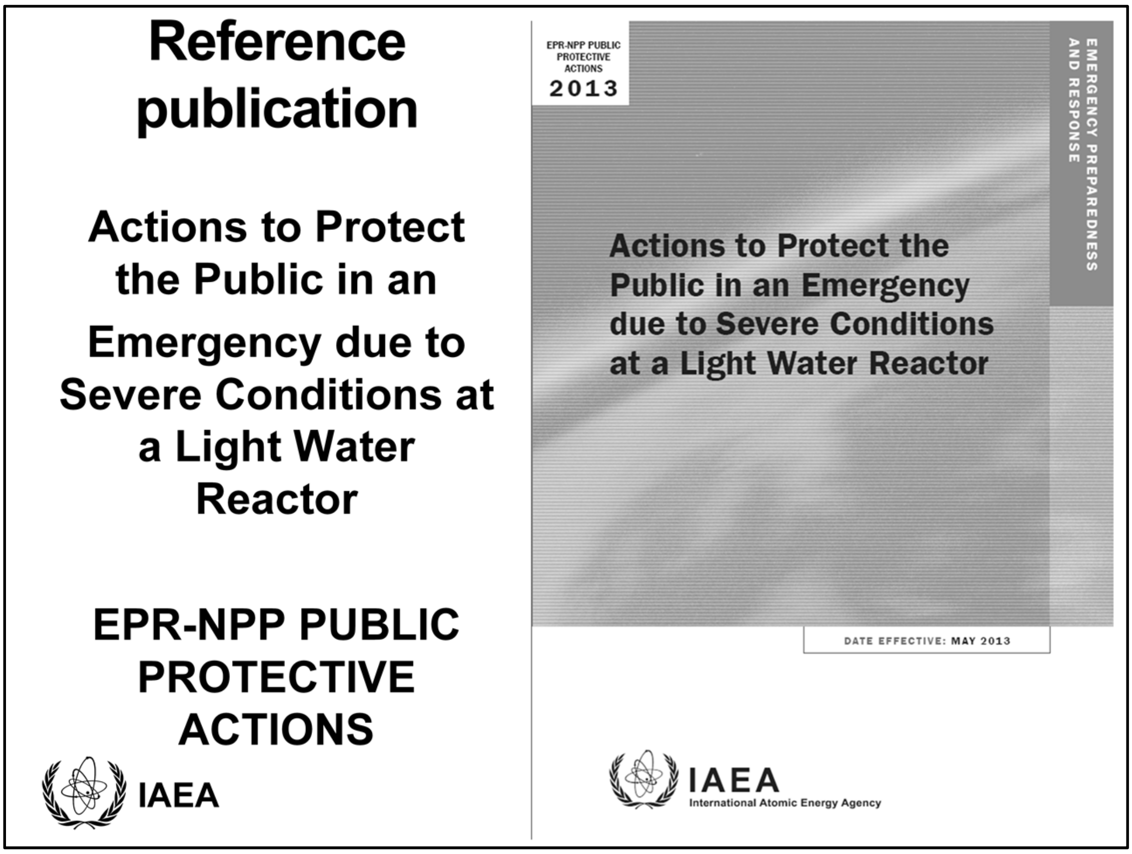
Lecture:
L-06 Overview of Emergencies at a Nuclear Power Plant
Purpose:
To provide an overview of emergencies at a nuclear power plant.
Learning objectives :
Upon completion of this lecture, the participants will:
- Diagram the major reactor and spent fuel structures
- State the plant damage that must occur before there can be any off-site health effects
- List the barriers and systems that must fail before a major release takes place
- State how quickly a major release can occur
- Explain why protective actions should be taken before a release occurs to be most effective
- Describe how control room staff **can** predict damage to the core or spent fuel but **cannot** predict the timing or size of a release
- State when protective actions should begin following a projection of damage to the core or spent fuel by the control room staff

Author: Thomas MCKENNA **Revisions:** Phillip VILAR WELTER, Brian DODD, Eduardo LURASCHI
Duration: 2.5 hours

Learning objectives

- Upon completion of this module participants will be able to:
  - Diagram the major reactor and spent fuel structures and describe their behaviour during an emergency
  - State the plant damage that must occur before there can be any off-site health effects
  - State how quickly a major release can occur
  - Explain how the operators of the facility provide the most important input for taking action to protect the public
  - Describe how control room staff **can** predict damage to the core or spent fuel but **cannot** predict the timing or size of a release
  - State when protective actions should begin following a projection of damage to the core or spent fuel by the control room staff

IAEA



This presentation is based on the material contained in the EPR publication entitled Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor, EPR-NPP PUBLIC PROTECTIVE ACTIONS (2013).

References to pages tables figures in square brackets within this presentation are to this book.

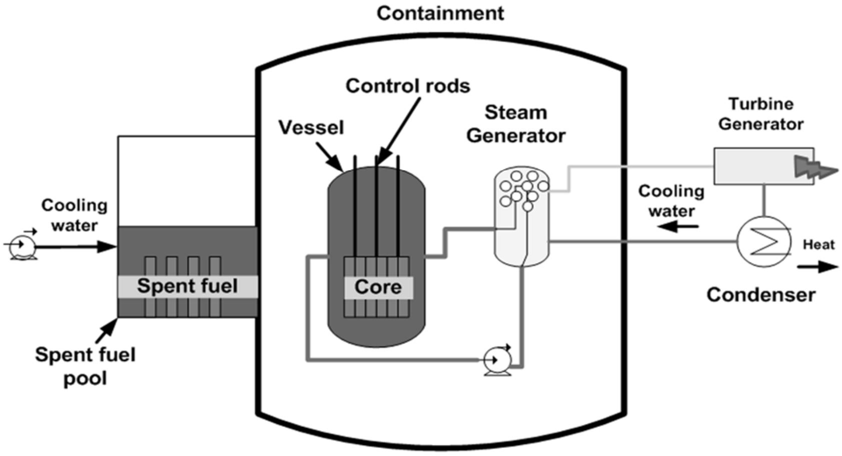
Focus is on light water reactors (LWRs)

- Pressurized water reactors (PWRs)
- Boiling water reactor (BWRs)
- Worldwide
  - PWRs – 60%
  - BWRs – 20%
- The basic concepts presented here apply to all reactor designs

IAEA

The purpose of this section is to describe the general characteristics of reactors, spent fuel pool and reactor emergencies that are important for protection of the public. We will discuss these characteristics in terms of the light water reactors (LWRs) which are the most common type of reactor, with 80% of all the reactors in the world being LWRs. There are two types of LWRs, the pressurized water reactor (PWR) and the boiling water reactor (BWR). Sixty per cent of the reactors worldwide are PWRs and 20% are BWRs.

PWR with a large dry containment

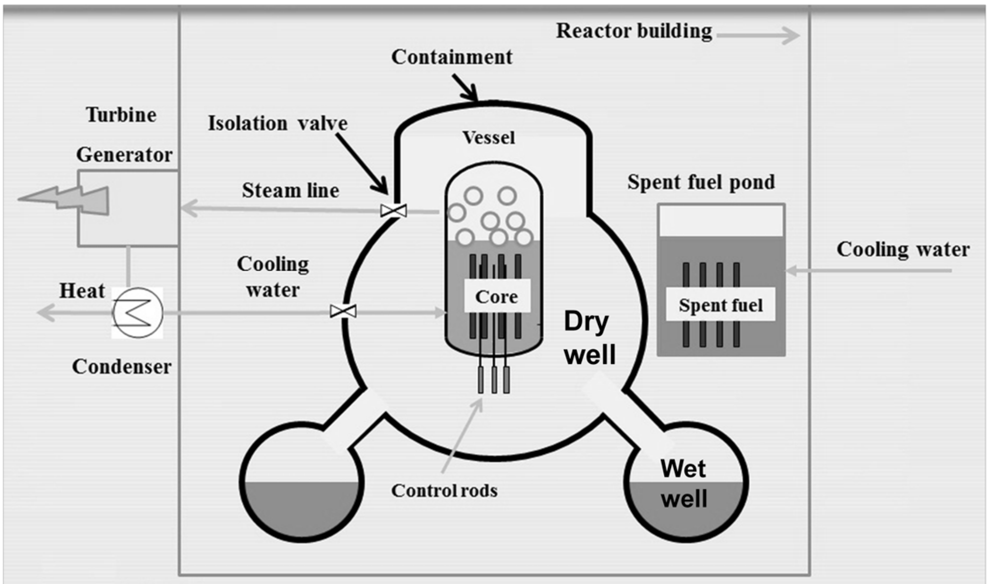


IAEA

This is a pressurized water reactor (PWR) and is the most common type of LWR. It is called a pressurized water reactor because the pressure of the water surrounding the fuel is kept sufficiently high to prevent boiling. The energy from a nuclear power plant (NPP) comes from the fission of the nuclear fuel. This fission is controlled by control rods, which when fully inserted into the core, stop the fission reaction. As we will see, it is essential that fission (i.e. the nuclear reaction) in the core be stopped at the onset of any emergency. The control rods in a PWR enter from the top of the vessel holding the core of reactor. The nuclear reaction takes place in the fuel, which is contained in thousands of sealed fuel pins which form the reactor core. The core is contained within a reactor vessel, which is part of the primary system which holds the water that cools the core. The fuel pins must always be kept covered with cooling water, otherwise they will overheat and fail, releasing radioactive material. The water in the vessel is circulated within the primary system and cooled, in this case in the steam generator. The steam generator produces steam, which is used to turn a generator and make electric power. Once the steam is cooled, the resulting cooled water is pumped back into the system. Most of the primary system containing the reactor core is surrounded by a containment, which is designed to reduce any release of radioactive material that escapes from the fuel. In this case, the containment is just a simple very large structure surrounding the primary system, which is called a large dry containment.

‘Used’ fuel, called spent fuel, is periodically removed from the reactor core. This spent fuel is highly radioactive and must be cooled in order to prevent a release of radioactive material. Therefore, once fuel is removed from the core of the reactor, it is stored under water in the spent fuel pool, which keeps the fuel cool and provides shielding from radiation. The water in the pool must also be cooled to remove decay heat from the spent fuel. As you can see from the diagram, the spent fuel pool can be outside the containment, which means that a release of radioactive material from the spent fuel pool could go directly to the atmosphere.

BWR with a Mark I containment



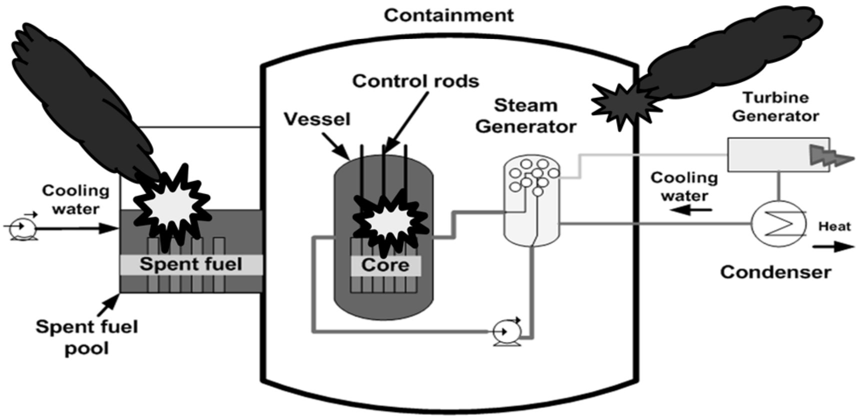
IAEA …similar to Fukushima

This shows one of the types of boiling water reactors (BWRs) with a Mark I containment similar to that at Fukushima. In this case, the cooling water that covers the reactor fuel pins in the core is allowed to boil, and therefore, it is called a boiling water reactor (BWR). However, as with all LWR reactors, the level of the water must always be kept above the top of the fuel pins (core) in order to prevent overheating and subsequent failure of the fuel pins (core damage) and a release of radioactive material from the fuel. The energy from an NPP comes from the fission of the nuclear fuel. This fission (i.e. the nuclear reaction) is controlled by control rods, which in a BWR enter from the bottom of the vessel. As you can see, the core of the reactor is contained within the primary system, which includes the reactor vessel and associated pipes and pumps that hold the water used to cool the core. Most of the primary system lies within a containment. However, unlike a PWR, the water in the vessel that covers and cools the core is allowed to boil and the resulting steam is allowed to leave the containment where it is used in a turbine generator to produce electricity. The steam produced by boiling within the reactor vessel is cooled (condensed) and returned to the reactor vessel. There are isolation values in the primary system pipes (e.g. steam and coolant lines) that extend outside the containment and that are designed to close at the onset of an emergency. If these isolation valves do not close, the containment is not sealed and there could be a release to the atmosphere of material released from the fuel in the core.

There are many different containment designs, and in this case the containment is considerably different from the PWR example. The containment design shown is a Mark I BWR containment, which has two parts. First, it has a structure around the reactor vessel, which is called the dry well, and below it lies a large doughnut shaped structure called the wet well. These two structures form the containment. As with the PWR, the spent fuel removed from the reactor core is highly radioactive and must be cooled. Therefore, once fuel is removed from the core of the reactor, it is stored under water in the spent fuel pool, which keeps the fuel cool and provides shielding from radiation. The water in the pool must also be cooled to remove decay heat from the spent fuel. In boiling water reactors the containment and spent fuel pools are typically located within a reactor building. This building is typically an industrial structure and is not designed to prevent a release in the event of a severe emergency. Therefore, in the event of a severe emergency, radioactive material released from fuel in the pool could also be released directly to the atmosphere.

Health effects off-site arise from:

- Severe damage to fuel in the core of the reactor or spent fuel pool
- A major release (e.g. containment failure)

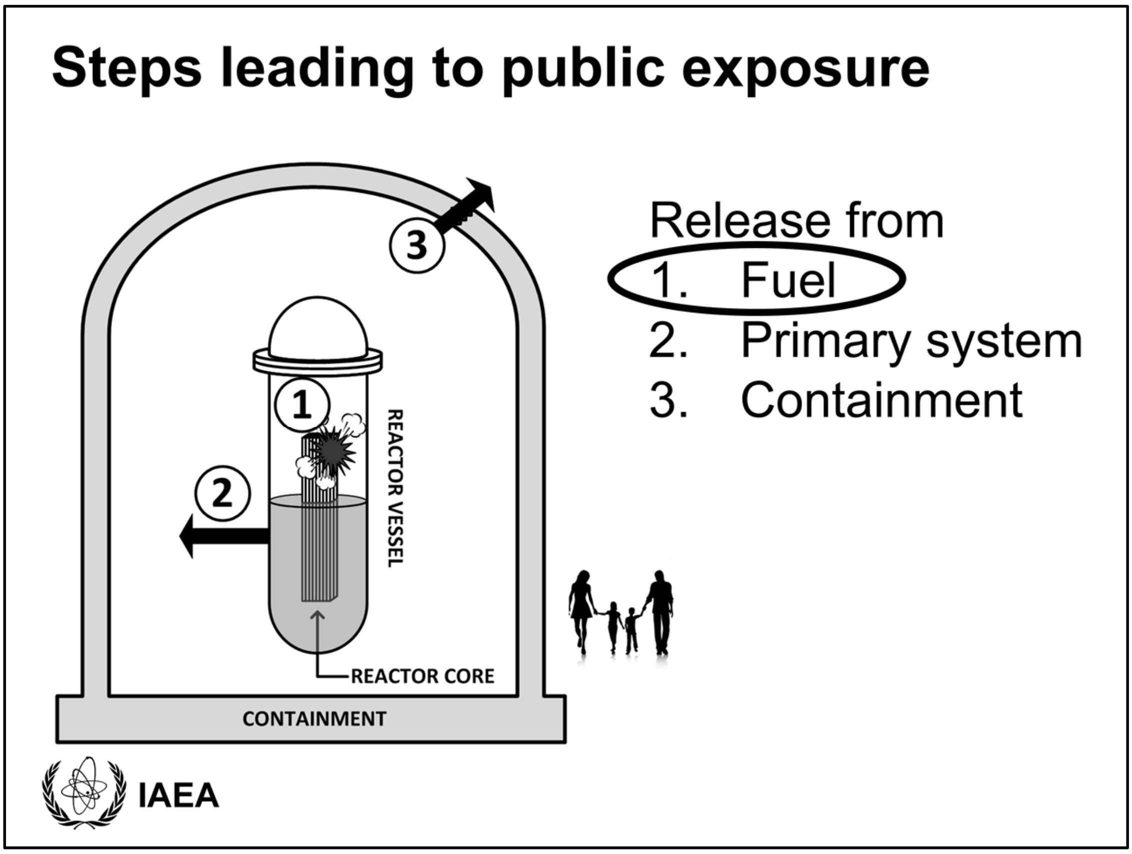


Only the fuel in the reactor core and spent fuel pool has enough fission products (radioactive material) and energy (heat and pressure) to cause a release resulting in health effects outside the plant.

The fuel contained within the reactor core represents the greatest risk to the off-site population for two reasons. First, it contains a large amount of fission products that are particularly dangerous (e.g. I-131) and these fission products could be released within hours if the core is not kept covered by cooling water. The worst possible release from a reactor core could result in severe health effects which include deaths, and contamination of a very large area, possibly more than several hundred kilometres from the plant, warranting taking protective actions. These events occurred at Chernobyl.

The fuel contained within the spent fuel pool represents a smaller risk because it produces significantly less decay heat than the fuel in the core reactor and therefore, is much easier to keep cool.

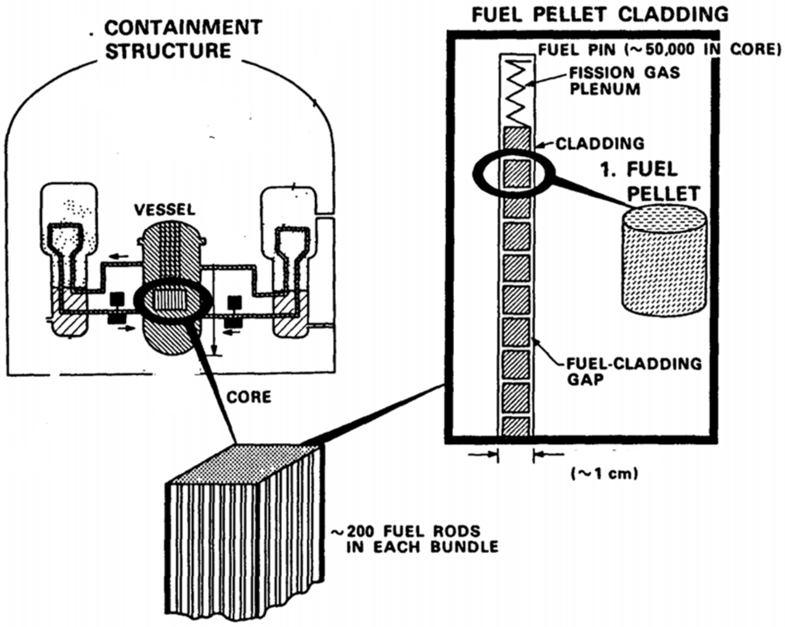
Damage to the fuel in the spent fuel pool or the core can be predicted based on instruments in the control room; however, releases following fuel damage are unpredictable.



We will now review the steps leading to public exposure: 1) release of radioactive material from the fuel; 2) release of the radioactive material from the primary system; and finally, 3) release of radioactive material from the containment.

We will start with release of radioactive material from the fuel.

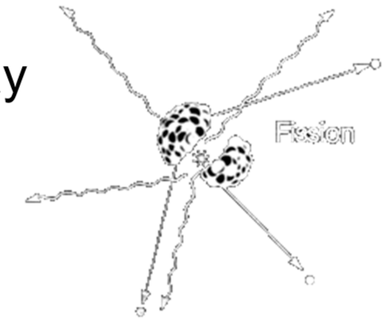
Reactor fuel



The fuel in the reactor is contained within thousands of fuel pins, as shown in the figure – these pins are in bundles. Fuel pins contain a stack of ceramic uranium oxide (UO_2) fuel pellets. The vast majority of fission products produced are trapped within the fuel pellets. However, a small fraction of the gaseous and volatile fission products diffuse out of the fuel pellet during normal operation and collect in the gap plenum and between the pellets and the fuel cladding, These gaseous fission products are often referred to as the “gap inventory” or “the gap”. The gap inventory will include a few per cent of the total core inventory of noble gases such as xenon (Xe) and krypton (Kr), and other volatile elements including iodine (I) and cesium (Cs). The gap will be immediately released if the fuel pin cladding fails. This is called a gap release. The detection of the gap release by radiation monitors may be the first indisputable evidence of failure of the fuel cladding. Further heating of the fuel will lead to the release of the other fission products trapped within the fuel pellets.

Fission products

- Undergo radioactive decay
- Produce radiation and heat in the fuel
- Release of a few per cent to the atmosphere could cause severe health effects off-site
- Cooling the fuel (i.e. removal of decay heat) is a must, otherwise fission products will be released



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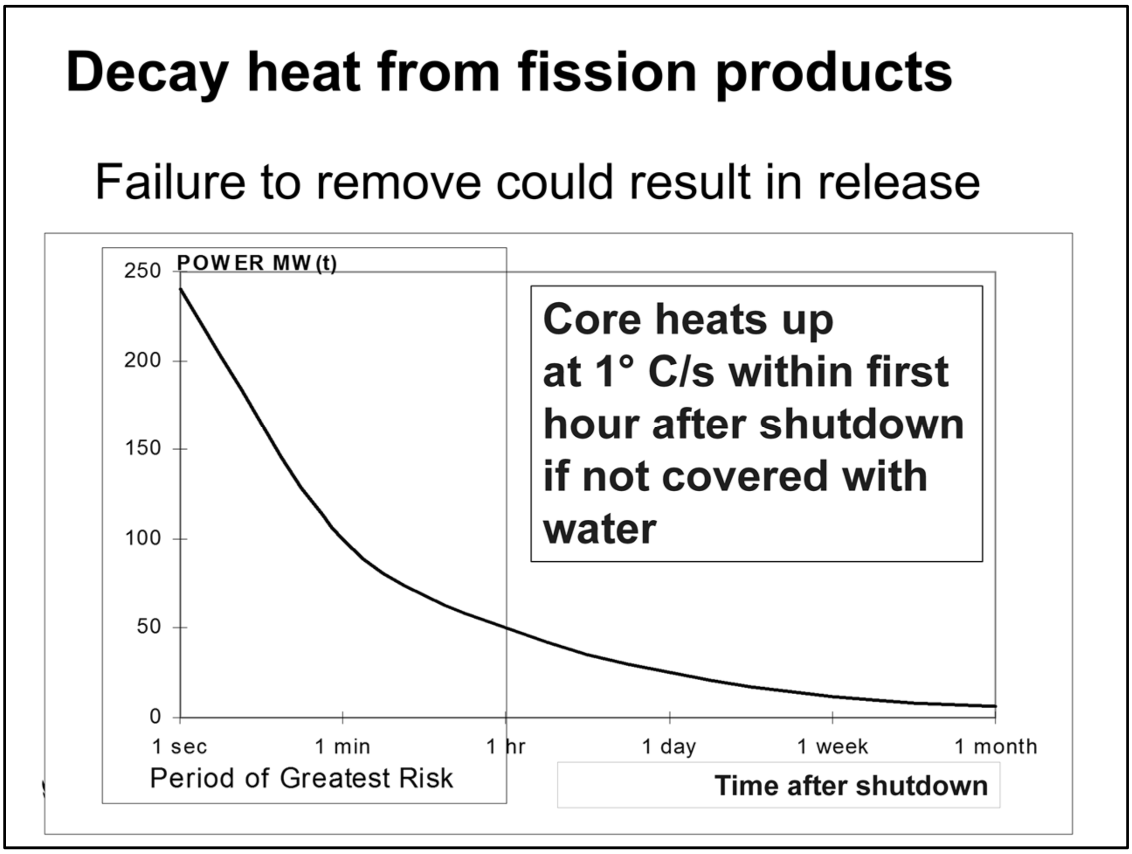
Like a fossil fuelled plant, an NPP boils water to produce electricity. However, unlike a fossil-fuelled plant such as a coal fired plant, the nuclear plant's energy does not come from the burning of fuel but from a nuclear reaction involving the fission (or splitting) of fuel atoms. Since nuclear power plants produce electricity by fission rather than combustion their by-products, called fission products, are very different from those associated with fossil-fuelled plants. Fission products are unstable and undergo radioactive decay, which produces harmful radiation and heat.

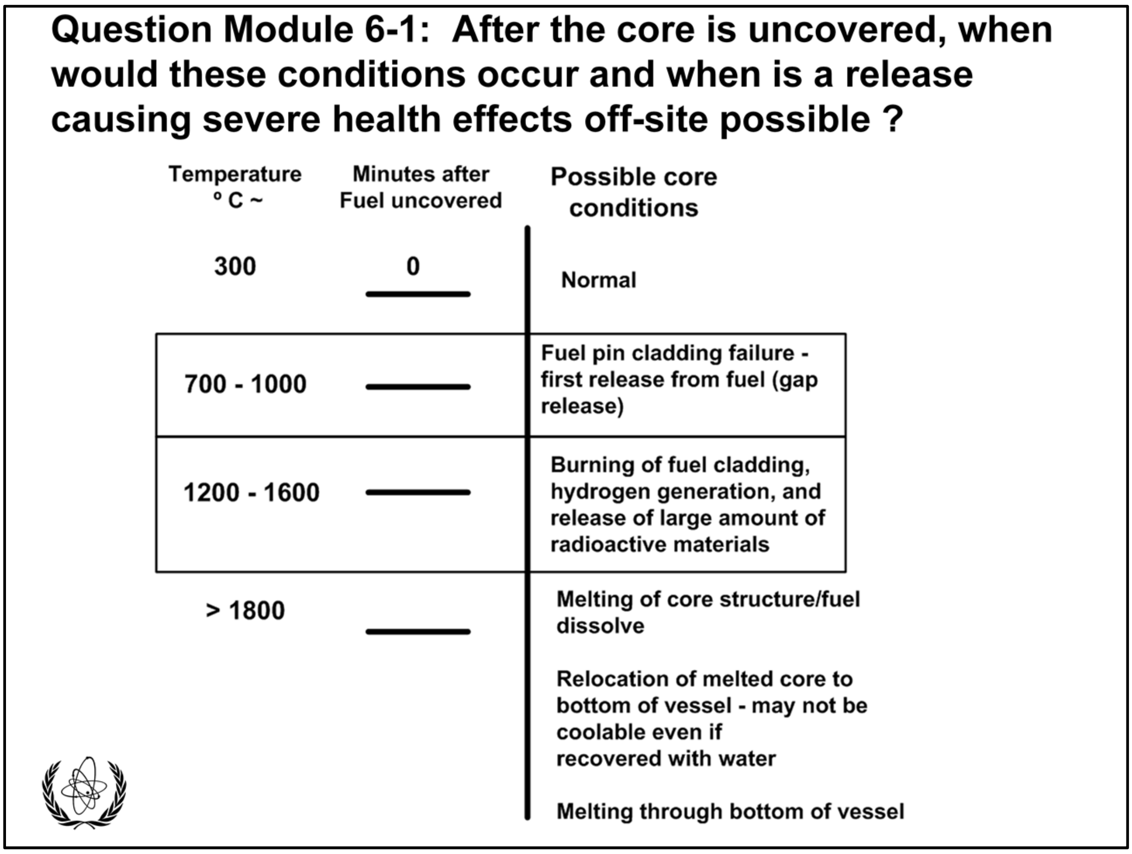
Fission products are produced within the fuel in the reactor core during the operation of the reactor. The fuel in the reactor core and spent fuel pool contain large amounts of fission products. Fission products are highly radioactive and must be contained to prevent exposure of the public and workers. If only a few per cent of the fission products are released to the atmosphere, this could cause severe health effects among the public.

In addition, the rapid rate of decay of the fission products causes a significant amount of energy (heat) to be generated. This is called "decay (or residual) heat". Unless decay heat is removed, it can damage the fuel and result in a major release into the environment. Therefore, the fuel in the core and spent fuel pool must be cooled. Failure to do so could cause the fuel to overheat and release large amounts of fission products.



This shows the power level in megawatts of thermal power (MW(th)) on the vertical scale from decay heat vs. time after the plant has shut down (fissions stopped) for a 3000 MW(th) reactor. The figure illustrates that in the early hours after shutdown there is a large amount of energy that must be removed from the fuel in the core of a reactor in order to protect the fuel in the core and prevent a release. The decay heat power level drops 80% within the first hour; therefore, this is the period of greatest concern during an emergency as this is when the emergency systems and the operators are under the greatest challenge.

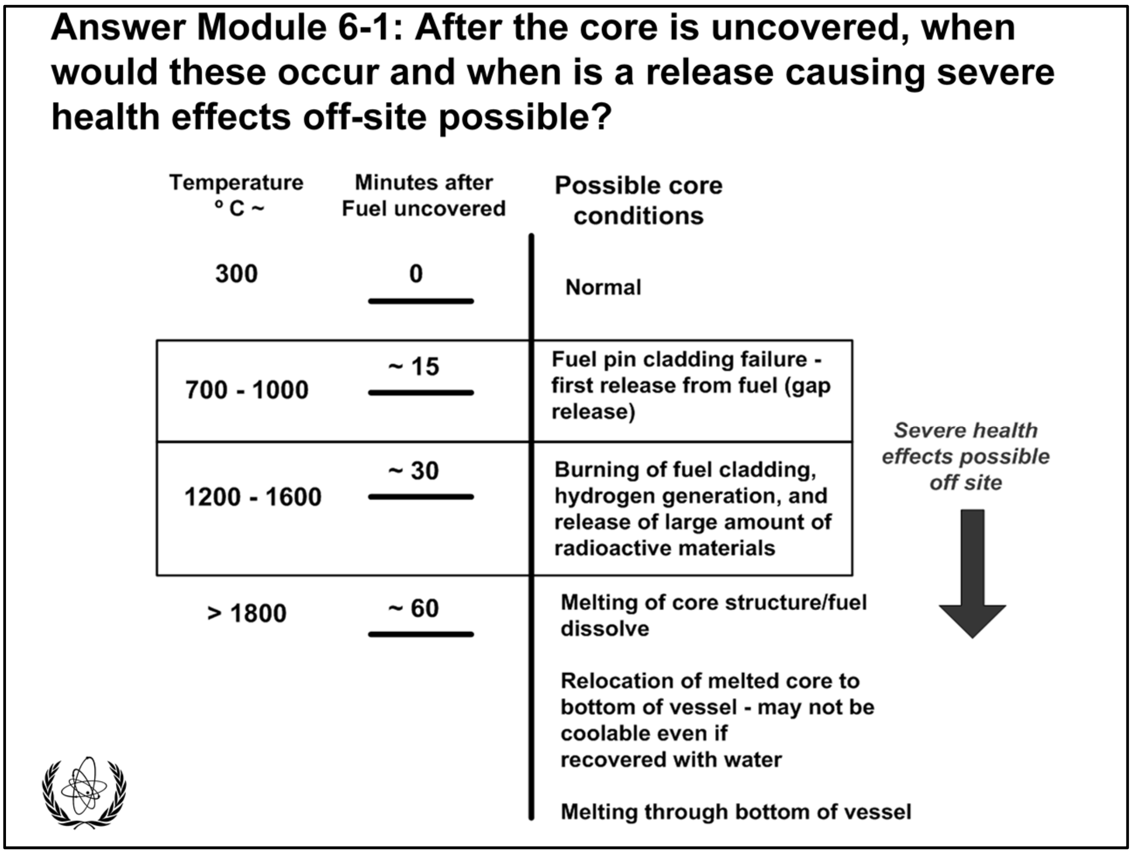
If the fuel within a reactor core is no longer covered with water, it can heat up at rate of between 0.5 and 1°C per second within the first hour after the reactor shuts down (fission has stopped).



This slide shows the condition of the core with temperature, as explained below. **Ask the students how many minutes after the core is uncovered would they expect these conditions and when would they think a severe release off-site resulting in health effects off-site is possible. Tell them to assume that temperature in the core increases approximately 1°C/s after the fuel in the core is uncovered.**

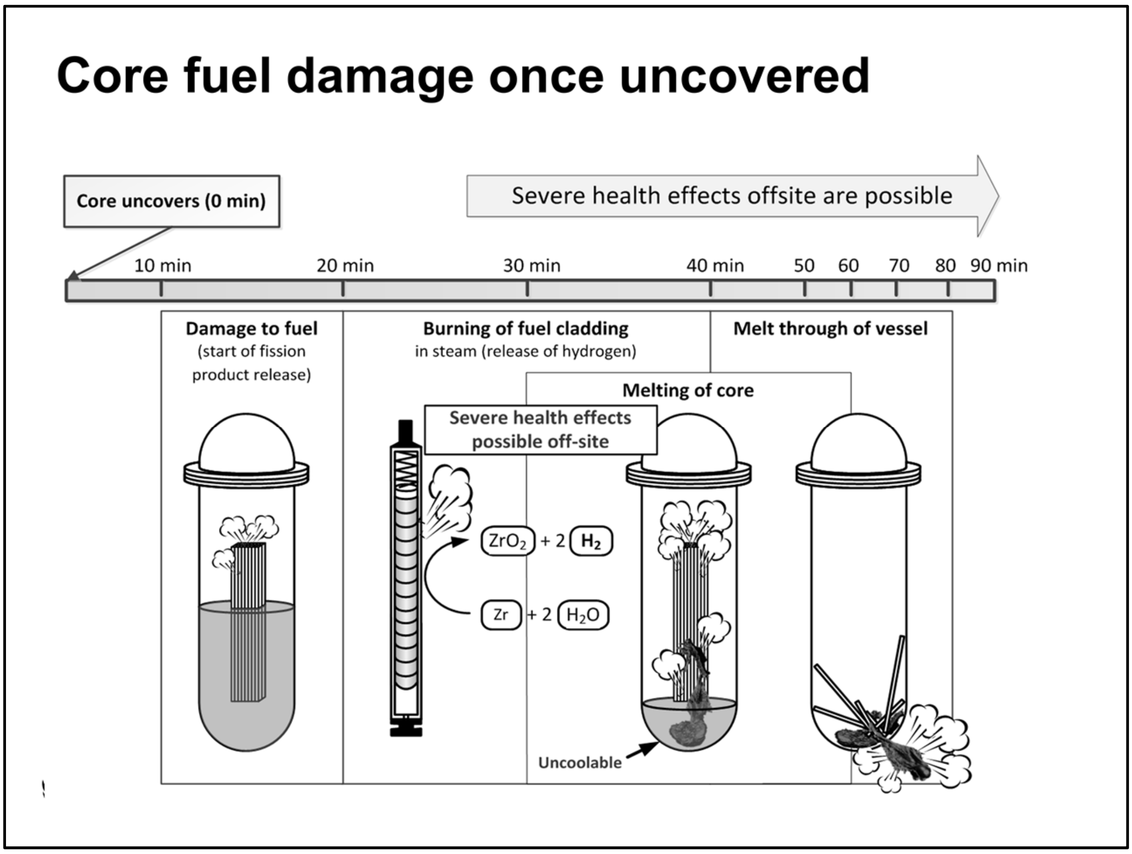
Significant cladding damage is not possible if the fuel in the core of an LWR remains covered with water. However, if the core becomes uncovered, the fuel cladding of an LWR will heat up at a rate of approximately 0.5 to 1.0°C/s and within a few minutes of being uncovered. The first releases of radioactive material from the fuel occurs when the fuel pins rupture, releasing the gaseous fission products of the fuel pin (the gap release) when the temperature reaches about 700–1000^{o}C. At about 1200^{o}C, the hot fuel pin cladding reacts or burns with the steam (this is known as the Zircaloy (Zr) water reaction); this reaction is exothermic (produces heat), is thus self-sustaining and produces hydrogen, which could threaten the containment if it explodes. This was the source of the hydrogen that exploded at the Fukushima reactor in Japan. Once the fuel reaches about 1800°C the structures that hold the fuel and the core will start to the melt and this melted material will dissolve the fuel, resulting in a further release of radioactive material. Shortly thereafter this mass of melted and dissolved material could flow to the bottom of the vessel and could melt through the bottom of the vessel as occurred at Fukushima. The melted material in the bottom of the vessel may not be coolable, even if it is covered with water once again.

Source: US NRC NUREG/CR-6042

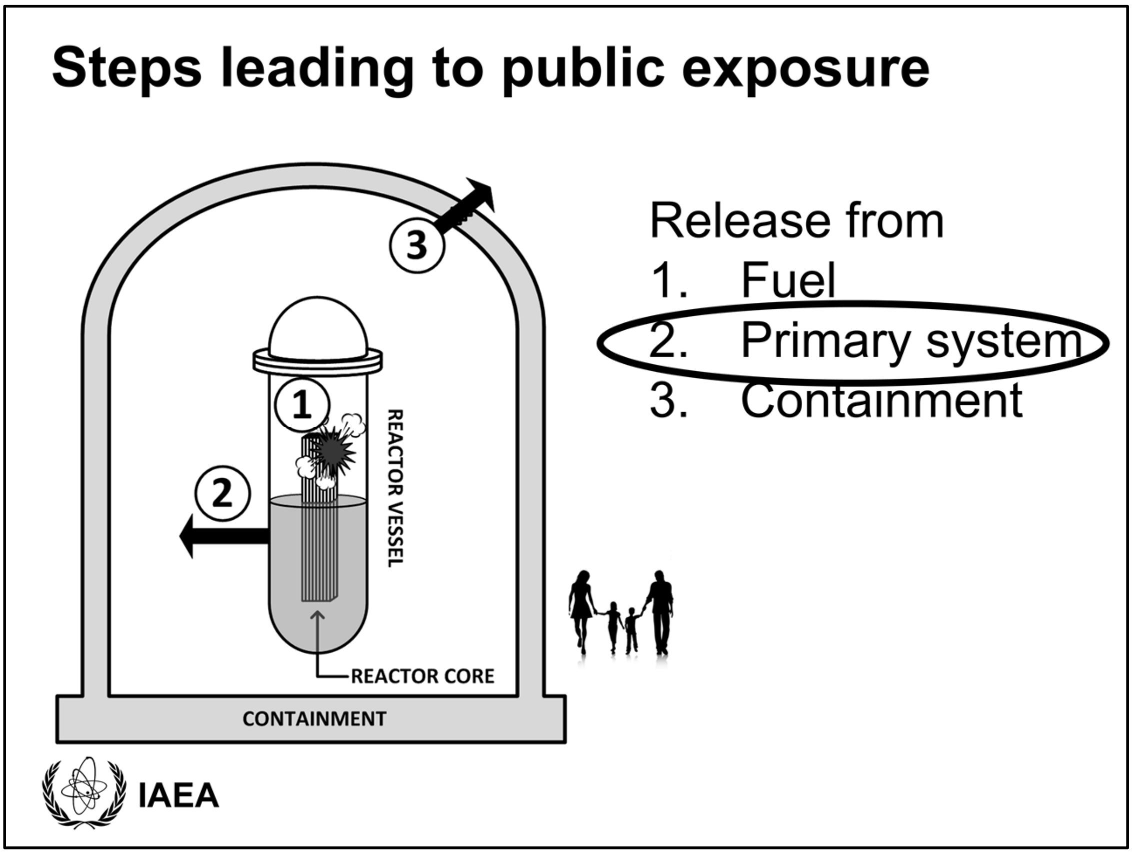


Once the core has been uncovered for more than 15 to 30 min, a release to the atmosphere that can result in severe health effects off-site is possible because: (a) sufficient radioactive material may have been released from the fuel and is available for immediate release to the atmosphere if the containment should fail or be bypassed, (b), it cannot be assumed that the containment will prevent such a release since, as we will see, there are many ways the containment could fail unpredictably; and (c) there may be melted fuel in the bottom of the vessel that cannot be cooled even if covered with water that could melt through the vessel at any time, which is a further threat to the containment.

Source: NUCLEAR REGULATORY COMMISSION, Perspectives on Reactor Safety; HASKIN, F.E., CAMP, A.L., HODGE, S.A., POWERS, D.A., Rep. NUREG/CR-6042, SAND93-0971, Rev. 2, USNRC, Washington, DC (2002).



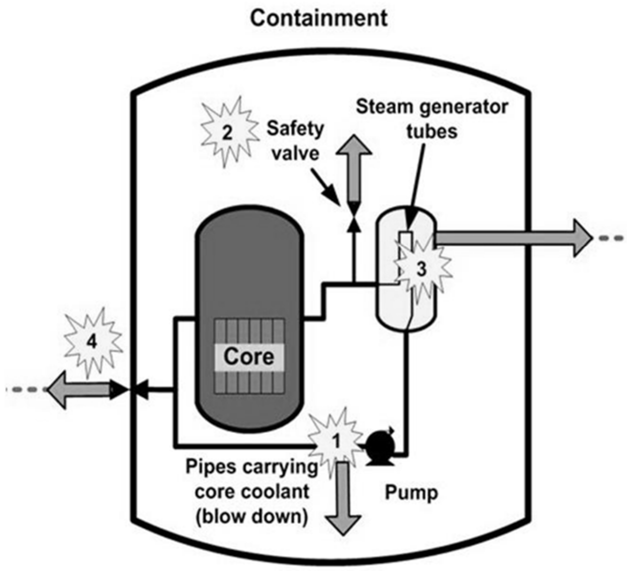
This shows graphically the progression of damage to the fuel pins (the core of the reactor) after the fuel is uncovered (no longer covered with water), and assuming no water is being injected into the core. Within 10–20 minutes after being uncovered, the fuel pin temperature could reach over 700–1000°C, causing some of the fuel pins to fail due to overpressure, resulting in the first release of fission products (a gap release). Within 20–40 minutes the fuel reaches 1200–1600°C, which is hot enough to cause a rapid reaction, or burning of the fuel pin cladding in the steam, which releases a large amount of hydrogen (which is an explosion hazard). This results in rapid failure of the fuel pins and the rapid release of fission products from the fuel and at this point a release from the plant is possible that can cause severe deterministic health effects off-site. Within 30–60 minutes, the fuel temperature can reach over 1800°C and at this temperature the structure supporting the core will start to melt and dissolve the fuel pellets releasing further radioactive material and destroying the structure holding the fuel. This damage will interfere with cooling if water is once again supplied to the core and the dissolved/melted core may slump or flow to the bottom of the vessel, forming a large mass of melted fuel and other components of the core. This mass may be impossible to cool ("uncoolable") even if it is covered with water. This mass may then melt through the bottom of the vessel, as occurred at Fukushima. As we will see, this can threaten the containment.



Let us now turn to the release of radioactive material that may have been released from the fuel into the primary system.

Release from vessel – primary system

- Fuel damage means that there is, or will be, a leak allowing radioactive material from the fuel to be released into the containment or atmosphere



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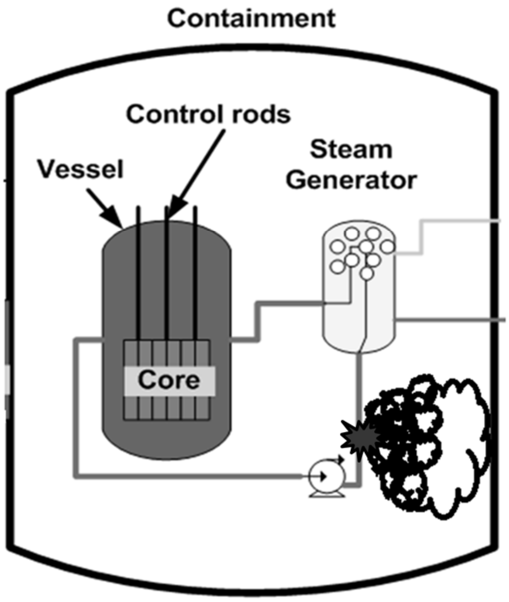
There are many ways in which the primary system containing the core could fail or leak, allowing radioactive material released from the fuel to be released into the containment or possibly the atmosphere. In most emergencies the primary system will have failed before the core is damaged. The more likely failure points for the primary system are: (1) pipe breaks and failures of pump seals, which allow a release inside the containment, (2) failures of safety valves that are designed to open in many emergencies and allow a release inside the containment, (3) steam generator tube ruptures (SGTR) in a PWR, which allow a release outside the containment and possibly directly to the atmosphere and (4) failures of valves designed to shut at the start of an emergency (e.g. steam line isolation valves in a BWR), which allow a release outside the containment and possibly directly to the atmosphere. Breaks in the primary system resulting in loss of coolant water are called "loss of coolant accidents" (LOCAs).

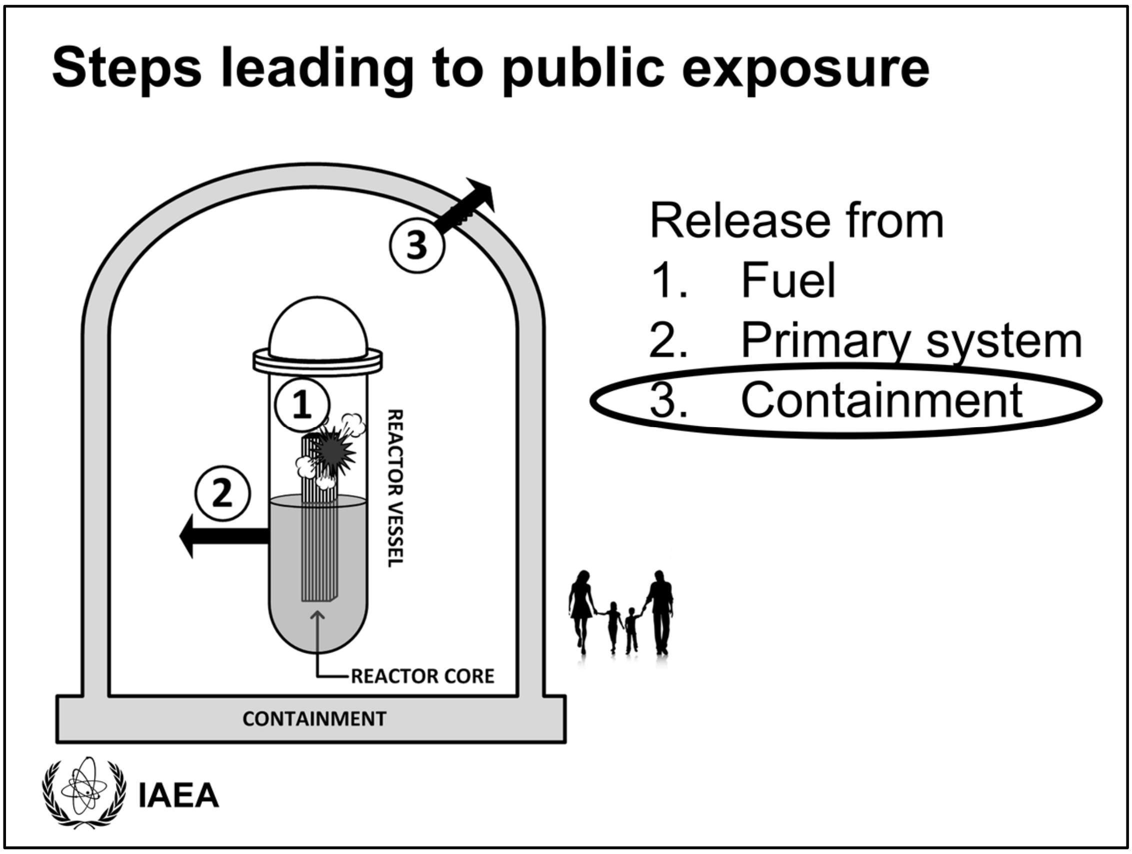
Abnormal water levels, pressures, temperatures or radiation levels monitored in the control room all may indicate a failure of the primary system to the control room staff.

Primary system blowdown



- Large break in primary system:
  - Loss of cooling water
  - Large increase in pressure and temperature inside containment

A large break in the primary system can result in a blowdown. A blowdown is a release of a large amount of steam or water, which flashes to steam immediately. A blowdown can result in a very large increase in pressure inside the containment, and if not controlled, can lead the containment to fail. Therefore, containments are designed to withstand a blowdown principally by condensing or suppressing the steam produced and cooling the containment.



Let us now examine the release of radioactive material that may be in the containment.

Containment (many different designs)

Designed to

- Withstand a break (blowdown) in the primary system
  - Strong – or with pressure suppression system
- Provide long term decay heat removal
- Reduce release of fission products

Not designed for core melt

- Some designs may withstand core melt conditions
- Others may not

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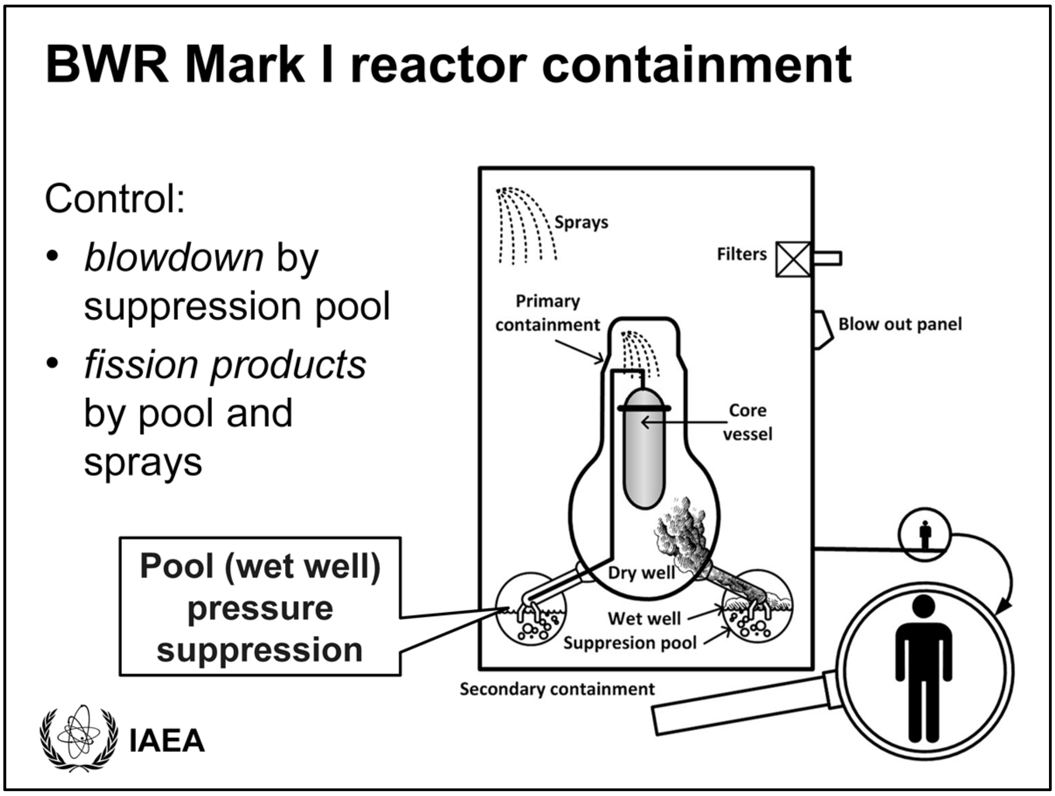
The majority of the primary coolant system is inside the containment. The containment is designed to: (a) withstand the pressure and heat resulting from a large break in the primary system, called a blowdown; (b) provide long-term cooling; and (c) contain or hold-up any release from the primary coolant system, thus preventing the release of fission products into the environment. Protection from a blowdown is accomplished in different ways depending on the containment design. Some containment designs have a method to condense (or suppress) the steam resulting from the blowdown such as pools of water or large vats of ice. Other containment designs have valves that release the steam from the initial blowdown to the atmosphere, while others are designed to withstand the blowdown. Decay heat and resulting pressure released over time from the primary system could, if not removed, lead to containment failure. Therefore, containments also have systems for long term cooling to remove decay heat. This typically involves recirculating and cooling hot water from inside the containment. The containment is also equipped with systems such as sprays, filters, or pools of water, which can reduce the amount of fission products that would be released if the containment were to leak or fail.

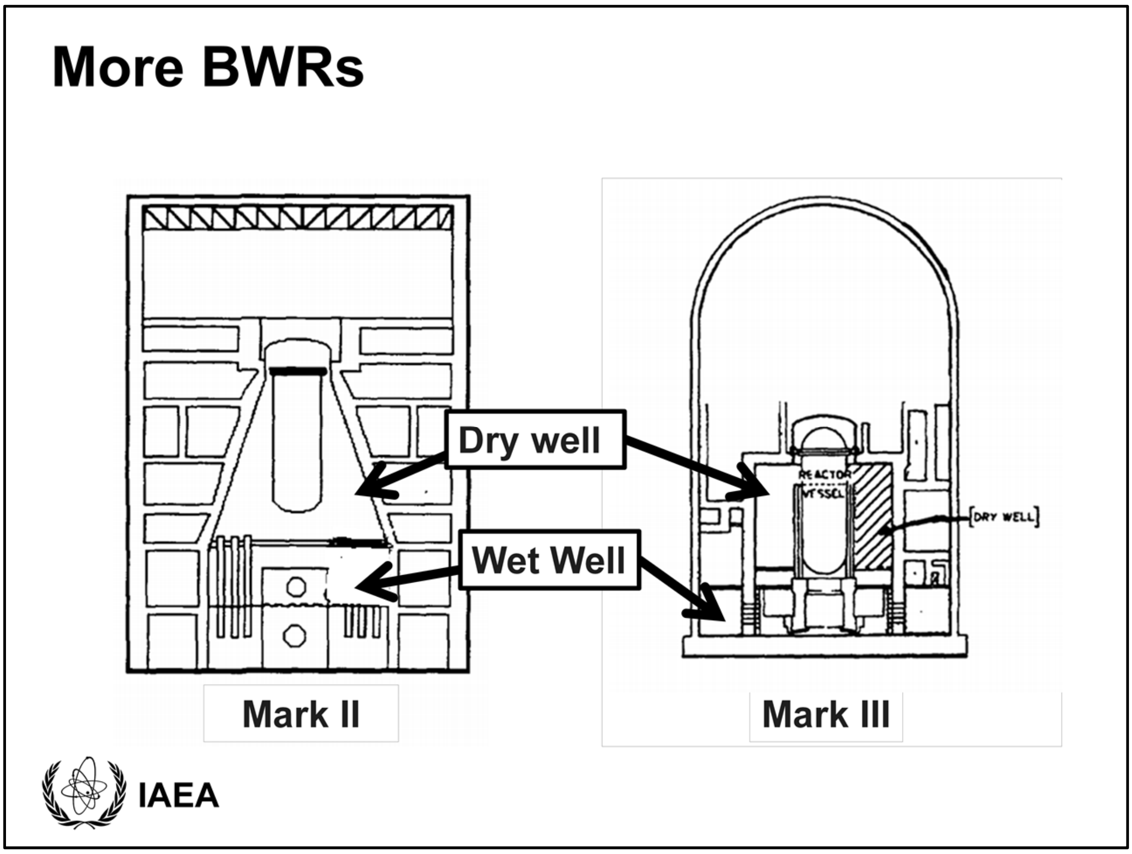
There are many different containment designs with very different capabilities. Most of the currently existing containments are not designed to withstand emergencies involving melting of the fuel in the core. However, some containment designs are thought to be strong enough to withstand even the worst possible emergencies involving melting of the core.



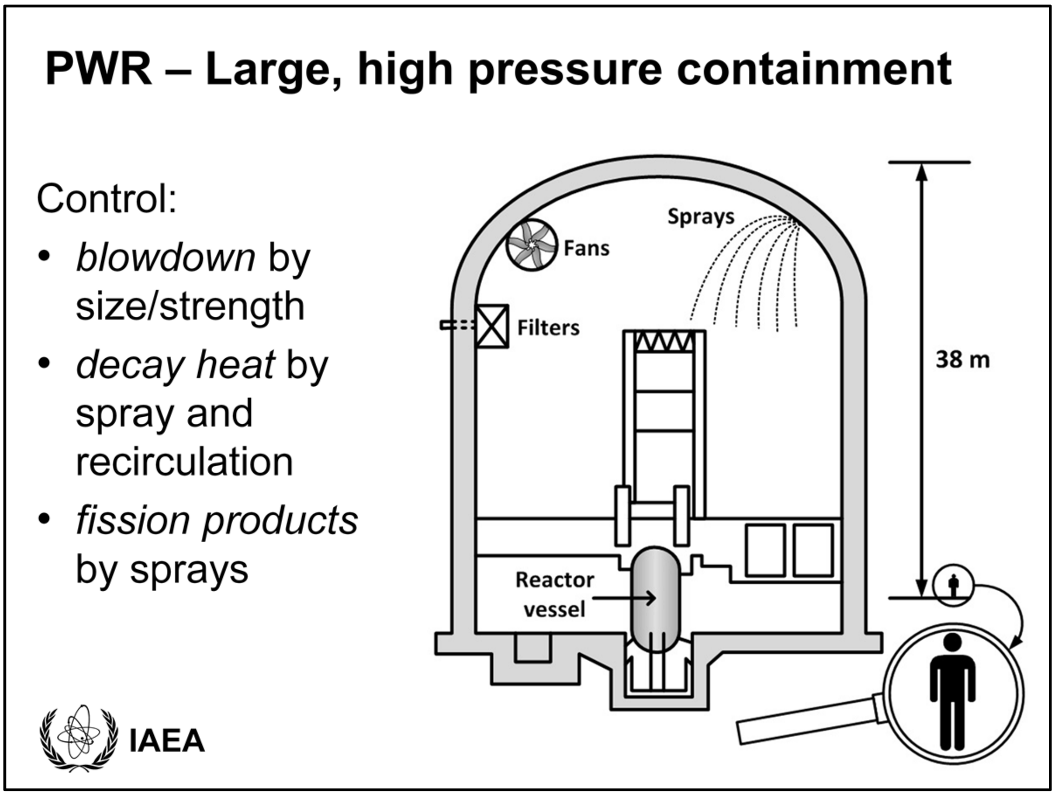
This is a BWR Mark I containment, which is probably the most common type of BWR reactor containment. This design, like most BWR designs, is divided into two areas: the dry well and the wet well. The light bulb shaped structure is the dry well and is connected to the wet well by large pipes. The wet well contains a very large pool of water called the suppression pool. If there's a large break in the primary system (blowdown) into the dry well, as shown in the diagram, the resulting steam and heat is directed by pipes into the wet well and under the water in the suppression pool, thus cooling and condensing it. There are systems providing long-term cooling of both the dry well and wet well. The pool acts as an excellent filter that traps large amounts of fission products released from the fuel. Therefore, as shown in the diagram, there is piping that would allow venting from the wet well to the atmosphere. Venting could be used to control pressure in the containment, and venting through the suppression pool will greatly reduce the amount of fission products released to the atmosphere.

The dry well and wet well may be contained within a large structure called the reactor building. The reactor building is typically no more than a normal metal structure and is not designed to withstand the conditions prevalent during an emergency. In fact, some reactor buildings have blowout panels that are designed to blow out if there's a large increase of pressure or hydrogen explosion.

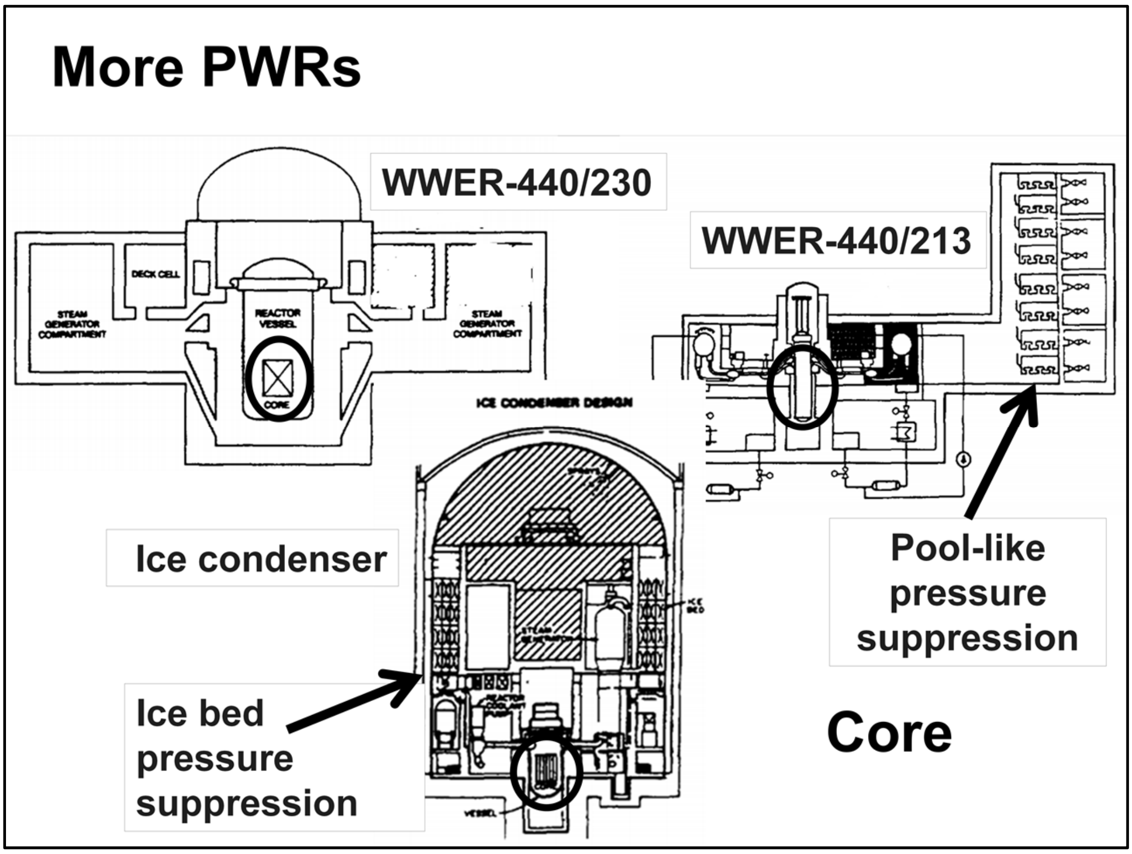
The Fukushima reactors had this type of containment.



The slide shows two more types of BWR containments, both with dry and wet wells.



This shows the most common PWR containment – called a large dry containment because it does not contain any ice condensers or pools of water which are used in some containments. It is very large and is designed to withstand a blowdown owing to its size and strength. There are sprays and cooling systems that are used to remove decay heat and cool the containment over a long period. The sprays are also very effective in removing fission products that might be airborne inside the containment. The Three Mile Island reactor (TMI) had this type of containment.



This slide shows examples of other types of PWR are containments. The WWER-440/230 uses vents which open and release the steam from a blowdown to the atmosphere; the WWER-440/213 uses a tower with small suppression pools to condense the steam from a blowdown, and the ice condenser containment uses large vats of ice to condense the steam from a blowdown.

Containment failure – mechanisms

Unpredictable:

- Existing leak or failure to isolate
- Break or leak of primary system outside containment (bypass – SGTR)
- Overpressure
- Hydrogen explosion
- Melt-through

Predictable:

- Intentional venting by control room staff, but it is not certain that it can be stopped

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In order to have a major release off-site, the containment must fail, be bypassed or be opened to allow radioactive material from the fuel in the core to be released into the atmosphere.

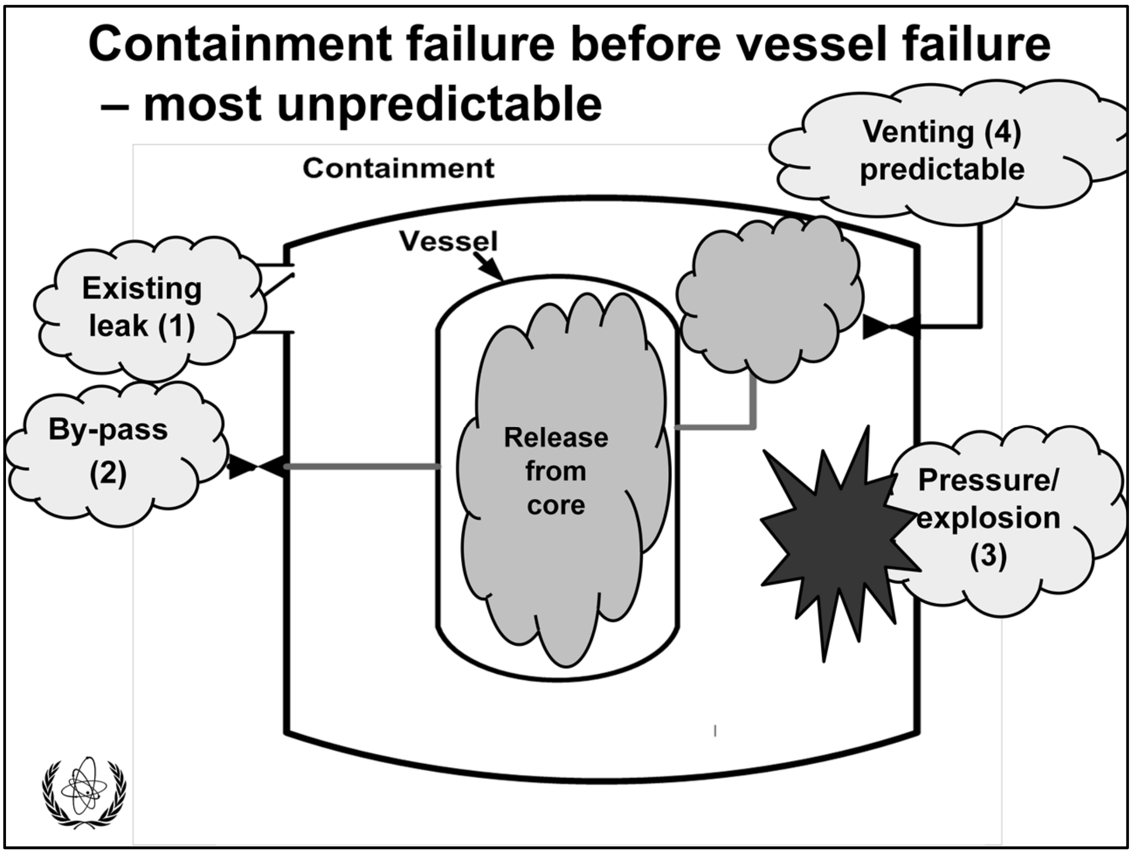
Most of the ways the containment can fail **are unpredictable** and can occur without warning. They include:

- an existing leak or failure to isolate (closing up the containment) at the beginning of the emergency;
- a break or leak of the primary system outside the containment, thus allowing materials from the fuel to be released directly to the atmosphere by-passing the containment (for a PWR this could result from a steam generator tube rupture (SGTR) and for a BWR from a failure of the main steam line isolation valves to close at the beginning of the emergency). This type of failure is often called a 'bypass'.
- a failure due to overpressurization;
- an explosion of hydrogen produced when the fuel in the core is damaged;
- a failure due to conditions that occur when fuel melts through the vessel such as large pressure increases, hydrogen explosions or melting through the containment liner.

Intentional venting that is initiated by the control room staff is the only instance of release from a containment that **can be predicted**; however, once venting starts, it is not certain that it can be stopped.

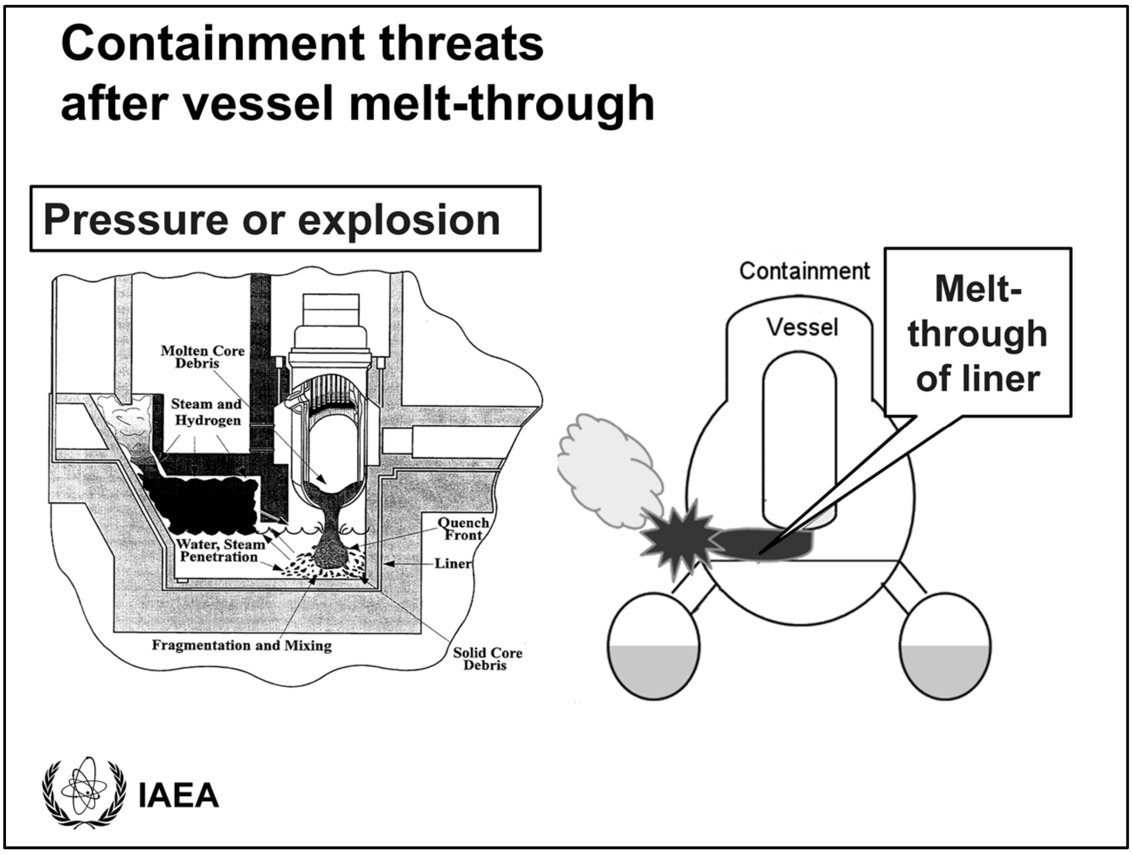
While the containment may not fail at all, if it did, in most cases the timing and extent of containment failure is unpredictable. Therefore no one, including the control room staff, will be able to predict when a failure may occur and once a failure occurs they cannot predict the magnitude or duration of any release. The timing and magnitude of a containment release is certain only for intentional venting of the containment by the control room staff.

With such a large uncertainty, the control room staff will have no way to predict precisely what will be the size and duration of any release and thus, in most cases, dose projection models cannot be used.

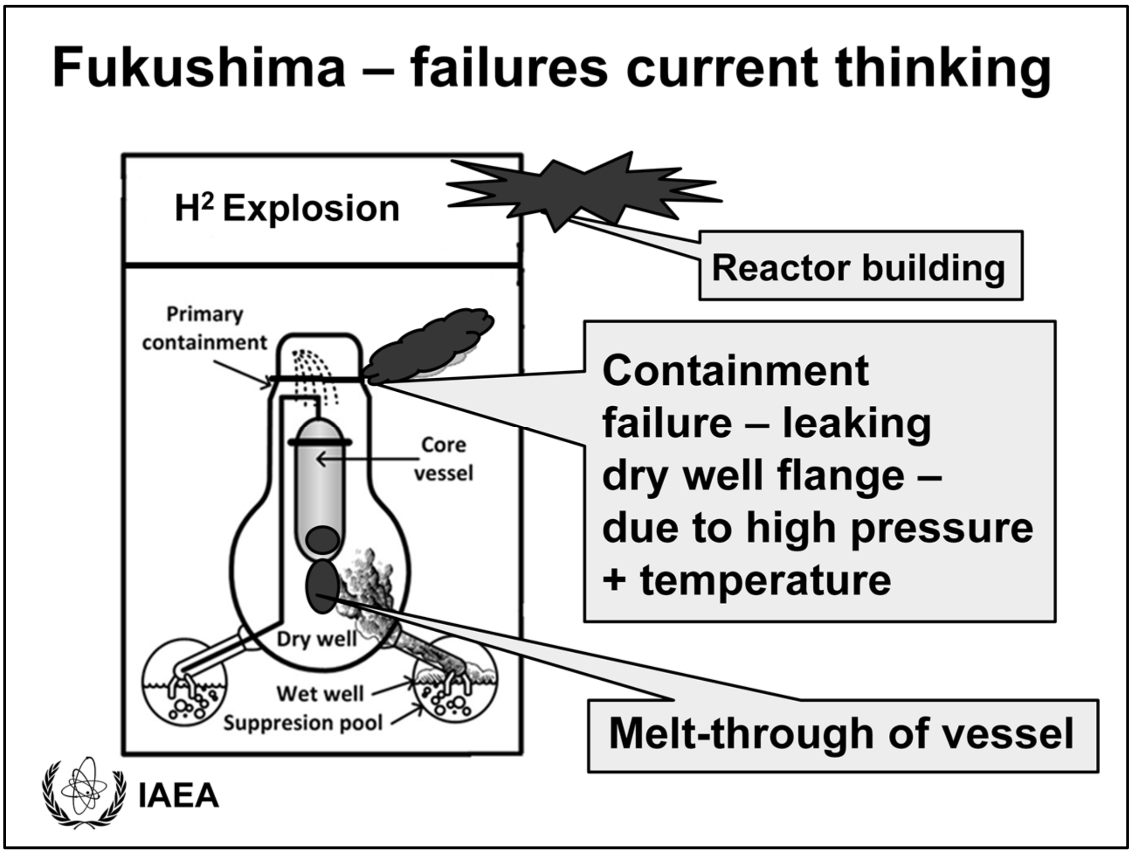


This shows the different ways the containment can fail before the fuel in the core melts through the bottom of the vessel:

(1) an existing leak or failure to isolate (closing up the containment) at the beginning of the emergency;
(2) a break or leak of the primary system outside the containment, thus allowing materials from the fuel to be released directly to the atmosphere, by-passing the containment (for a PWR this could result from a steam generator tube rupture and for a BWR a failure of the main steam line to close at the beginning of the emergency);
(3) from overpressurization or explosion of hydrogen produced when the fuel in the core is damaged; and
(4) intentional venting initiated by the control room staff (the only way a release from the containment can be predicted); however, once venting starts, it is not certain that it can be stopped.

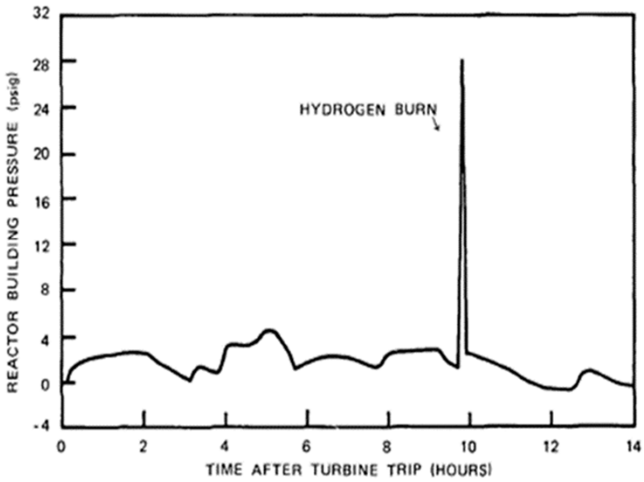


There are several mechanisms that could result in failure of the containment if the core melts through the bottom of the vessel. This slide shows some possibilities. When the core melts to the bottom of the vessel it could produce large pressure increases and hydrogen explosions or the melted fuel and core structures could melt through the containment liner.



The current thinking is that the containment of Fukushima failed when the gasket for the dry well flange leaked or failed due to high pressure and temperature. The vessel failed owing to melt-through and the reactor building failed when hydrogen released during field damage exploded.

Hydrogen explosion



- The TMI containment withstood the explosion
- Other containments may not
- A hydrogen explosion could cause a containment failure unpredictably any time after the core is uncovered

IAEA

This slide shows the pressure spike that occurred in the TMI containment which occurred about 9 hours after the core was uncovered. This was the result of an explosion of the hydrogen that collected in the containment. The hydrogen was generated when the core was uncovered and the fuel pin cladding reacted with steam to generate hydrogen. The TMI large dry containment was strong enough to withstand this increase in pressure, but all containments are not. Such an explosion could cause a containment failure and could occur unpredictably any time after the core is uncovered.

Abbreviation:
TMI = Three Mile Island nuclear power plant, USA.

Containment failure after core damage – Experience

Major release projected by models in 10%–50% of core damage cases; experience is 60% – 80%		
	Containment failure	**≈ Time after core damage**
TMI	No	
Chernobyl	Yes	Immediate
Fukushima (3 melted cores)	Yes (2 or 3 failures)	**Unit 1** ≈ 1 day **Unit 2** ≈ 3 days **Unit 3** - ?

The analysis of severe core damage accidents indicates that containments would fail, resulting in major releases, anywhere between 10% and 50% of the time depending on the type of containment. Experience so far indicates that it occurs about 60%–80% of the time. There have been three accidents involving core melt. During the TMI accident, the containment did not fail; however, in the Chernobyl and Fukushima accidents, the containments did. At Chernobyl the containment failed immediately. At Fukushima there were 3 core melts and it appears that 2 and possibly 3 of the containments failed 1 to 3 days after the melting of fuel in the reactor cores. It is currently believed that the failures at Fukushima were due to overpressure and the failure of seals due to overheating.

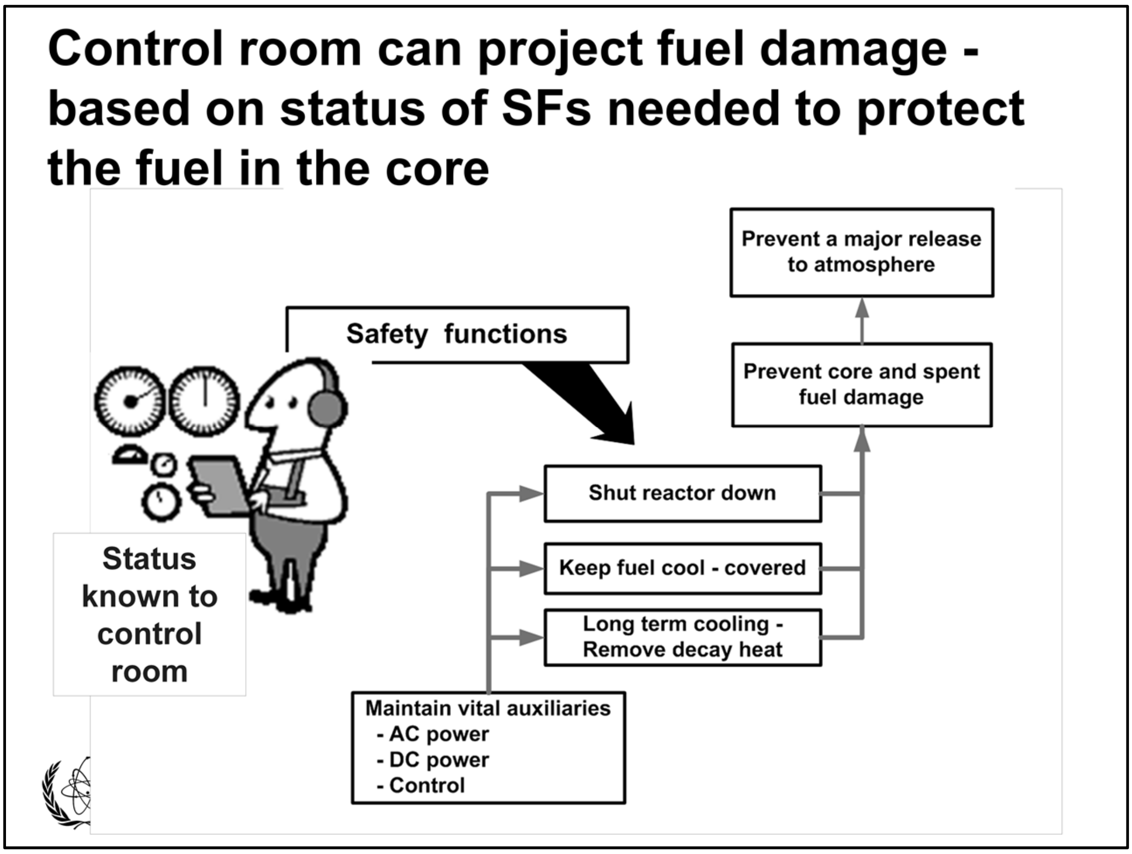
Safety functions (SF) must fail before damage to the fuel occurs

- SFs performed by multiple, diverse systems
- Status of SFs monitored in the control room
- An SF provides warning before fuel damage and thus before a release can occur
- In most cases the loss of the SF will occur several hours before a release – thus allowing time to initiate actions to protect the public before a release

IAEA

Several safety functions (SFs) must be performed, otherwise the fuel in the core and spent fuel pool will be damaged, possibly causing a release. Several safety systems (e.g. pumps) perform each of these SFs and multiple failures are required before a safety function is lost. Therefore, loss of these functions is very unlikely. If they are lost, this means that the fuel in the reactor core or spent fuel pool will be damaged and thus the public are at risk. Instruments in the control room monitor the performance of the safety functions. In most cases, a major release will not occur until several hours after the loss of the SF: this allows time to initiate action to protect the public when the loss of the SF is detected and before a release is to occur.

Abbreviation:
SF = safety funtion



The SFs that must be performed to prevent damage to the fuel in the core are:

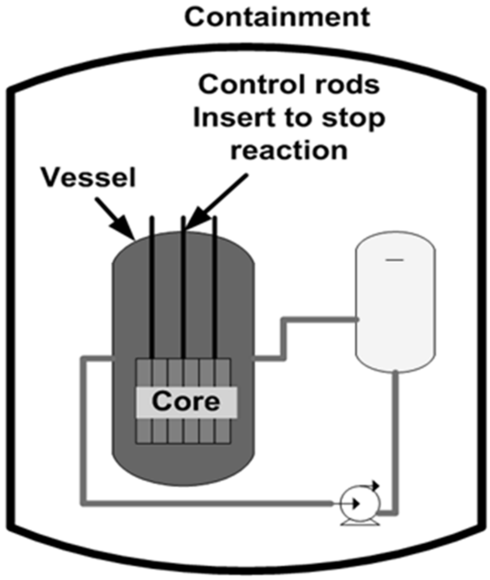
1) Shut the reactor down – reactor criticality control
2) Keep the core covered – cool the fuel pins
3) Provide long term cooling – remove decay heat from the reactor and the containment.

In all cases the vital auxiliaries including AC and DC power and control must be maintained, otherwise all the safety functions will be lost. Loss of AC and DC power and control, as a result of the tsunami, is what occurred at the Fukushima reactor in Japan, which led to core damage and a release.

The control room monitors the performance of the safety functions and thus can protect damage to fuel when a SF needed to protect the fuel is lost.

Shutting down the reactor (trip, scram)

- Reactor must be shut down for the safety system to protect the fuel in the core
- Rapid insertion of control rods (scram or trip)
- Failure may result in fuel damage in minutes
- Probability of failure is considered very low



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The first safety function is shutting down the reaction, also called criticality control, scram or trip. A reactor “scram” is the rapid (seconds) insertion of control rods to stop the fission chain reaction. A reactor scram causes a dramatic decrease in reactor power. It is vital that the reactor shuts down during an emergency because the emergency systems that that keep the core cool are only designed to remove decay heat (about 7% of rated power of an operating reactor) and not the heat generated by an operating reactor. A failure to scram at the start of an emergency could lead the fuel in the core to becoming uncovered and thus damaged within minutes.

Keeping the core covered and removing decay heat

- Function of the emergency core cooling system (ECCS)
  - Injection phase – injection of water into the core to keep the core covered with water and cool at the start of the emergency
  - Long term cooling or recirculation phase to remove the decay heat

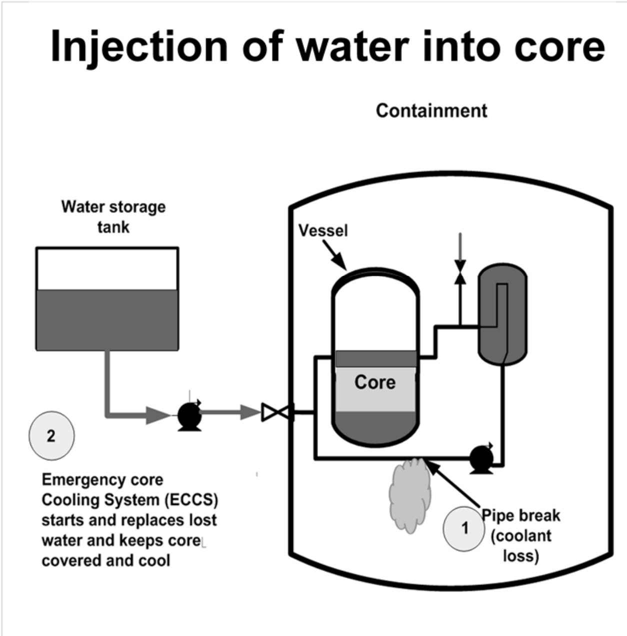
IAEA

The next safety function is to keep the core covered and cool, and this is performed mainly by the emergency core cooling system (ECCS). The ECCS is designed to keep the core covered and also provide cooling in the event of a loss of coolant from the primary system. However, the ECCS is designed to cool the core only after the reactor is shut down (has tripped). The ECCS typically works in two phases: (i) the injection phase and (ii) the long term cooling or recirculation phase.

Abbreviation:
ECCS = emergency core cooling system

ECCS injection phase – keeping the fuel in the core covered

- Failure could result in core damage in less than an hour
- Failure of the ECCS was the cause of the core melts at TMI and Fukushima



IAEA

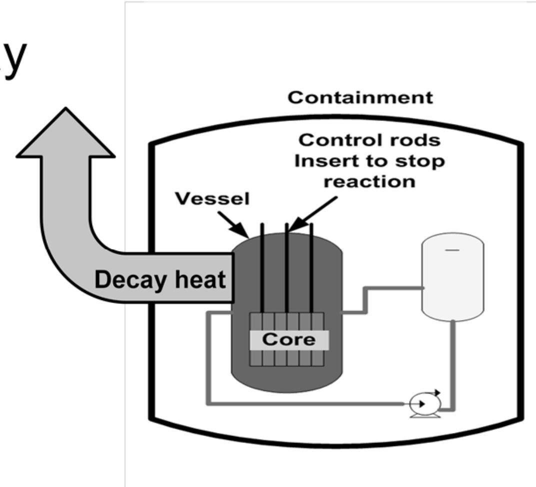
The injection phase starts as soon as the plant instrumentation detects that a loss of coolant from the primary system has occurred. The plant computer, as soon as it detects this loss of coolant from the primary system, will open a series of valves and activate several pumps. These pumps will inject water from storage tanks into the primary system so that the core remains covered. The ECCS is designed to deal with the largest possible break in the primary system. If the ECCS operates as designed, the fuel in the core may become uncovered for a few minutes but will be covered once again before it reaches a sufficient temperature to cause damage to a significant number (>20%) of the fuel pins.

If the ECCS fails during this injection phase, the core could become uncovered and damaged in less than an hour. Failure to keep the fuel in the core covered was the cause of the melting of the cores at the TMI and Fukushima reactors. At TMI, the control room staff turned the ECCS system off; at Fukushima the ECCS was lost when the AC power was lost owing to the tsunami.

Long term cooling phase – removing decay heat to the environment

Failure to remove decay heat could:

- result in fuel damage within hours
- result in containment failure within hours to days



IAEA

In the second phase of ECCS operations, once the initial sources of ECCS water are gone, the ECCS goes into the recirculation phase. This is a phase used for long term cooling of the core. During this phase, the ECCS pumps the water that has collected in the containment sump from the leak, cools it and injects it into the core to keep the core covered. The water is also sprayed into the containment to cool it and remove fission products. If the ECCS fails during recirculation, the fuel in the core could be damaged in a few hours and the containment lost within 10 or more hours due to overpressurization.

Maintain vital auxiliaries

Their loss could lead to failure of several safety functions

- Loss of AC power leading to:
  - Loss of pumps to keep core covered and cool
  - Loss of long term cooling
- Loss of DC power leading to:
  - Loss of control of pumps and valves
  - Loss of instrumentation
- Loss of control of safety functions

IAEA

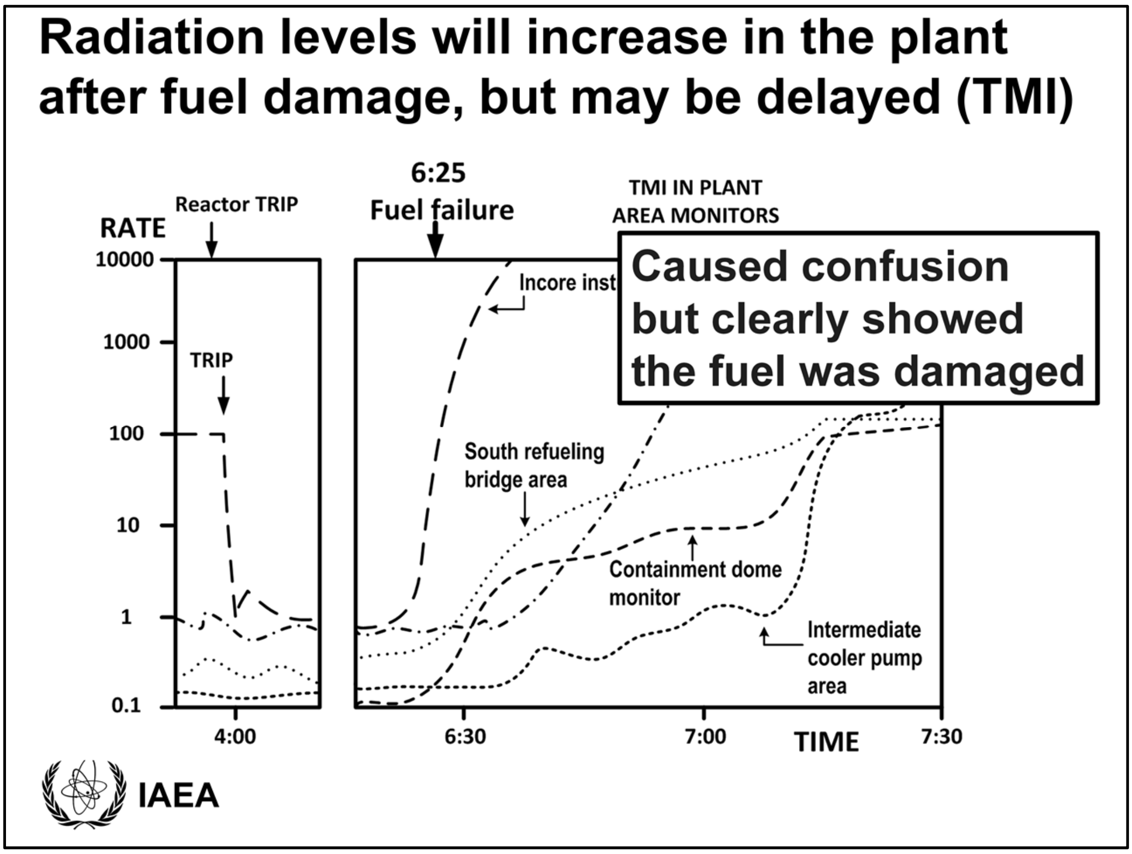
There are systems in the plant that are called vital auxiliaries. These systems must be maintained to perform the safety functions. If a vital auxiliary is lost, one or more of the safety functions may be lost. The vital auxiliaries include AC and DC power and control. AC power is used to run pumps to supply water and cooling, and DC power is needed to control and monitor most of the systems in the plant. The control room staff can also be considered a vital auxiliary. They could be put out of action due to a terrorist attack or other event that incapacitates them (toxic gas release) or requires them to evacuate the site. There may be other plant specific vital auxiliaries such as high-pressure air mechanisms used to control some systems.

Control room indicators of imminent or actual fuel damage

- Imminent fuel damage (depending on plant):
  - Water level below the top of active fuel (TAF)
  - High fuel temperatures
- Actual damage: Increased radiation levels throughout the plant
- Should not wait for confirmation of fuel damage, should act when safety functions (SFs) are lost

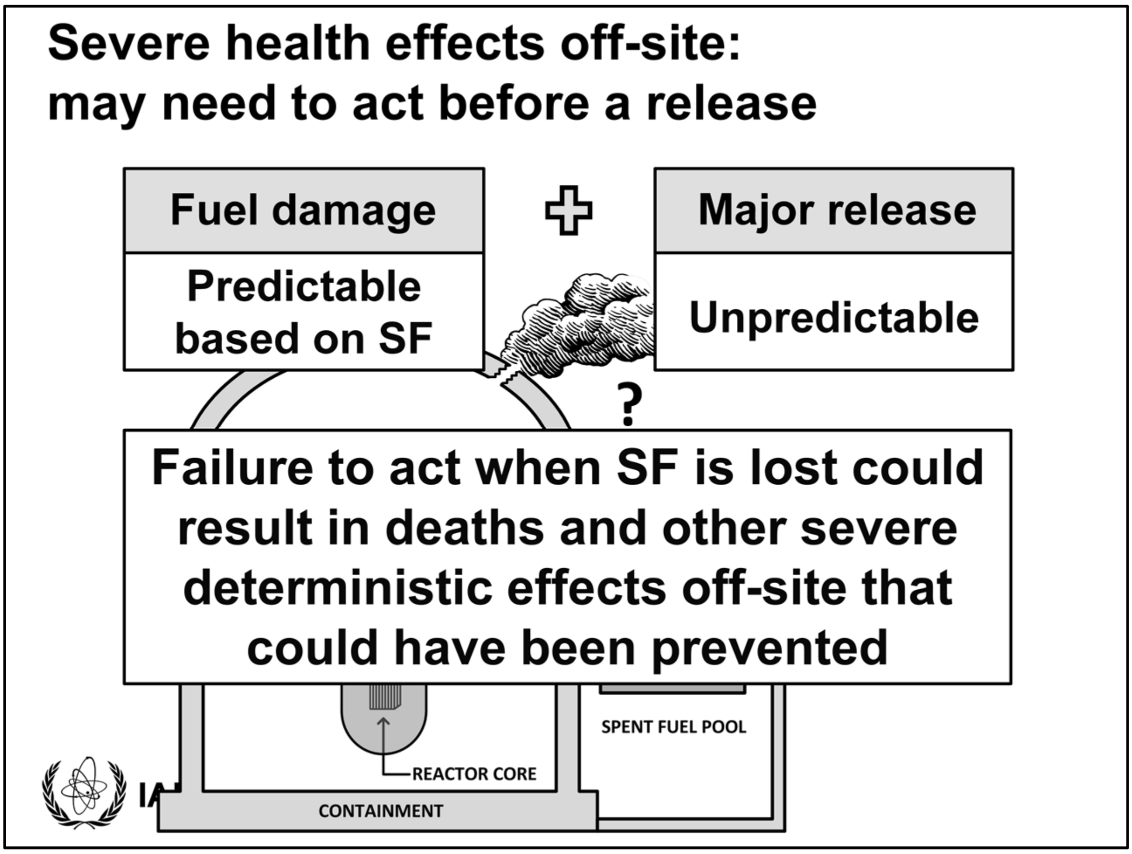
IAEA

The control room staff should also be able to detect imminent or actual fuel damage based on instrumentation available in the control room. In some plants, the water level in the core or spent fuel pool can be measured; once it falls below the top of active fuel (TAF), fuel damage can occur within a short time. In some plants, the control room can monitor the temperature just above the fuel. And finally, if there is severe damage to the core, fission products will start to be released throughout the plant, which will result in increased radiation levels. However, once damage to fuel occurs, a release resulting in health affects off-site can occur at any time. Therefore, the control staff should initiate the response when the safety function is lost and should not await confirmation of fuel damage.



The release of radioactive material from the core confirms that fuel in the core is damaged.

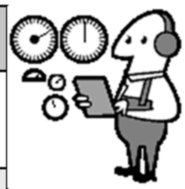
Once the fuel cladding fails, the “gap” (which is the gaseous fission products in the fuel pin) will be immediately released from the fuel pins. This will be followed by continued release of fission products because they are cooked out of the fuel as it heats up. Radiation monitors throughout the plant will measure this release of fission products. However, there may be a considerable delay before the releases are detected depending on the route they take. This shows the area radiation monitor readings during the hour after the TMI fuel failure. Clearly, many monitors increased their readings, but in some cases it was almost an hour following the damage. The radiation readings caused considerable confusion during the TMI accident because some were read incorrectly, some were not calibrated correctly, some were influenced by radiation in nearby areas, and other reasons. This highlights the need to understand how instruments will respond during emergencies and to verify readings that may indicate a problem.



Severe health effects off-site can occur if there is damage to the fuel in the core or spent fuel pool resulting in a major release. As will be discussed later, to be most effective, protective actions should be taken before the release occurs and failure to do so could result in deaths or other severe deterministic effects that could have been prevented. As we have seen, we can predict damage to fuel based on loss of safety functions which would occur before release. However, as we have also seen, failure of the containment resulting in a release is unpredictable. Therefore, to best ensure that protective actions are initiated before a release, action needs to be taken when the loss of the safety function is detected.

Question Module 6-2: When should off-site officials be notified and told to protect the public near the plant and why?

Event	Time
Large break in primary system – loss of core coolant water	0:00
Emergency core cooling systems – active – cooling water replaced	0:01
Loss of ECCS – no cooling water provided to fuel in core	1:00
Core fuel temperature goes off scale >800°C	1:30
Radiation monitors throughout plant increasing	1:45
Dose rate outside plant at main gate rapid increase to >1 mSv/h	4:00



Query participants on the timing for notification of off-site officials and for issuing instructions to initiate actions to protect the public near the plant. Prompt participants to explain why this would be appropriate. Tell the participants to assume that they are in the control room of a nuclear power plant and that their instruments tell them that the events listed have occurred at the times shown.

Answer Module 6-2: When should off-site officials be notified and told to protect the public near the plant and why?

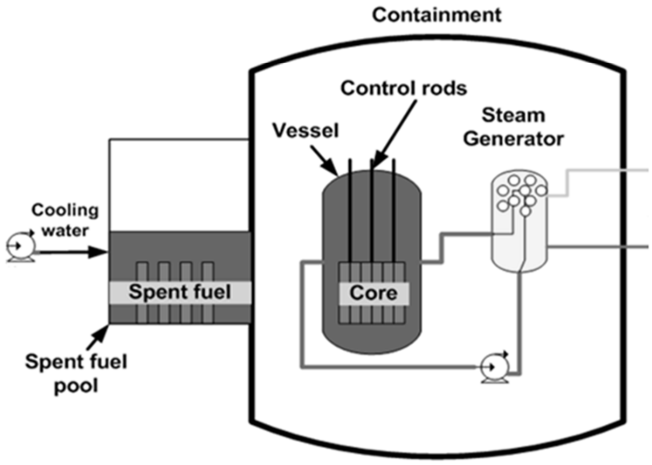
Event	Time
Large break in primary system – loss of core coolant water	0:00
Emergency core cooling systems – active – cooling water replaced	0:01
Loss of ECCS – no cooling water provided to fuel in the core	1:00
Core fuel temperature goes off scale > 800 °C	1:30
Radiation monitors throughout plant increasing	1:45
Dose rate outside plant at main gate rapid increase to > 1 mSv/h	4:00

Protective action should be recommended to off-site officials when the ECCS system providing cooling water to the core is lost (SF lost) at 1:00. Loss of the ECCS means that fuel damage will occur and thus a severe release to the atmosphere is possible. Since the timing of a release is not predictable, in order to have the best chance of initiating protective actions before a severe release to the atmosphere, actions must be initiated as soon as damage to the fuel in the core is projected (when the SF is lost).

Actions do not need to be recommended when the break occurs (at 0:00) as long as the ECCS systems are keeping the core covered and cool (0:01). And it would be inappropriate to delay recommending actions until core damage is confirmed by increased temperature and radiation levels (1:30 and beyond) because this would delay the initiation of protective actions. And clearly it is inappropriate to wait to initiate protective actions until radiation levels are detected off-site (4:00) because this means that the initiation of protective actions was delayed until the public was already being exposed.

Spent fuel pool – major release also possible

- Once fuel is uncovered, damage in hours – days
- Pool may be located outside the containment, allowing direct release into the atmosphere



IAEA

The other location of large amounts of fission products is in the pool that contains spent fuel that has been removed from the reactor core. The size of a release from a spent fuel pool is less certain than that from a core, and may be less of a threat than a core release because it does not contain as much of the most dangerous of the fission products (e.g. I-131).

Time to boil down to the top of fuel in the pool if cooling (SF) is lost

Decay Time Time after shutdown	Boiloff Time (hours) PWR	 BWR
60 days	100	145
1 year	195	253
2 years	272	337
5 years	400	459
10 years	476	532

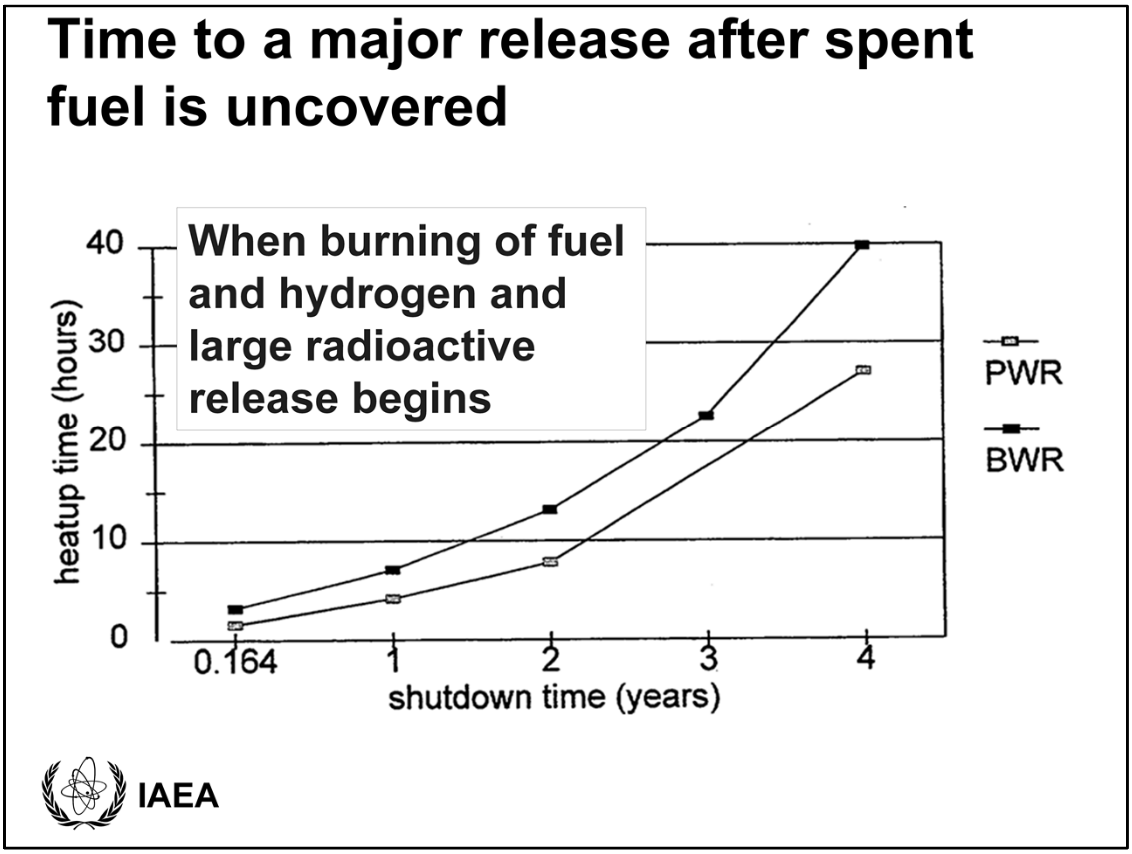
Fuel could be uncovered much faster if the pool leaked allowing the cooling water to drain out

IAEA

The spent fuel pool generates much smaller amounts of decay heat than the fuel in the core of an operating reactor. Thus, it is much easier to keep cool and protected and it takes longer for a major release to occur.

This slide shows the time it would take for boiling to uncover a spent fuel pool if cooling (safety function) to the spent fuel pool is lost. Note that the time it takes before the fuel would be uncovered depends on how long ago (time after shutdown) the fuel was removed from the core of the reactor. As you can see, it would take days at a minimum to uncover the pool. However, the fuel could be quickly uncovered if the pool drained because the pool failed in some way. As we have seen, the spent fuel may be located outside the containment and, as a result, any release from the spent fuel could be made directly into the atmosphere.

Source: US NUCLEAR REGULATORY COMMISSION, Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants, NUREG-1738, USNRC, Washington, DC (2001).

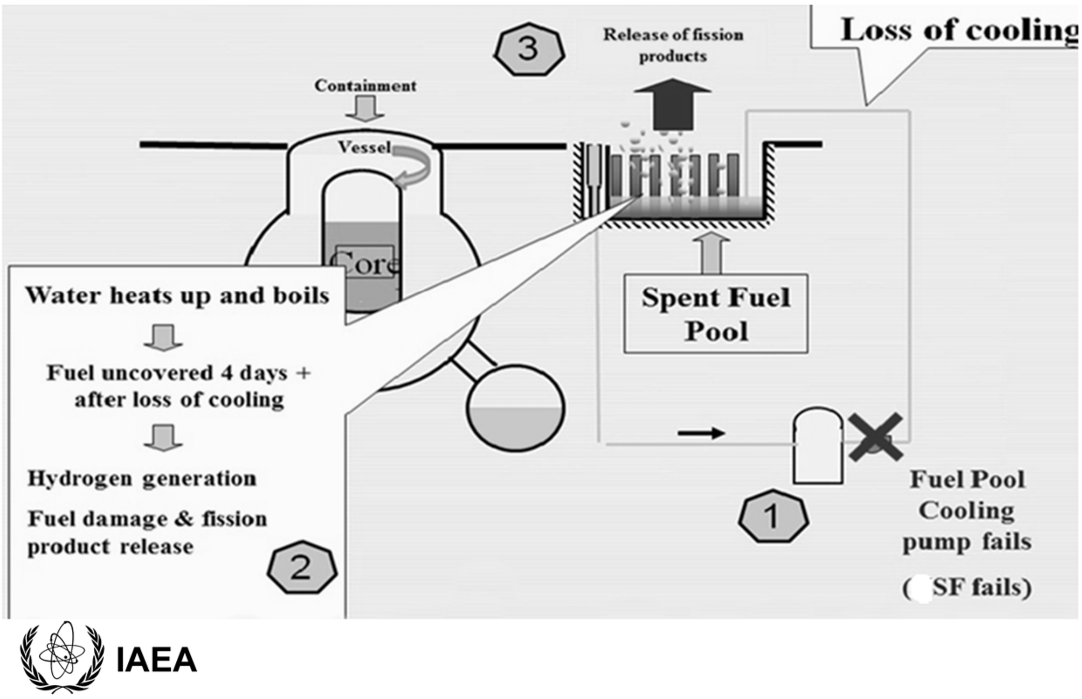


Once the fuel in a pool is uncovered, as shown in this table, it would take hours for the fuel to heat up to a temperature that could result in a large release. Note that the time it takes before major release depends on how long ago (time after shutdown) the fuel was removed from the reactor core.

If the fuel in the pool is uncovered it could possibly heat up, burn and generate hydrogen. In this condition, it would release large amounts of radioactive material that could result in severe deterministic effects off-site.

Source: US NUCLEAR REGULATORY COMMISSION, Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants, NUREG-1738, USNRC, Washington, DC (2001).

Spent fuel pool emergency example



This illustrates the failures leading to a release of fission products from the spent fuel pool. (1) First a system providing a SF must be lost. (2) The pool would start to heat up, several days later the water (if not replaced) will boil down to a level (3) at which the fuel pins would start to heat and burn (as happens in the fuel in the core), releasing hydrogen and fission products, possibly directly to the atmosphere. Control room instruments would immediately indicate when cooling was lost in the spent fuel pool, thus providing considerable warning before a major release and considerable time to take protective actions.

The big difference between an emergency involving the core and a spent fuel pool is the time available to act. Once cooling to the pool is lost, it may take days before fuel is uncovered and a major release is possible. However, if the fuel pool fails and drains, damage to the fuel could occur in several hours.

Source: US NUCLEAR REGULATORY COMMISSION, Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants, NUREG-1738, USNRC, Washington, DC (2001).

Emergency classification system

- Triggers fast and coordinated response (without meetings)
  - Activation and notification
  - On-site response
  - Off-site protective action
- Based on:
  - Plant conditions – e.g. loss of SF (most effective)
  - Environmental monitoring

IAEA

A prompt and effective response can be implemented if everyone knows what to do when the alarm sounds. There is no time to hold meetings to decide what to do. This is accomplished through the use of an emergency classification system. The emergency classification of an emergency will trigger immediate and coordinated action by all response organizations. This will include activation and notification of the response organization, and taking protective actions for the public. For each emergency class, both on-site and off-site response measures can be predetermined and incorporated into written procedures and training, thus making for a prompt and coordinated implementation.

IAEA classification system [Section 3, Table 1]

Class	Plant conditions	Protective actions off site
General Emergency	May not be safe off-site • Actual or projected severe damage to fuel • Loss of control	Immediate urgent protective actions
Site Area Emergency	Additional failures – severe damage to fuel	• Alert officials and public to prepare to take protective actions • Off-site monitoring
Facility Emergency	On-site risk only	None
Alert	Degraded or uncertain conditions – no known danger to fuel	None

IAEA

This summarizes the emergency classification system recommended by the IAEA and as described in Table 1 of Section 3 of the IAEA publication EPR-NPP PUBLIC PROTECTIVE ACTIONS.

The declaration of a **General Emergency** means that it may not be safe off-site because either: (a) events have occurred at the nuclear power plant that will lead to severe damage to the fuel in the reactor core or the spent fuel pool; (b) severe damage to the fuel has been detected; or (c) control over the facility has been lost. Therefore, the declaration of a General Emergency triggers immediate implementation of urgent protective actions and other response actions to protect the public. Upon declaration of a General Emergency, the shift supervision should promptly notify and recommend protective actions to the off-site decision maker (within less than 30 minutes). The off-site decision maker should implement protective actions immediately when notified by the plant.

The declaration of a **Site Area Emergency** means that any additional failures at the nuclear power plant will result in severe damage to the fuel in the reactor core or in the spent fuel pool. Thus, one more failure would result in declaration of a General Emergency. Therefore, upon declaration of a Site Area Emergency, it is prudent to advise the public to prepare to take protective actions and other response actions, to activate emergency response organizations and conduct radiological monitoring in the vicinity of the nuclear power plant.

The declaration of a **Facility emergency** means that something's occurred that represents a risk to those on the site but cannot result in any risk to those off-site.

The declaration of an **Alert** is not an emergency and declaration means something unusual has occurred that may have degraded conditions on site but does not represent a danger to the fuel in the core or spent fuel pool and thus does not represent a risk to those off-site.

Classification based on emergency action levels (EALs)

- Trigger for classification of the emergency
- Predetermined observable threshold

Plant conditions (e.g. SF loss)

Radiological monitoring

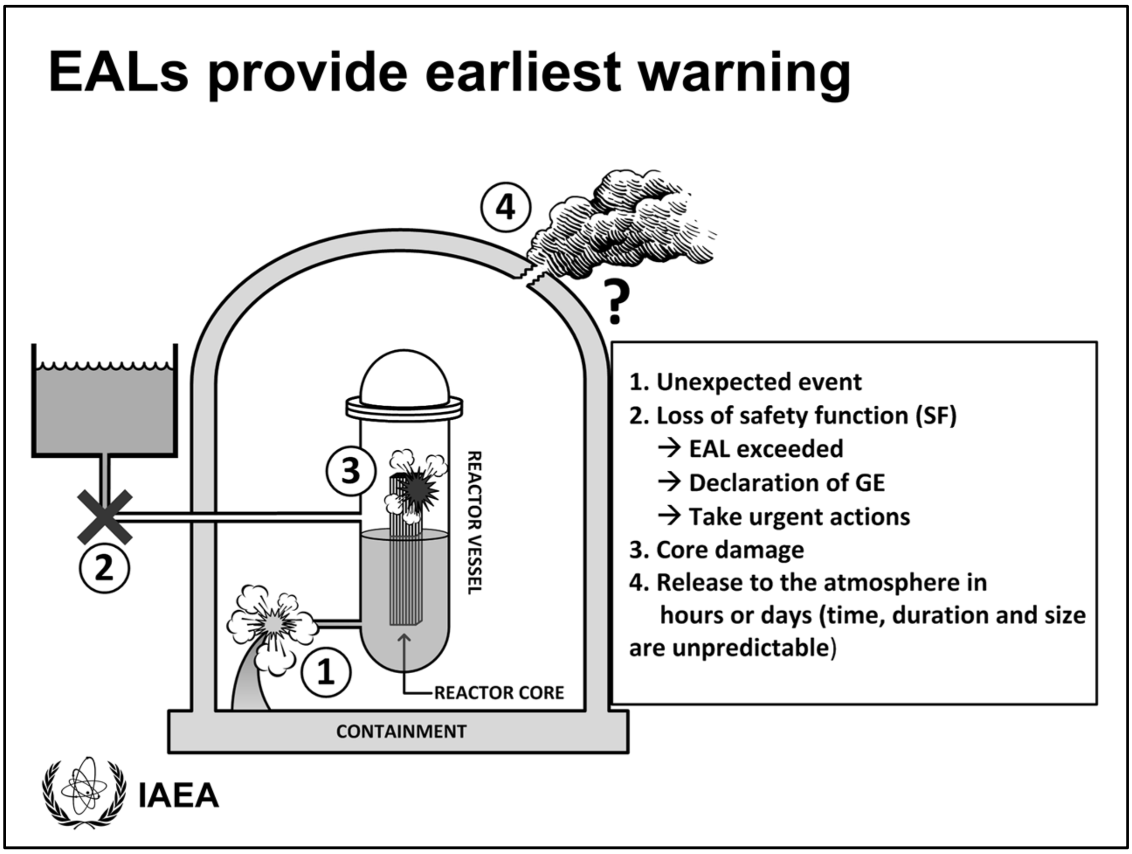
Other hazards/ threats

IAEA

The EAL is a predetermined observable threshold which, if met, triggers the appropriate classification of the emergency and response actions. EALs are based on: (a) information (symptoms) observable by the control room staff, such as indication of the loss of a safety function; (b) environmental monitoring and (c) other hazards or threats such as storms or terrorist attacks. However, the goal in using EALs is to classify an emergency as soon as possible so that in most cases it is based on plant conditions.

An emergency will be classified and action initiated when the EALs are exceeded. For example, a General Emergency would be declared and immediate protective actions for the public initiated when loss of cooling to the core is detected by the control room staff, thus allowing actions to be taken before any release starts. An emergency may also be declared if a radiological release is detected by environmental monitoring; however, this is not most effective because time might probably be lost that might have been used to protect the public if actions had been taken when the loss of a safety function was detected.

Abbreviation:
EAL = emergency action level



Many safety systems must fail before the fission product barriers also fail and lead to a release. The status of the safety systems (e.g., AC power) needed to cool and thereby protect the core or spent fuel pool, are continuously monitored in the control room. Therefore, the plant staff should be able to predict or, at least, detect core damage most likely hours before a release into the atmosphere. As happened in Japan, this gives an opportunity to take actions to protect the public (e.g. evacuation) before the release occurs.

The EALs should be structured to provide for the earliest possible classification of an event that could result in a major release, thereby giving responders and the public the greatest amount of time to respond. The criteria are provided in the following order:
1) Initiating event
2) Critical safety function; loss/impairment
3) Damage to fuel in core or spent fuel
4) Release – radiation level in the environment.

Example EALs for General Emergency – (projected or actual severe damage to fuel)

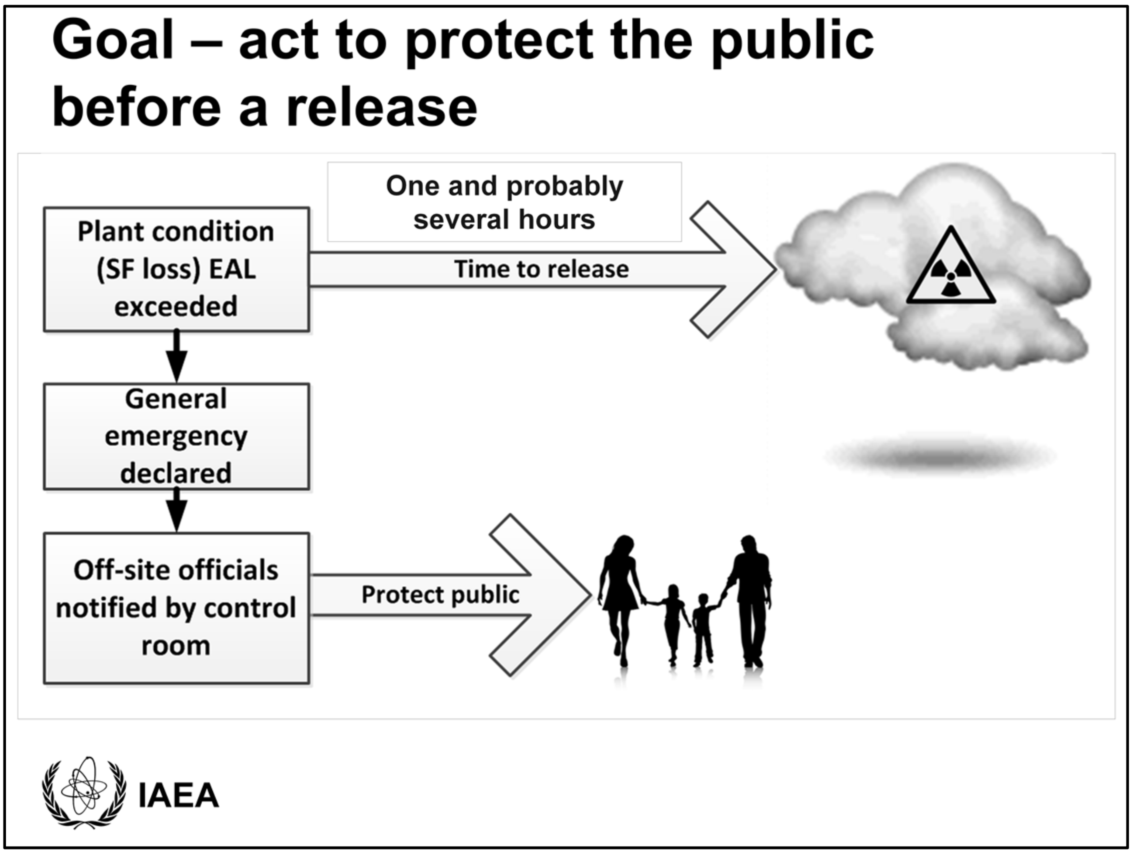
Before severe fuel damage (loss of SF)	Imminent severe fuel damage	Actual severe fuel damage	After release, monitoring off-site
Projected loss of AC and DC for a site-specific time (e.g. 40 min)	Core temperature (CET) >800°C	In-plant radiation levels increase	Dose rates >100 μSv/h

Classify as soon as you can

IAEA

This shows an example of emergency action levels (EALs) for declaration of a General Emergency. The General Emergency is declared when conditions exist that will result in or have resulted in severe damage to fuel. The goal is to classify the emergency as soon as possible, thus giving the greatest amount of time to take effective protective or other response actions before the public is exposed. The EALs are shown in the order in which emergency response actors or decision makers have the opportunity to classify the emergency.

Opportunities to classify the emergency:
First: The first opportunity to classify is when an SF is lost that will result in fuel damage. In this example, the EAL is "projected loss of AC and DC power for a time that will result in fuel damage" – for example 40 minutes.
Second: The second opportunity to classify is when conditions indicating imminent core damage are detected, such as core temperatures (e.g. core exit thermocouple (CET) in a PWR) greater than 800°C.
Third: The third opportunity to classify is when conditions indicate actual fuel damage, such as increased radiation levels throughout the plant.
Last opportunity: The last opportunity to classify the emergency is after a release, based on off-site monitoring. However, this also means that the public is already being exposed and classifying at this point may be too late to take the most effective protective actions.



The goal is to classify the emergency as soon as possible, thus allowing the greatest amount of time to take effective protective and other response actions before the public is exposed.

If the control room notifies off-site officials of a General Emergency within minutes when an SF is lost (or the EAL is exceeded), off-site officials should have one or more hours to initiate public protective actions before a release.

Question Module 6-3: What is the class?

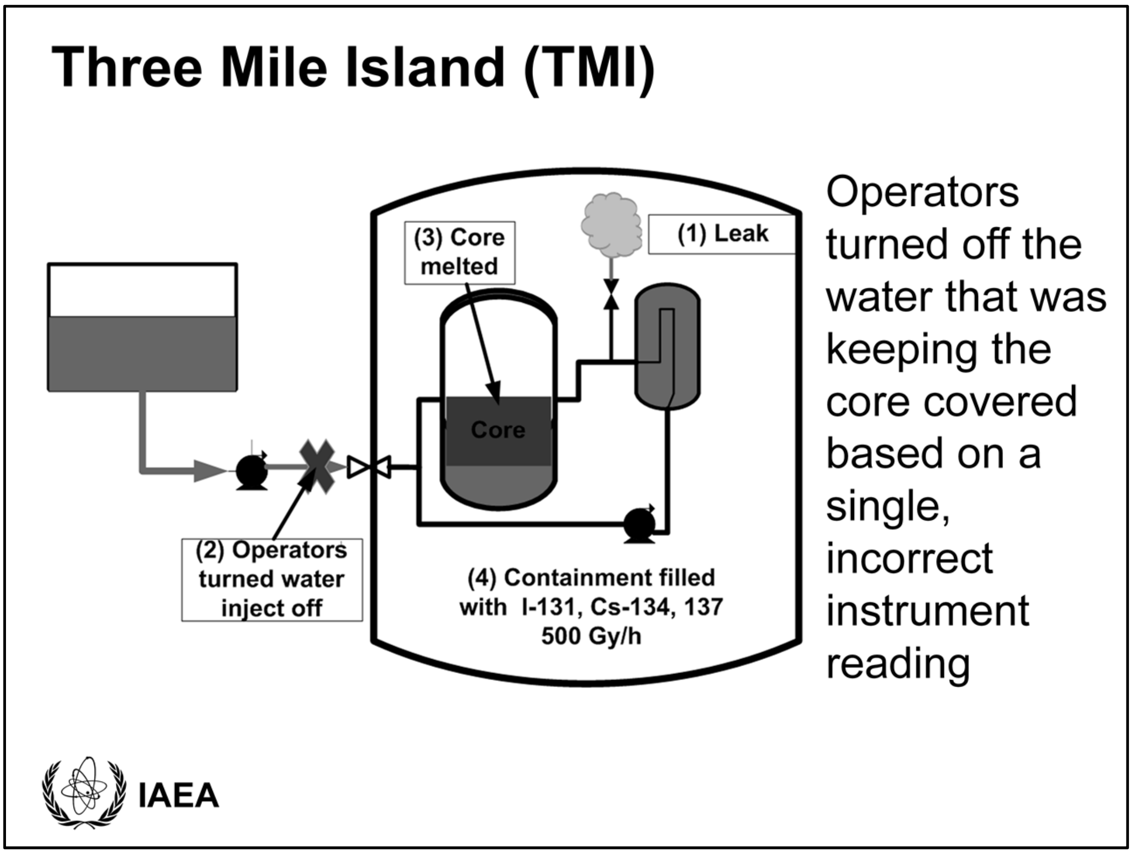
Event	Time	Class
Large break in primary system – loss of core coolant water	0:00	
Emergency core cooling systems active – core cooling water provided	0:01	
Loss of ECCS – no cooling water provided to the fuel in the core	1:00	
Core fuel temperature goes off scale >800 °C	1:30	
Radiation monitors throughout plant increasing	1:45	
Rapid increase to >1 mSv/h of dose rate at main gate outside the plant	4:00	

Ask the students to classify the emergency for each event.

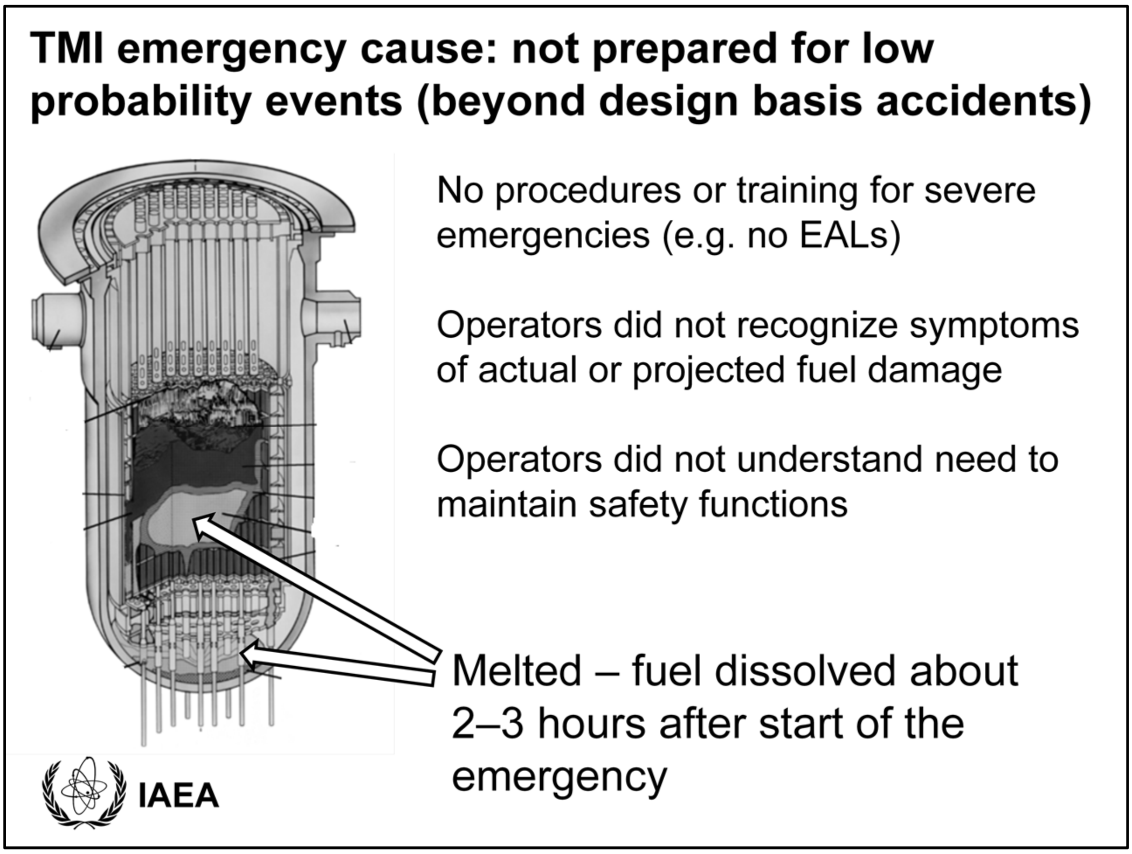
Answer Module 6-3: What is the class?

Event	Time	Class
Large break in primary system – loss of core coolant water	0:00	Alert
Emergency core cooling systems active – core cooling water provided	0:01	Alert
Loss of ECCS – no cooling water provided to the fuel in the core	1:00	GE
Core fuel temperature goes off scale >800 °C	1:30	GE
Radiation monitors throughout plant increasing	1:45	GE
Rapid increase to >1 mSv/h of dose rate at main gate outside the plant	4:00	GE

The large break in the primary system would be declared an Alert as long as cooling water is provided to the core by the emergency core cooling systems (ECCS). A General Emergency is declared at 1:00 because cooling to the core has been lost and damage to the fuel in the core will occur. When a General Emergency occurs, off-site officials would be immediately contacted and advised that they should immediately initiate protective actions to protect the public. The high core temperatures at 1:30 indicates that core damage is imminent, the increase in radiation levels within the plant at 1:45 indicates core damage has occurred and finally the high dose rates off-site at 4:00 indicate a severe release has started.



The accident at TMI in the USA in 1979 resulted in melting of the reactor core. The accident started when the operators lost the normal cooling for the reactor. The ECCS came on, as designed, to keep the core cool. At the same time there was a small leak from a safety valve in the primary system ((1) in the figure), which resulted in an ongoing loss of coolant from the primary system. The operators did not recognize this leak even though there were numerous indications that the valve was leaking and coolant was being lost. The operators focused on a single instrument that indicated, erroneously, that there was too much water in the reactor primary system and as a result turned off the ECCS (2 in the figure), ultimately, since the water being lost out of the primary system was not being replaced the core was uncovered and melted (3 in the figure) releasing a large amount of radioactive material into the containment, dose rates greater than 500 Gy/h were measured in the containment (4 in the figure). The containment did not fail and only small releases occurred; however, if the containment had failed there could have been severe health effects among the public off-site.



The primary cause of the emergency at TMI was that the operators were not prepared for low probability events (beyond design basis accidents). They did not have procedures available nor had been training to recognize the symptoms of actual or projected core damage. Moreover, they did not understand the need to maintain certain safety functions in order to protect the core and know how to determine if these safety functions were being performed adequately. This shows the importance of training and procedures for severe emergencies to include predetermined criteria (e.g. EALs) for taking emergency actions.

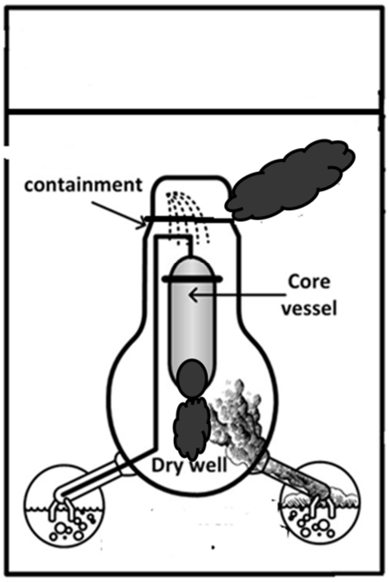
The figure shows the status of the reactor core about 2–3 hours after the start of the emergency. You can see that about 20 tons of the core flowed down to the bottom of the vessel.

Source: NUCLEAR REGULATORY COMMISSION, Perspectives on Reactor Safety; HASKIN, F.E., CAMP, A.L., HODGE, S.A., POWERS, D.A., Rep. NUREG/CR-6042, SAND93-0971, Rev. 2, USNRC, Washington, DC (2002).

Fukushima emergency 2011

Elapsed time (hours) after tsunami hit (loss of AC and DC)			
Unit	**Loss of core cooling (loss of SF)**	**Melt**	**Release**
1	0	≈ 2	24
2	≈ 70	≈ 74	≈ 80
3	≈ 36	≈ 42	?

2–6 hrs



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This shows the approximate elapsed time of various events following the start of the emergency of Fukushima. The emergency started when the tsunami caused the loss of all AC/DC power on-site. The loss of all AC/DC power meant that the plant operators immediately lost the ability to provide cooling water to the core in Unit 1 and ultimately to Units 2 and 3. The operators recognized the severity of the emergency and notified off-site officials within about an hour. Note that core melt occurred 2–6 hours after the loss of core cooling and releases started between several hours and a day after core melt.

Actual releases

	Characteristics	Release % volatiles (I – Cs) –
Fukushima	Long duration release with numerous wind shifts	≈ 5% ?
Chernobyl		≈ 30-50%

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Questions Module 6-4:

You are the off-site decision maker near a nuclear power plant (NPP). The NPP notifies you that they have lost the capability to keep the core covered with water and cooled.

1. Is the public at risk?
2. When will a major release occur?
3. Should an independent assessment of the reactor conditions at the NPP be made?
4. Should you perform a dose projection?
5. Should you meet with local officials to decide on the actions to be taken?
6. How long do you have to take effective protective actions?

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Ask participants to answer these questions.

Answers Module 6-4:

1. Is the public at risk? **Yes!**
2. When will a release occur? **We do not know – possibly as soon as the core is damaged, but probability not before several hours**
3. Should an independent assessment of the reactor conditions at the NPP be made? **No. There is no time and only the control room staff of the plant can know what is going on**

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1. Is the public at risk? Yes, because this will result in damage to fuel in the core.
2. When will a major release occur? We do not know. But a major release is possible as soon as the core is damaged.
3. Should an independent assessment of the reactor conditions at the NPP be made? No. There is no time and it is impossible to make such an assessment. Only the control room staff of the plant can know what is going on**.**

Answer Module 6-4

4. Should you perform a dose projection? **No. It is impossible to make meaningful dose projections because the timing and size of the release are unknown**
5. Should you meet with local officials to decide on the actions to be taken? **No. Actions need to be implemented promptly based on preparations made in advance**
6. How long do you have to take effective protective actions? **Action may need to be started within an hour after declaration of an emergency in the worst case**

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4. Should you perform a dose projection? No. It is impossible to make a meaningful dose projections because the timing and size of the release are unknown.
5. Should you meet with local officials to decide on the actions to be taken? No. There is no time – actions should be predetermined and implemented when a General Emergency is declared.
6. How long do you have to take effective protective actions? Action may need to be started within one hour after declaration of an emergency in the worst case.

Environmental Characteristics of a Release during a Severe Emergency at a Nuclear Power Plant

Module 7

Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

IAEA

International Atomic Energy Agency

Lecture:
L-07 Environmental Characteristics of a Release during a Severe Emergency at a Nuclear Power Plant

Purpose:
To explain the environmental characteristics of a release from an emergency at a reactor or spent fuel pool of a nuclear power plant, and how it impacts off-site decision making to ensure the effective protection of the public.

Learning objectives:
On completion of this lecture participants will be able to:

- Describe the main characteristics and likely unknown factors for a release following a severe emergency.
- Explain why monitoring the plume can be very difficult and why there will be large variations in the monitoring results.
- Explain the impact of changes in wind direction and the implications for protective actions.
- Explain why dose projection may not be the basis for implementing protective and other response actions early in an emergency.
- State how dose rate and contamination varies with distance from the plant.
- Describe the types of monitoring and sample analysis that should be made and when, as well as how long they are likely to take.
- Describe why deposition is so complex and how uncertainties impact decision making.

Author: Phillip VILAR WELTER **Reviewers:** Tom MCKENNA, Brian DODD and Eduardo LURASCHI

Duration: 2 hours

Questions Module 7-1

- Is it possible to predict the consequences of a major release of fission products from an NPP?
- What areas around an NPP could be affected by a major release?
- How reliable are models? Are deposition patterns predictable?
- When and for what purpose do you perform environmental monitoring and sampling?
- How long will it take to get useful monitoring results?
- Should initial protective actions be based on monitoring results?

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Is it possible to predict the consequences of a major release of fission products from an NPP?
No, the number of uncertainties is too high.

What areas around an NPP could be affected by a major release?
All areas around an NPP could be affected. After the Chernobyl accident, food restrictions were warranted up to 2000 km from the plant.

How reliable are models? Are deposition patterns predictable?
Deposition patterns are not predictable, do not rely on models to implement protective actions.

When and for what purpose do you perform environmental monitoring and sampling?
After initial protective actions and other response actions, such as evacuation and food restrictions, have been implemented based on plant conditions. The main purpose of monitoring is to confirm initial protective actions and to support long term decision making.

How long will it take to get useful monitoring results?
Very simple monitoring results may not be available for days after the release, too long for the implementation of initial protective actions.

Should initial protective actions be based on monitoring results?
Plant conditions should be the basis for initial urgent protective actions close to the plant. Once the release has started, monitoring can be used in those areas were protective actions have not been implemented based on plant conditions.

Learning objectives

Upon completing this module participants will be able to:

- Describe the main characteristics and likely unknown factors for a release following a severe emergency
- Explain why monitoring the plume can be very difficult and why there will be large variations in the monitoring results
- Explain the impact of changes in wind direction and the implications for protective actions
- Explain why dose projection models may NOT be the basis for implementing protective and other response actions early in an emergency

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Learning objectives

On completing this module participants will be able to:

- State how dose rate and contamination varies with distance from the plant
- Describe what kind of monitoring and sampling should be implemented where and when, as well as how long they are likely to take
- Describe why deposition patterns are so complex and how uncertainties impact decision making

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Main ideas of this module

1. Past emergencies have shown that it is **NOT POSSIBLE** to predict the consequences of a major nuclear power plant emergency in detail, because it would require being able to:

- predict the properties of the release (e.g. radionuclide mixture, timing, size, effective height, etc.)
- predict the movement of the radioactive material in the atmosphere (transport and deposition)
- predict the dose and health effects (consequences) among the public.

None of these could be predicted accurately during previous emergencies

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This module will discuss why the detailed prediction of doses to the public during a major emergency is not realistic, and how this fact impacts off-site decision making.

Main ideas of this module

2. Monitoring and sampling will require time and resources that may not be available during the initial phase of an emergency (when protective actions are most urgently required).

3. Despite of limited, incoherent and conflicting data, the offsite decision maker will have to implement protective and other response actions early in the emergency and know how to deal with high variations and uncertainties in the monitoring and sampling results.

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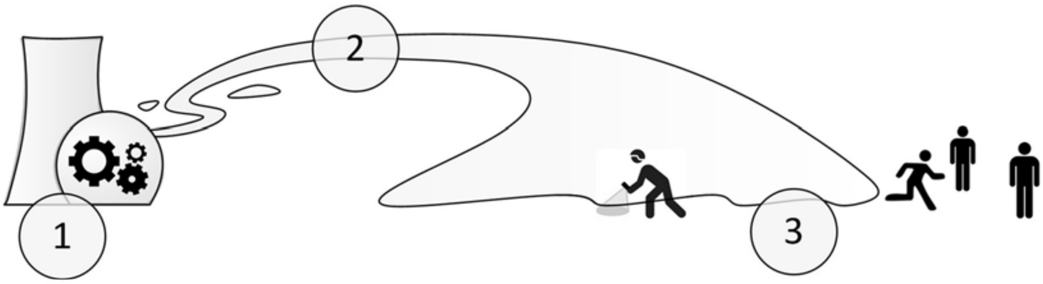
Contents



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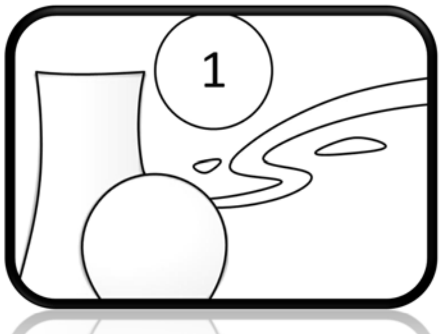
The previous modules addressed severe reactor accidents from the technical perspective of a nuclear power plant. This module discusses the release of radioactive material from the NPP into the environment, focusing on (1) the uncertainties associated with the release, (2) the behaviour of the emitted radioactive plume and (3) the deposition and behaviour of the radionuclides in the environment and the corresponding monitoring and sampling.

In the following modules, the media, economic and physiological impact of a major emergency, the generic and operational criteria, the threats resulting from a fission release and the required protective action strategies will be addressed.

The participant should keep in mind that only the most relevant factors for the implementation of effective off-site response actions and for the support of swift decision making are presented throughout this course.

1. The release



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The first section presents three key ideas regarding the release of radioactive material from a nuclear power plant during a severe emergency.

1.1. The properties (such as composition, timing, size or duration) of the release will be unknown

The release most likely will be by an unmonitored pathway

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Studies and experience show that releases to the atmosphere during severe NPP emergencies are unpredictable. They can occur via an unmonitored release route and can begin within minutes. Consequently, plant operators cannot predict with certainty the occurrence of a major release, the magnitude and duration of any such release, or its radiological consequences. However, studies show that taking protective actions based upon the detection of conditions in the facility that might lead to fuel being damaged (e.g. station blackout or loss of control room), followed by prompt monitoring and further protective actions after a release will greatly reduce the off-site consequences [1,2,3].

The timing of the release is especially important in relation to the possible consequences of an accident. Early releases are much more likely to result in early deaths or severe health effects off-site than late releases. A late release allows more time for the reduction mechanisms to remove the most dangerous fission products and also allows more time to take protective actions.

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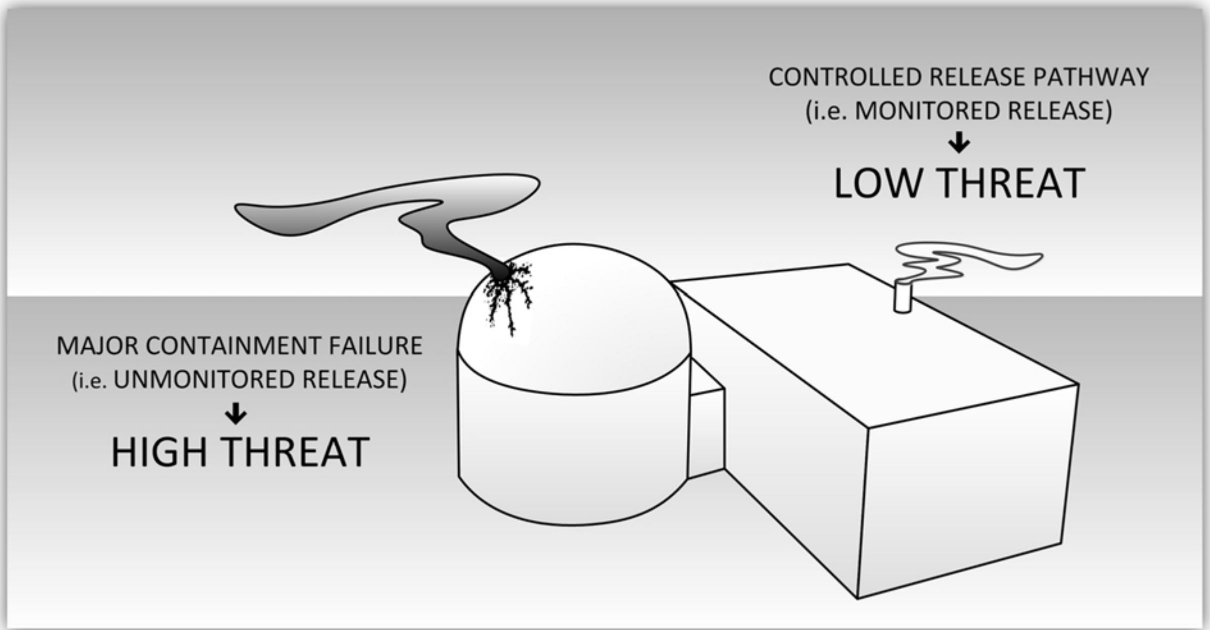
[1] U.S. NUCLEAR REGULATORY COMMISSION, Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants, NUREG-1150, USNRC, Washington, DC (1990).

[2] U.S. NUCLEAR REGULATORY COMMISSION, Perspectives on Reactor Safety, NUREG/CR-6042, SAND93-0971, Rev. 2, USNRC, Washington, DC (2002).

[3] U.S. NUCLEAR REGULATORY COMMISSION, Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants, USNRC, Washington, DC (2001).

1.1. Unmonitored pathway



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The timing, duration and size of a containment failure or leak is unpredictable. Large releases will, in most cases, result from major failures of the containment that will most likely take place at an unmonitored point. Releases from locations that are measurable in the control room are probably of little threat off-site. Since the duration and amount of a serious release will be unknown it may be impossible to project off-site doses with sufficient accuracy to be a basis for taking effective actions to protect the public.

1.2. Expect a long duration low level release that could last for weeks

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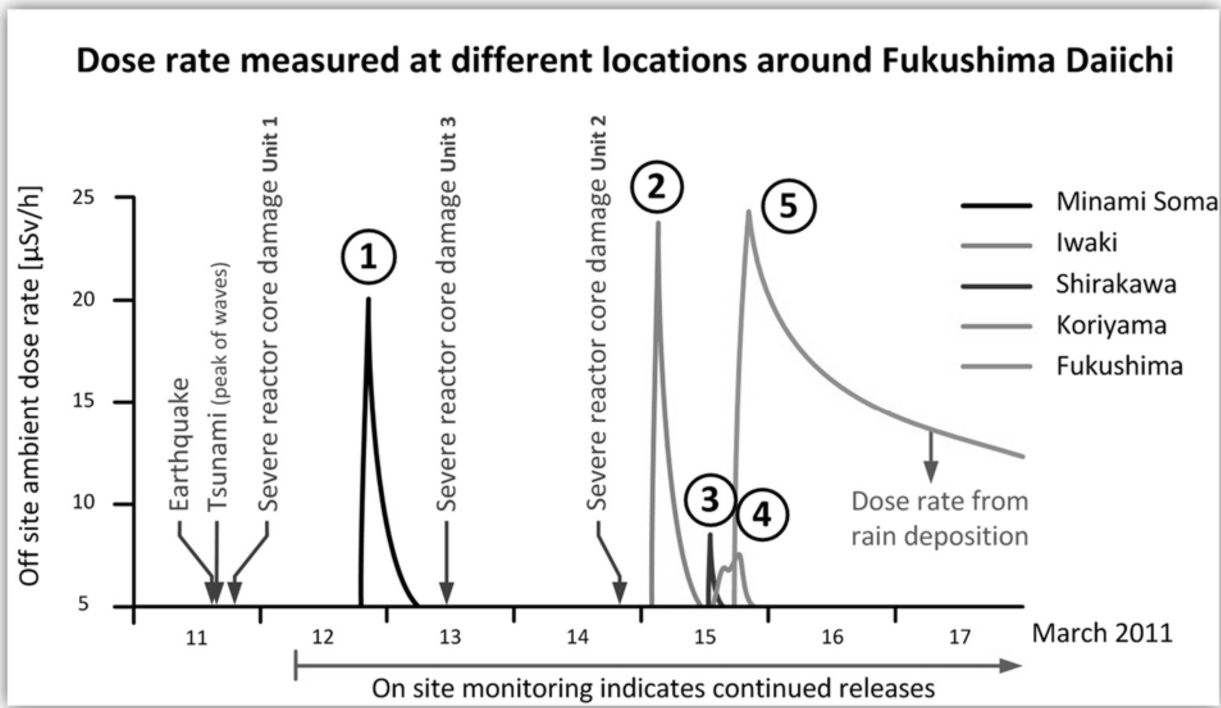
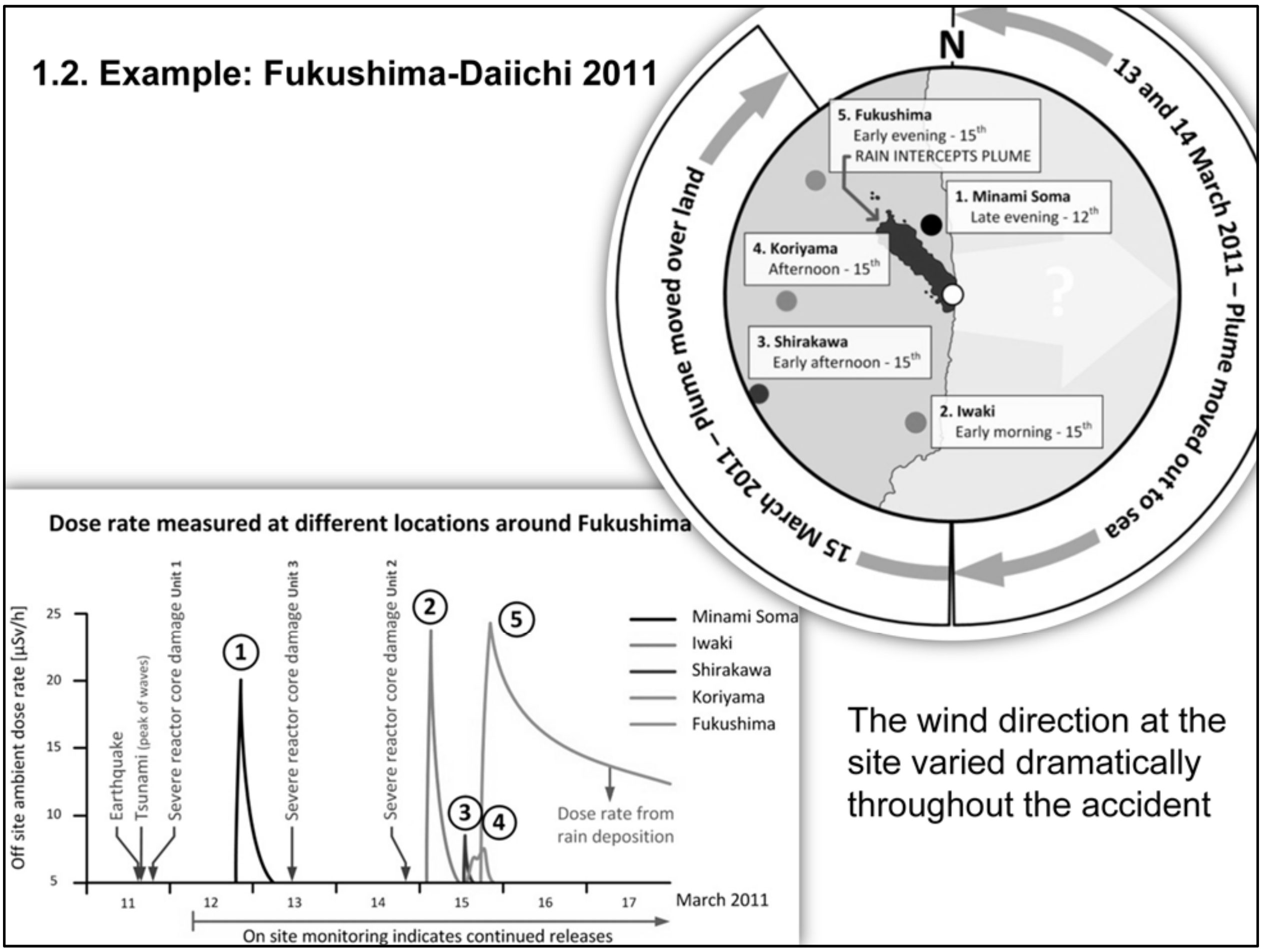
1.2. Long duration release



The release duration of a major NPP accident is unpredictable, but it will likely follow the same pattern as the one observed at the Fukushima accident.

Starting on 12 March 2011, variations in the dose rates near the site of the Fukushima Daiichi nuclear power plant indicated that there was an ongoing release to the atmosphere, but the size of the release was unknown. The figure shows the dose rate measured at the towns around the Fukushima Daiichi plant. The sharp peaks in the dose rate (1, 2, 3) indicate that the plume passed over the monitoring location without any significant deposition of radioactive material. The sharp increase in the dose rate at Fukushima City (5), followed by a gradual decrease in the dose rate, indicates that radioactive material was deposited when the plume was intercepted by rain.

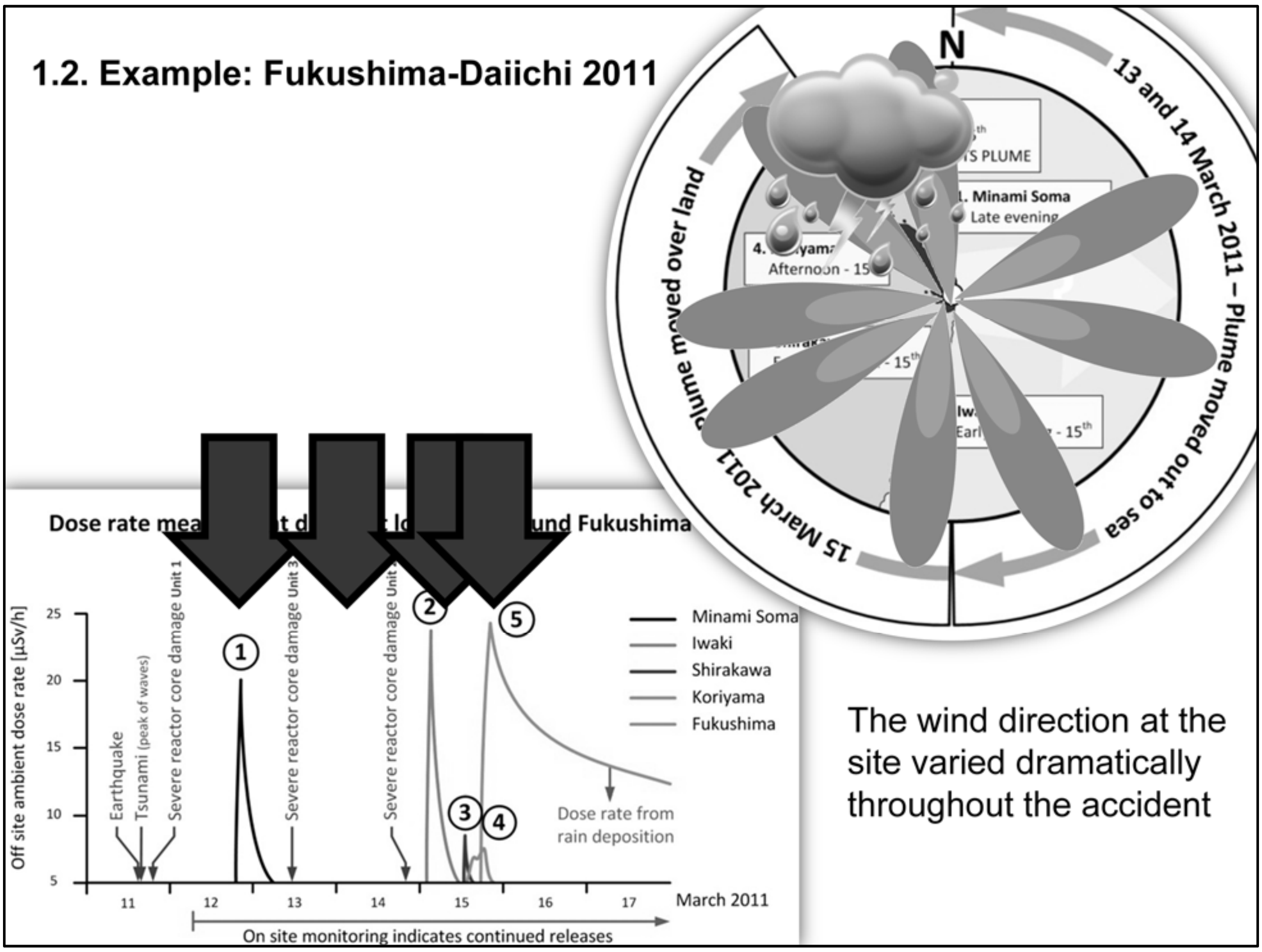


Starting on 12 March 2011, variations in the dose rates near the site of the Fukushima Daiichi plant indicated that there was an ongoing release to the atmosphere, but the size of the release was unknown. This slide illustrates the complexity of the resulting plume (please be aware that this represents current knowledge that may be refined later on):

- The upper figure (circle) shows the location of the plume based on monitoring at specific towns. The plume was detectable over land in the late evening of 12 March 2011 and, as a result of a shift in the wind direction, moved out over the sea for the next two days and moved back over land on the early morning of 15 March. On 15 March, the direction of the release continuously shifted from southwards through westwards to northwards, the release passing over Shirakawa in the early afternoon and afterwards over Koriyama until it reached Fukushima City in the evening. There it was intercepted by rain, which resulted in a significant deposition of radioactive material onto the ground.

- The lower part of the figure shows the dose rate measured at the towns around the Fukushima Daiichi plant. The sharp peaks in the dose rate at locations 1 to 4 indicate that the plume passed over the monitoring location without any significant deposition of radioactive material. The sharp increase in the dose rate at Fukushima City (location 5), followed by a gradual decrease in the dose rate, indicate that radioactive material was deposited when the plume was intercepted by rain.

All areas around the Fukushima Daiichi plant could have been affected. If this had been a nuclear power plant located inland, deposition on land could have occurred in all directions. There was no clear downwind direction during the releases from the accident at the Fukushima Daiichi nuclear power plant because the wind direction was continually changing. These are important lessons to be emphasized from the Fukushima accident. The experience in these two emergencies is consistent with the results of severe accident analysis, which indicate that protective actions need to be implemented in all directions, since the timing, direction and duration of a release are not predictable.



This simple animation shows the possible behaviour of the plume during the Fukushima emergency.

1.3. The isotopic mixture of the release will change over time

due to changing core damage states, release route conditions, decay and ingrowth

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We do not understand the physics and chemistry well enough to predict the source term with accuracy. Any estimates of the release made during a major accident will necessarily be **very** uncertain. We are still not completely certain about the size of the release from Chernobyl.

1.3. Unknown isotopic mixture

The detailed isotopic mixture will be unknown and changing, and there will be a need to act before it is known.

IAEA tools take this (and other) uncertainties into account

Make use of them

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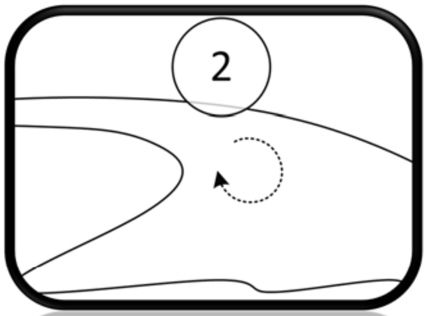
A major release from a reactor will be composed of a complex mixture of fission products, each having its own characteristics and associated risk. For example, early in a reactor accident Iodine-131 is considered to be the primary cause of health effects. Cesium-137 is the primary source of long term dose from material deposited by the release. Therefore it is important to know the isotopic composition (mix) of the release to accurately project consequences. Determining the isotopic mixture of the plume or deposition is time consuming and will require experts and high-tech equipment. Therefore we must be prepared to act before the mixture is known!

The IAEA generic procedures provide tools for assessment of environmental data before the mix is known. They are based on default estimates of the release mixture. The default used depends on the core damage state and amount of reduction afforded by the release route. Later the actual mixture, as determined by measurements, can be used to revise these criteria if appropriate.

2. Plume behaviour



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This section presents five main properties of the behaviour of the plume in the environment, relevant for off-site decision making.

2.1. Monitoring the plume is difficult

It may be very narrow and difficult to find.
If found, there will be large variations in the measured dose rates

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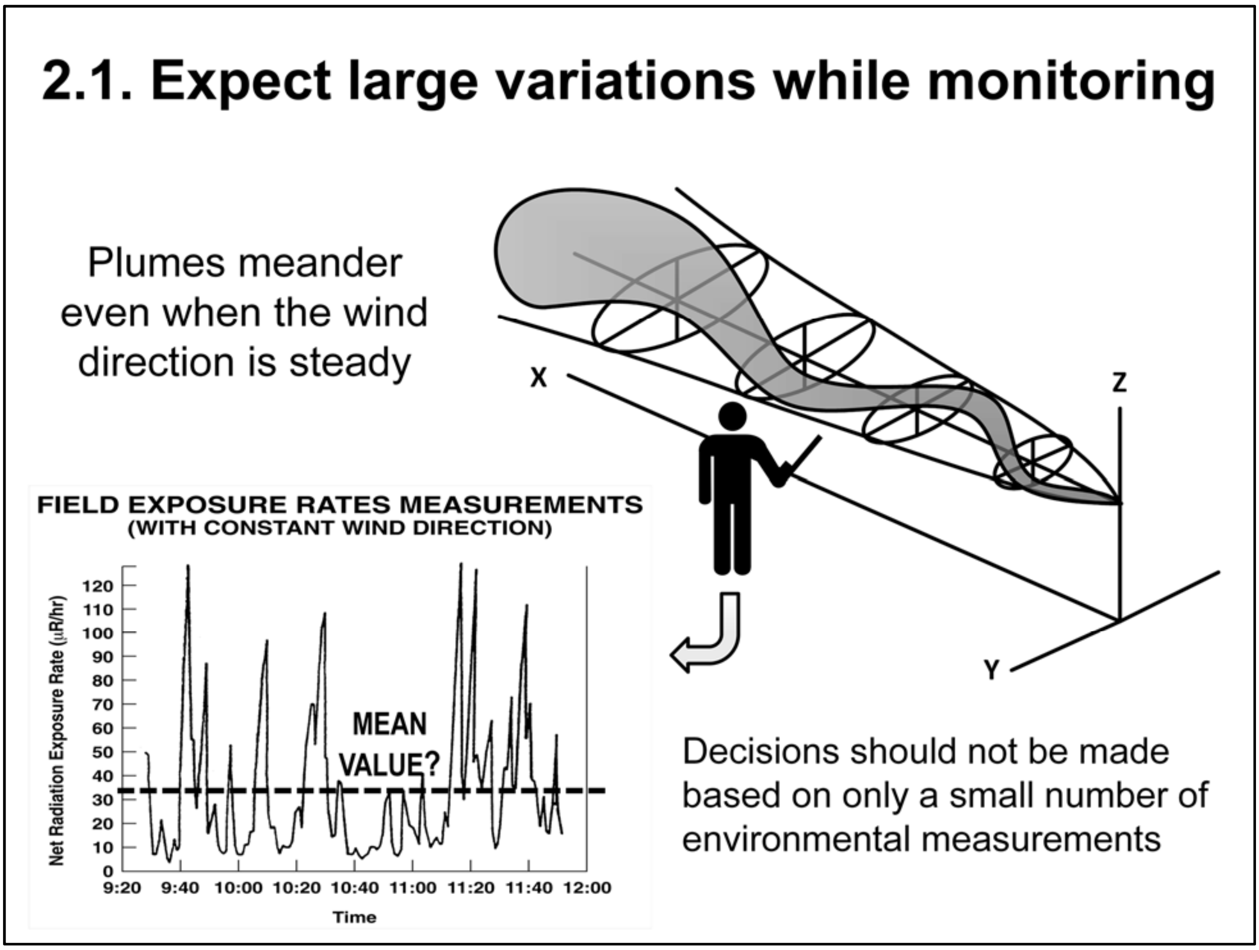

Plumes are narrow and meander even when the wind direction is steady. This can result in considerable variation in the instantaneous dose rate, as shown in the graph in this slide. The graph shows the instantaneous gamma dose rate from a plume as measured by a stationary instrument at about 1000 m from a release point during a field experiment. The wind direction was constant in the direction of the monitor. Note the considerable variation in reading caused by the narrow plume as it moves back and forth over the monitor. This shows that measurements made by a stationary monitor may not provide an accurate reading of the plume dose.

Due to this movement the average dose rate measured along the plume trajectory will be lower than that measured at the centre of the plume.

A limited number of environmental measurements will not be sufficient to characterize the plume and should not be trusted. The same is applicable to individual stationary monitoring points (high fluctuations) and to a small number of monitoring teams.

2.2. ALL DIRECTIONS around the NPP will be affected by the release

due to the numerous wind shifts expected during a release

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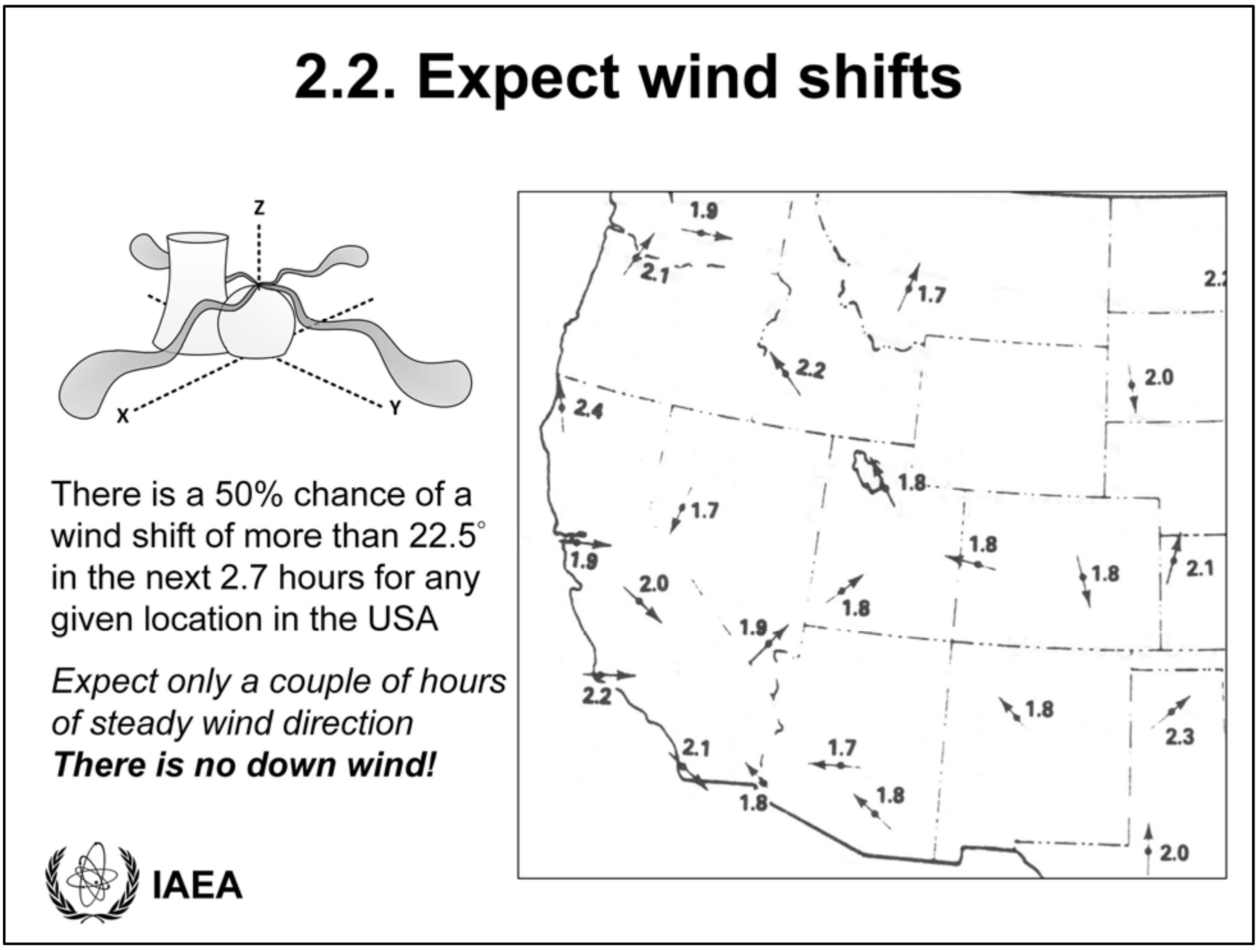
The release will most likely will occur over many hours or days during which there will be numerous wind shifts resulting in elevated doses and contamination levels in ALL DIRECTIONS around the plant. There will be no clear downwind!

As a result it will be impossible to predict all the areas that will be affected by the accident. In fact, most accidents have (or could have) impacted all directions near the plant, as can be seen for the Windscale, Three Mile Island and Chernobyl accidents. If the Fukushima Daiichi plant had been located inland, deposition would have been monitored in all directions. There was no clear downwind direction during the releases from the accident at the Fukushima Daiichi plant because the wind direction was continually changing.

This is an important lesson to be emphasized; urgent protective actions and other response actions that are critical for preventing serious health effects need to be implemented in all directions around the plant, since the timing, direction and duration of a release are not predictable.



The figure shows the probabilities of hours of wind persistence in 22.5° sectors as obtained from an analysis of National Weather Station meteorological data across the USA [4]. This study concludes that there is an even chance of a significant wind shift occurring in the next two to four hours at any given location in the USA, and that the lower the wind speed the lower the direction persistence will be. This means that during a major release variations of the wind direction should be expected, making any accurate prediction of the plume movement virtually impossible.

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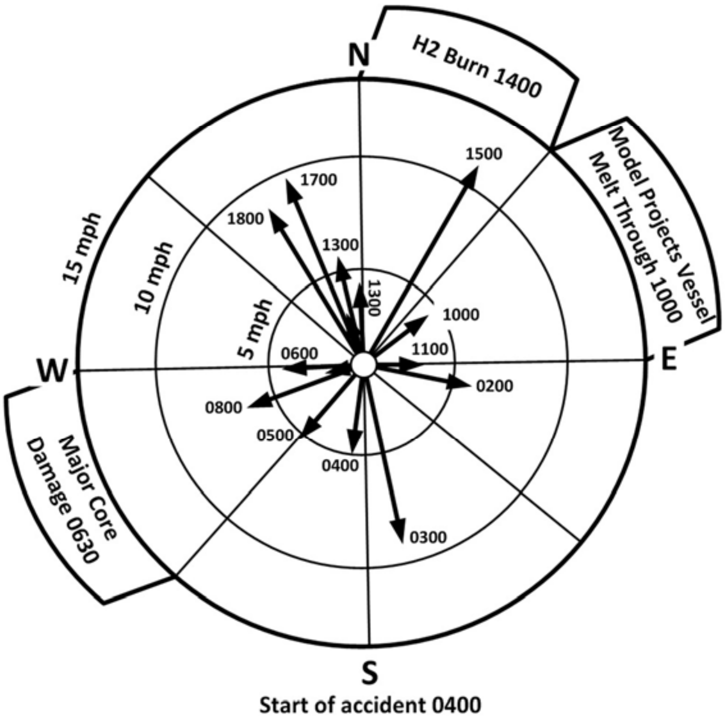
[4] DAVIS, E.A., YOSHIOKA, G.A., MARGULIES, T.S., A Systems Study of Regional Air Transport Modeling For Emergency Response Applications, Report JHU-T-22, John Hopkins University Applied Physics Laboratory, Laurel, MD (1982).

2.2. Example: Three Mile Island Accident 1979



The wind direction* at the site varied dramatically throughout the accident

Accident state	Wind direction*
Start of the accident	S
Major core damage	W
Vessel melt through	NW
H_2 burn	NE
Later on	E

All directions around the NPP would have been affected!

This slide represents the hourly wind vectors* as measured by the site meteorological systems during the first day of the Three Mile Island accident [5] and moments at which a major release to the environment would have been possible. It is evident that wind direction around the site varied dramatically throughout the 12 hour period. If an evacuation had been initiated based on the wind direction, the wrong people would have been told to evacuate.

It is evident from this example that precautionary and early protective actions have to be implemented in all directions around the NPP.

* Wind direction in this case is the direction toward which the wind blows.

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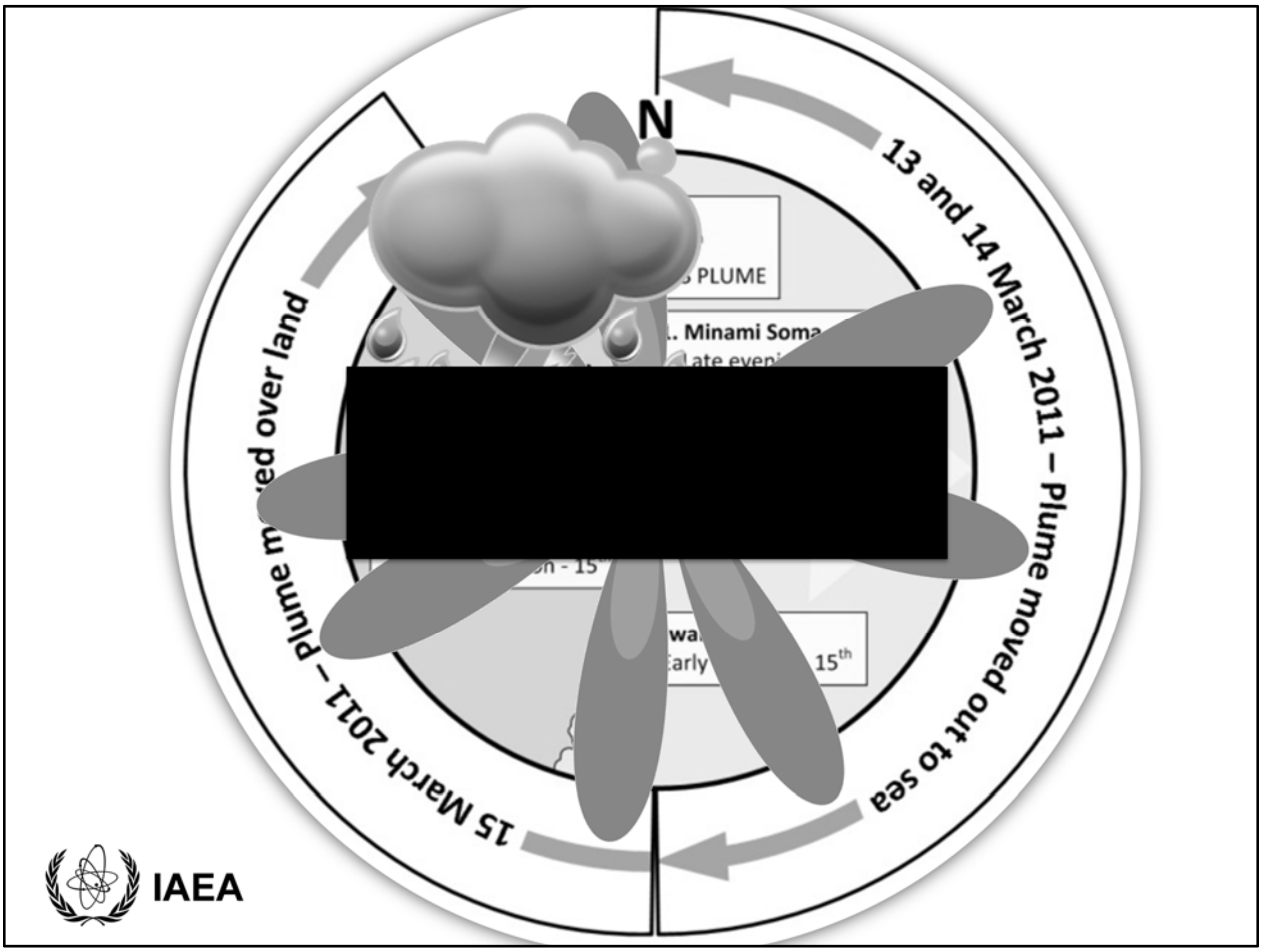
[5] U.S. NUCLEAR REGULATORY COMISSION, Pilot Program: NRC Severe Reactor Accident Incident Response Training Manual, Severe Reactor Accident Overview, USNRC, Washington, DC (1987) p. 46.



As discussed before the wind direction at the Fukushima Daiichi site also varied dramatically throughout the accident.
See Section 1.2. for an explanation of this animation.

2.3. Relying on the wind direction at the plant is insufficient

for the effective implementation of protective actions

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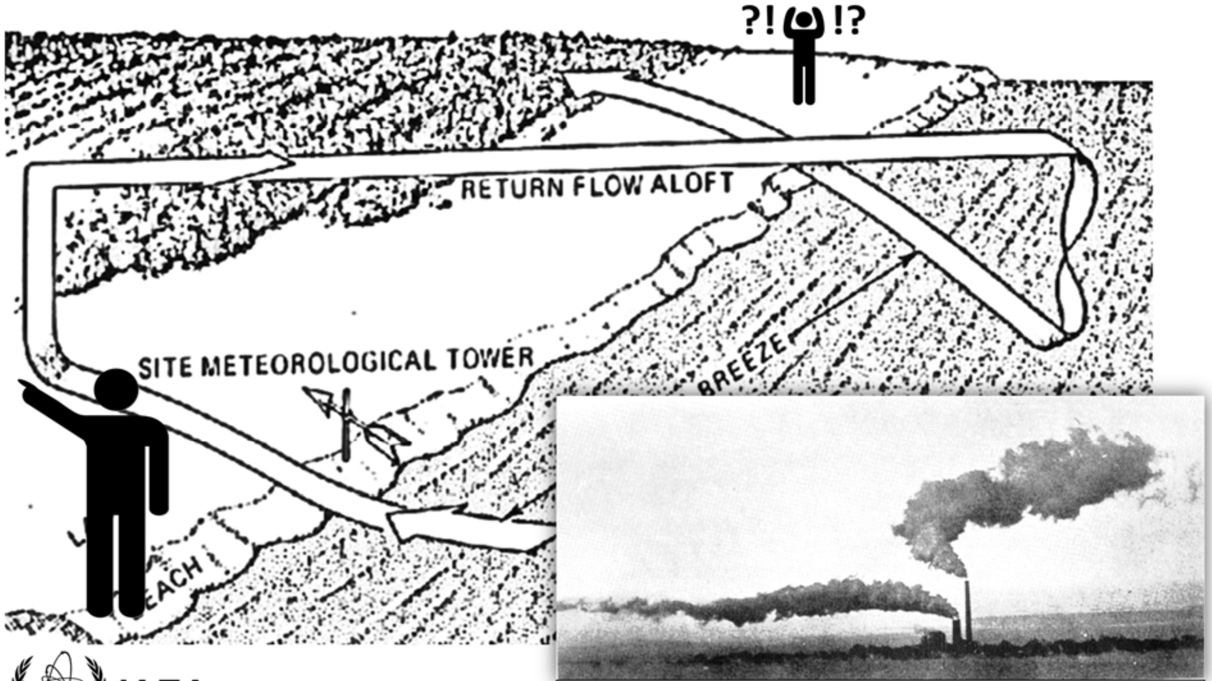
The wind direction may be useful to prioritize the implementation of urgent protective actions, or to send out monitoring teams, but in the long term all close areas around the plant will warrant urgent protective actions.

2.3. Local wind directions cannot be used to predict the plume movement



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Importance of the effective release height.

Numerous topological features, such as hills, river valleys, water masses, thermal islands (cities) and coasts, will significantly alter the stability and the direction of wind, i.e. atmospheric transport in general [6]. As a result, the wind direction at the site may not be a good indicator of plume location off-site. This illustration [7] shows a common effect seen on the coast, called a “sea breeze.” Cool air masses coming from the sea go inland, are heated over the land surface, rise, and return seaward. Once over water, they cool down and the cycle occurs again. The result is that the plume, which appears to be going inland, performs a spiral movement and reappears further down the coast.

Nuclear power plants are often built near bodies of water or in valleys (near rivers), which result in very complex local wind patterns. The local wind direction may be of little help in determining plume movement in such complex cases. Therefore, to be sure you know where the plume is, you must monitor in all directions around the site.

The lower image of the stacks stresses the importance of the effective height of the release. In this particular case the plume from the lower chimney is transported by a low-level sea breeze; that from the taller chimney moves in an opposite direction. Being a fundamental variable for the prediction of plume dynamics, it is not possible to accurately determine the effective height of the release, due to the uncertainties related to parameters such as the release point and the release temperature.

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[6] U.S. NUCLEAR REGULATORY COMISSION, Dose Calculations for Severe LWR Accident Scenarios, NUREG-1062, USNRC, Washington, DC (1984).

[7] U.S. NUCLEAR REGULATORY COMISSION, Pilot Program: NRC Severe Reactor Accident Incident Response Training Manual, Severe Reactor Accident Overview, USNRC, Washington, DC (1987) p. 108.

2.4. Dose projection models should NOT be the basis for the implementation of urgent protective actions early on in the emergency and close to the NPP

Projecting the movement of the plume close to the plant is virtually impossible

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Severe releases from a reactor core or spent fuel pool warranting protective actions off the site are unpredictable. They can occur via an unmonitored release route and can begin within minutes. The control room operators cannot predict the timing of such a release, or the magnitude, composition, effective height and duration of any such release. In addition, releases warranting protective actions off the site could occur over several days resulting in very complex deposition patterns off-site. Consequently, dose projection models cannot be used for making decisions on urgent protective actions and other urgent response actions, especially for decisions that need to be taken before or shortly after the release in order to be most effective.

The above points are illustrated by the accidents at the Chernobyl and Fukushima Daiichi plants. For these accidents, the size and timing of the releases were not predicted, releases occurred over a period of days to weeks and the release rates and composition could not be assessed by the control room operators. In both cases, the release rates and mixture of the radioactive material had to be estimated based on dose rate and other environmental data following the release [8, 9]. Furthermore, the estimates continued to be revised more than two years after the accidents, as more data became available.

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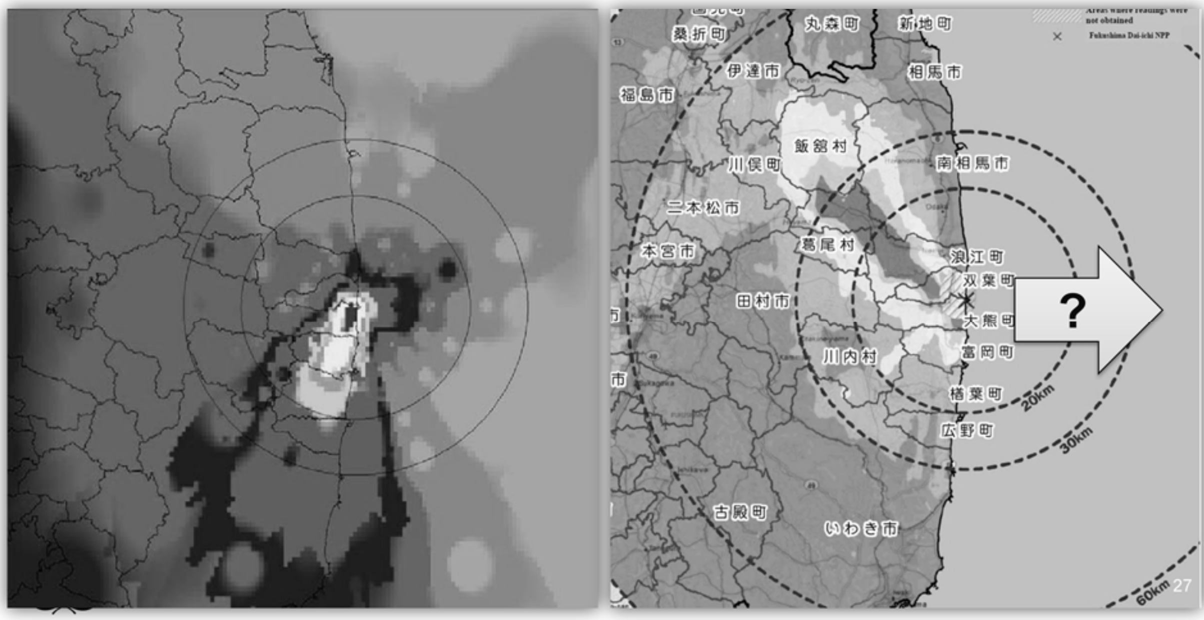
[8] TOKYO ELECTRICAL POWER COMPANY, Press release on the Estimated Amount of Radioactive Materials Released into the Air and the Ocean Caused by Fukushima Daiichi Nuclear Power Station Accident Due to the Tohoku-Chihou-Taiheiyou-Oki Earthquake (as of May 2012), (2012).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, The International Chernobyl Project: Technical Report, IAEA, Vienna (1991).

2.4. Dose projection models: Fukushima emergency

Model
(after the release, without feedback)

Actual deposition



This slide shows the calculated Cs-137 contamination for a combined release of Units 1, 2 and 3 of the Fukushima NPP (Level 3 PSA calculation with MELCOR source term) [10] and the monitored air dose rate 1 m above the ground developed by MEXT (Ministry of Education, Culture, Sports, Science and Technology of the Government of Japan) and DOE (U.S. Department of Energy) [11]. It is obvious that the model does not determine the release accurately.

Dose projection models deal with chaotic systems, i.e. systems that are highly sensitive to small changes in their initial conditions (small initial changes yield widely diverging outcomes). Detailed long-term predictions are mathematically impossible, even under the assumption of deterministic and linear behaviour. The fundamental impossibility of predicting the dynamics of chaotic systems in detail has been sufficiently stressed by mathematicians and physicists such as Poincaré, Lorenz, Mandelbrot or Feigenbaum.

The plume movement near the plant can be considerably different from that projected by regional models. On a larger scale, the prediction becomes increasingly easier and models seem to be more effective.

Later on in the course of the emergency, dose projection models might have gathered enough monitoring data to give a relatively accurate projection of the dose distribution.

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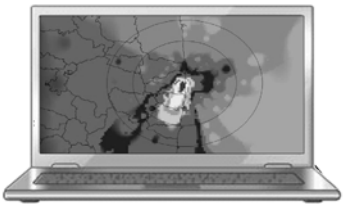
[10] TOSHIMITSU HOMMA, “Radiation protection issues on preparedness and response for a severe nuclear accident: Experiences of the Fukushima accident” (ICRP Symp., International System of Radiological Protection, 24-26 Oct. 2011) Bethesda, MD, USA.

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Status of the Fukushima Daiichi Nuclear Power Plant and related environmental conditions (May 6, 2011) p. 35 (IEC)

2.4. Use of dose projection models

Field of application	Useful?	Reliability
Development of safety plans during the preparedness stage	YES	Rough estimations of the size of the emergency zones and distances
Implementation of urgent protective and other response actions (early on in the emergency)	NO	Unreliable (and confusing to the decision maker). May be used for prioritization of monitoring or protective actions
Extrapolation of monitoring data to project doses (late in the emergency)	YES	Reconstruction of the release based on real monitoring data, but not on source term or other estimations



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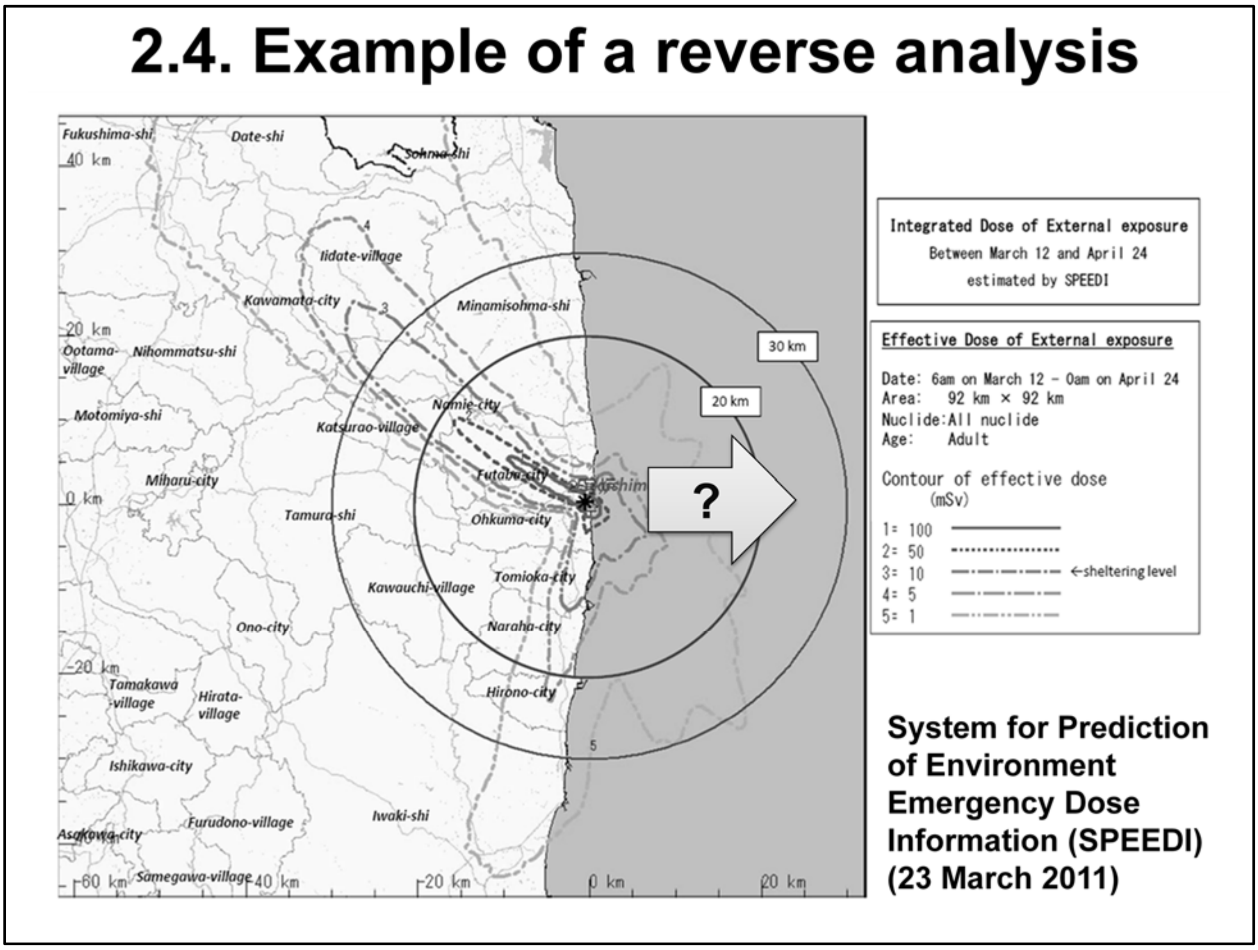
Dose projection models should not be used as a basis for determining initial protective and other response actions during the emergency. Dose projection models only allow rough estimations of the properties of a release. This rough information can be used during the preparedness stage in the development of safety plans (e.g. for the determination of the size of the emergency zones and distances).

Models and projections of wind direction may be useful in determining the areas within the PAZ (precautionary action zone) or UPZ (urgent protective action planning zone) that need to be evacuated first if the population cannot be effectively evacuated in all directions simultaneously. However, ultimately the UPZ may need to be evacuated in all directions due to the wind shifts that could take place during a release or throughout the time period of a potential severe release.

After a release, wind directions and models may be useful in initially directing resources for off-site monitoring and sampling. However, monitoring and sampling need to be conducted in all directions close to the nuclear power plant and not just in those areas indicated by models. Networks of automated environmental monitoring stations can also be useful in directing monitoring teams and when combined with operational intervention levels (OILs) in identifying areas warranting evacuation, relocation and food restrictions following a release.

Model projections always need to be accompanied with a plain language explanation that stresses that the results are very uncertain and need to be qualified, and that the actual situation can only be assessed on the basis of monitoring results.

In all cases, tools used as a basis for urgent protective actions must be integrated into decision making systems in such a way that their use will not delay the implementation of urgent protective actions, especially for making decisions concerning those that need to be taken before or shortly after the release to be most effective.



After the initial phase of an emergency, and once sufficient monitoring and sampling data are available, dose projection models and other computer-based tools may also be used to assess environmental monitoring data in order to develop deposition and dose maps for decision making.

An example of a reconstruction of the release based on monitoring data is shown in this slide. The System for Prediction of Environment Emergency Dose Information (SPEEDI) is a computer based decision support system for dose assessments. The calculations were performed based on environmental monitoring data taken from 16 March onwards. The SPEEDI data were made publicly available by the Nuclear Regulation Authority of Japan on 23 March [12].

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[12] NUCLEAR REGULATION AUTHORITY OF JAPAN, Press release, posted at http://www.nsr.go.jp/archive/nsc/NSCenglish/geje/2011_0425_press.pdf

2.5. Response actions close to the NPP have the highest priority

the radiological risk will be high close to the plant, but it will fall off rapidly with increasing distance

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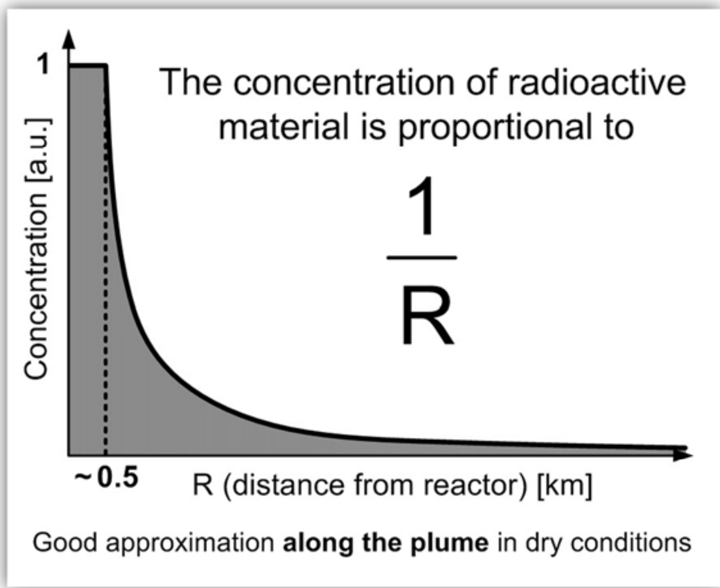
This Section provides a simple but powerful tool during the response to an emergency.

2.5. Concentration vs. distance (rule of thumb)



SIMPLE and therefore powerful tool during the response to an emergency!

Useful even with rain because this rule describes the <u>potential</u> for deposition

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This rule can be used to roughly estimate the ground deposition, dose rate, dose, food concentration…, i.e. all quantities that are proportional to the concentration

This graph shows a very simple approximation to be used as a "rule of thumb" for the projected concentration of radioactive material vs. the distance from the plant. Note that for the sorts of distances we are most interested in, the concentration falls off like 1/R to a good approximation under average dry meteorological conditions and Pasquill D stability. For distances smaller than approximately 0.5 km building wake dominates and the concentration remains fairly constant.

However, due to complex meteorological phenomena the expected deposition pattern will be very complex. This rule of thumb is also useful for more realistic meteorological phenomena because it describes the <u>potential</u> for the deposition of radioactive material.

This rule of thumb should be regarded as a simple but powerful tool during the response to an emergency that can also be used to roughly estimate the ground deposition, dose rate, dose, food concentration…, i.e. all quantities that are proportional to the concentration.

2.5. Example

Projected whole body dose (along the plume) vs. distance, for a standard PWR accident assuming dry meteorological conditions

Supported by the experience gathered in previous emergencies

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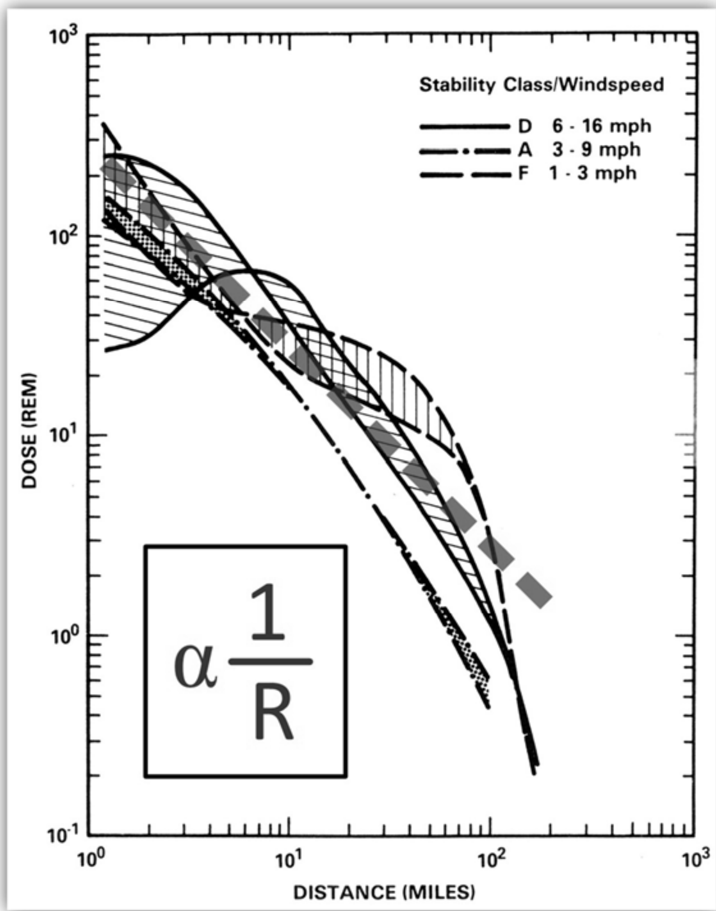

The previous rule of thumb is supported by the analysis performed in [13] and by first hand experience during past emergencies. The graph shows the projected whole body dose vs. the distance for a standard PWR accident. This approximation is valid for several meteorological stability classes and wind speeds, as shown in [13].

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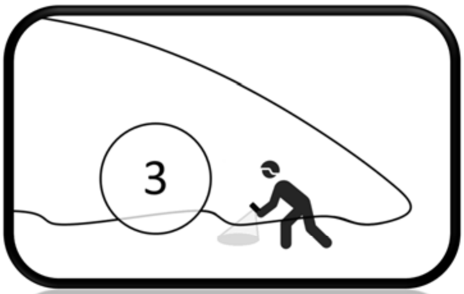
[13] U.S. NUCLEAR REGULATORY COMISSION, Dose calculations for severe LWR accident scenarios, NUREG-1062, USNRC, Washington, DC (1984) p. 37.

3. Environmental monitoring and sampling as a basis for decision making



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3.1. The general aim of monitoring

- Confirmation of initial protective actions
- Long term decision making

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Environmental radiological monitoring is a key element for the management of nuclear emergencies, especially in cases with significant radiological releases [14].

As stated before, the main objective of this course is to support decision makers in the implementation of effective emergency responses. In the context of emergency response, we can say that the general aim of monitoring is to assist the decision making process, by confirming protective actions taken based on plant conditions, or determining **whether** protective actions should be applied in the long run, and if so, **when** and **where** they should be applied.

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[14] IAEA MISSION REPORT, IAEA International Fact Finding Expert Mission of the Fukushima Dai-Ichi NPP Accident following the Great East Japan Earthquake and Tsunami (2011).

3.2. Basic monitoring quantities

What	Why	When
Dose rate [mSv/h]	• Easy to measure with simple instruments and little training • Determines where evacuation or relocation is necessary • Determines where food restrictions are required	Immediately (initial decision)
Isotope concentration [Bq/m³ or Bq/kg or Bq/l]	Determines where food restrictions have to be kept or expanded.	As soon as reasonably possible (for the confirmation of initial actions)

Virtually ALL urgent and early decisions based on environmental monitoring and sampling are based on the dose rate

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Gamma dose rate measurements are the most important environmental measurements made early in an accident. They are easy to measure with simple instruments, by teams with only minimal training. Gamma dose rate measurements can answer the most important questions of indicating where deterministic health effects are possible and where urgent protective actions, such as evacuation, sheltering, thyroid blocking or relocation, are warranted. The dose rate is a measure of the energy deposited by radiation in a target, defined over any unit of time (usually minutes, hours or days). Frequent units are Sv (sieverts), rem (roentgen equivalent man), Gy (gray) and rad (radiation absorbed dose) over any any unit of time [15].

The isotope concentration is usually determined by measuring the activity of the sample, i.e. the number of nuclear transformations per second that occur in the sample. The SI unit of activity is the reciprocal second (s^{-1}), termed the becquerel (Bq) [15]. It is used to determine where food restrictions have to be kept or expanded.

One of the problems inherent in reporting measurements is the possible confusion between "old units" and SI units. Units should be consistent with the instruments used. In cases where instruments are used with both systems of units, it is crucial to be highly aware of the problem. Drills in conversion between units should be performed regularly.

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[15] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safety Glossary – Terminology Used in Nuclear Safety and Radiation Protection, IAEA, Vienna (2007).

3.3. Five problems related to environmental monitoring and sampling you will have to face

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This subsection presents the five main problems you will have to face when dealing with monitoring and sampling during an emergency due to severe conditions at a Nuclear Power Plant.

1st Problem

Monitoring will take time and consume resources

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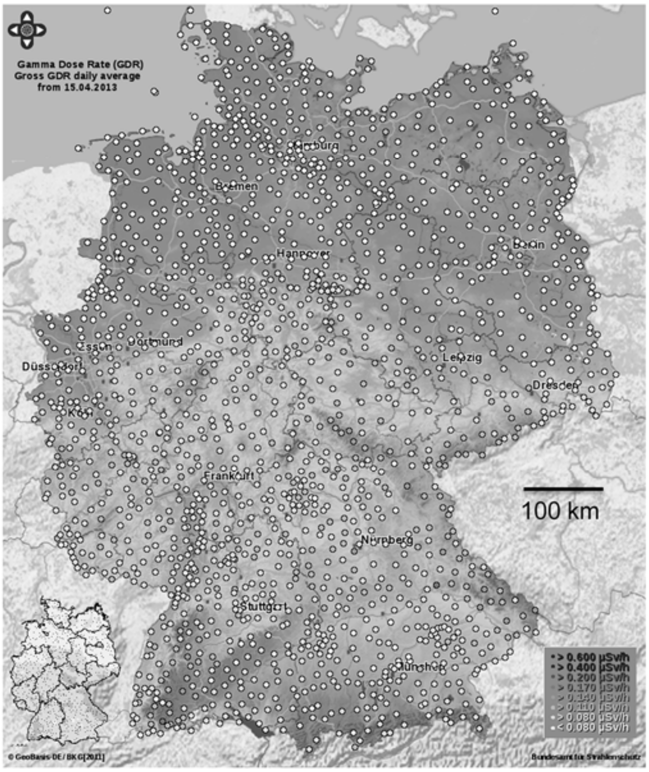
It should be underscored that monitoring will take time and consume resources: it will therefore not be available to support the decision making process in the beginning of the emergency. Initial protective actions should be taken based on plant conditions.

Most of the time is spent for the physical gathering of data. Driving the route, flying a plane, or taking samples will unavoidably take time.

The fastest results: Dense stationary monitoring networks



Infrastructure must be operational and information immediately available to the decision makers

This may not be the case during an emergency

Backup plans must be ready

This map shows the gamma dose rate (GDR) measured at the approximately 1800 stations of the measurement network operated by the German Federal Office for Radiation Protection [16] . Only operational stations are shown here.

These networks can be used to monitor the plume and support dose projection models. For this purpose the infrastructure would have to be operational and the information immediately available to decision makers. However, this may not be the case during an emergency, it is possible that the incident that triggered the emergency will disrupt the correct operation of these networks. Backup plans (such as described in this workshop) should be ready for such an event.

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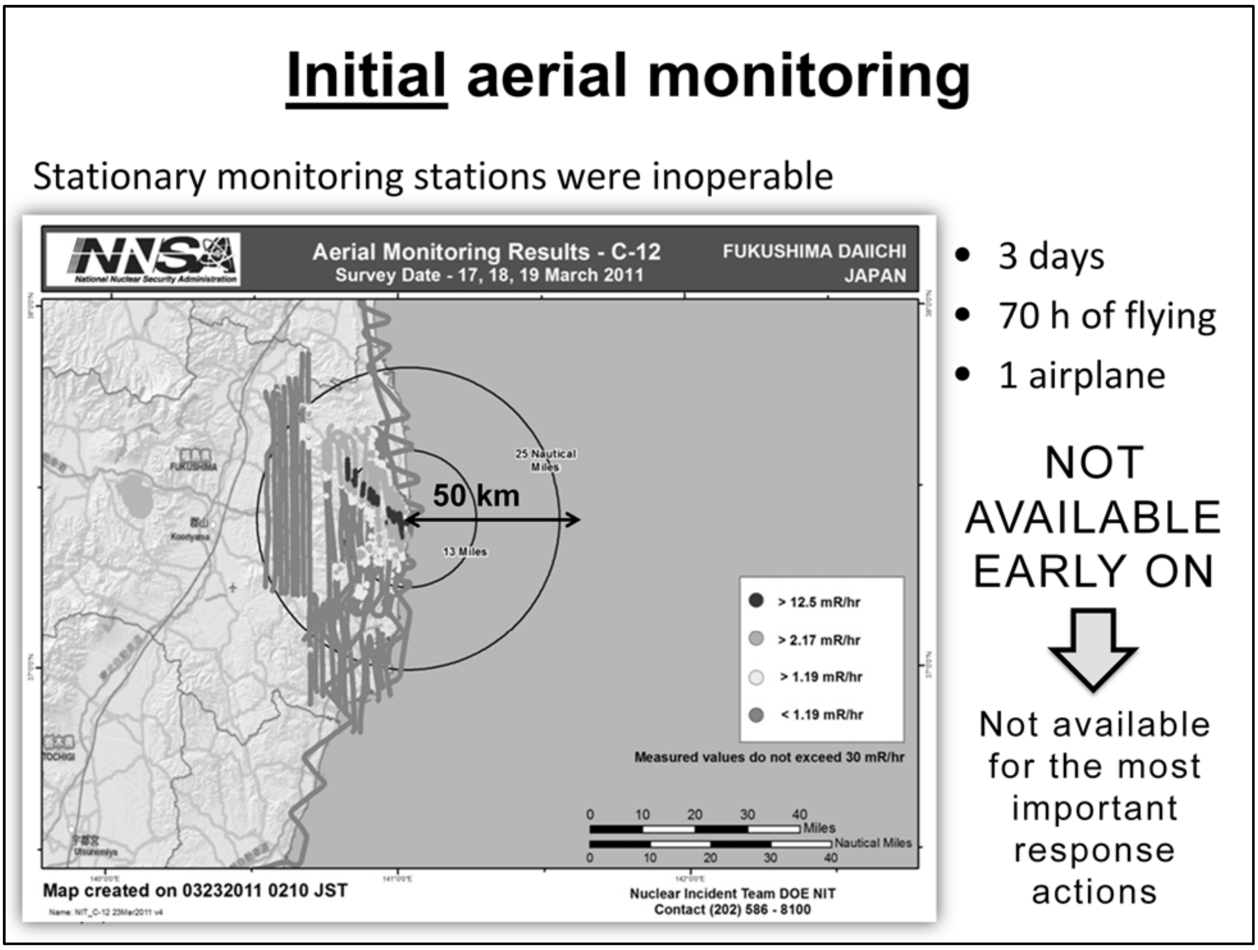
[16] GERMAN FEDERAL OFFICE FOR RADIATION PROTECTION, posted at http://odlinfo.bfs.de/index.php?lang=EN



This air dose rate map [17] was developed in three days and required 70 hours of flying (air dose rate at 1 m above ground level by DOE). The image gives a rough idea about the deposition pattern after the Fukushima Daiichi accident. It must be stressed that this kind of information will NOT BE AVAILABLE in the first hours or days of an emergency where the implementation of urgent protective and other response actions is essential for the well-being of the public.

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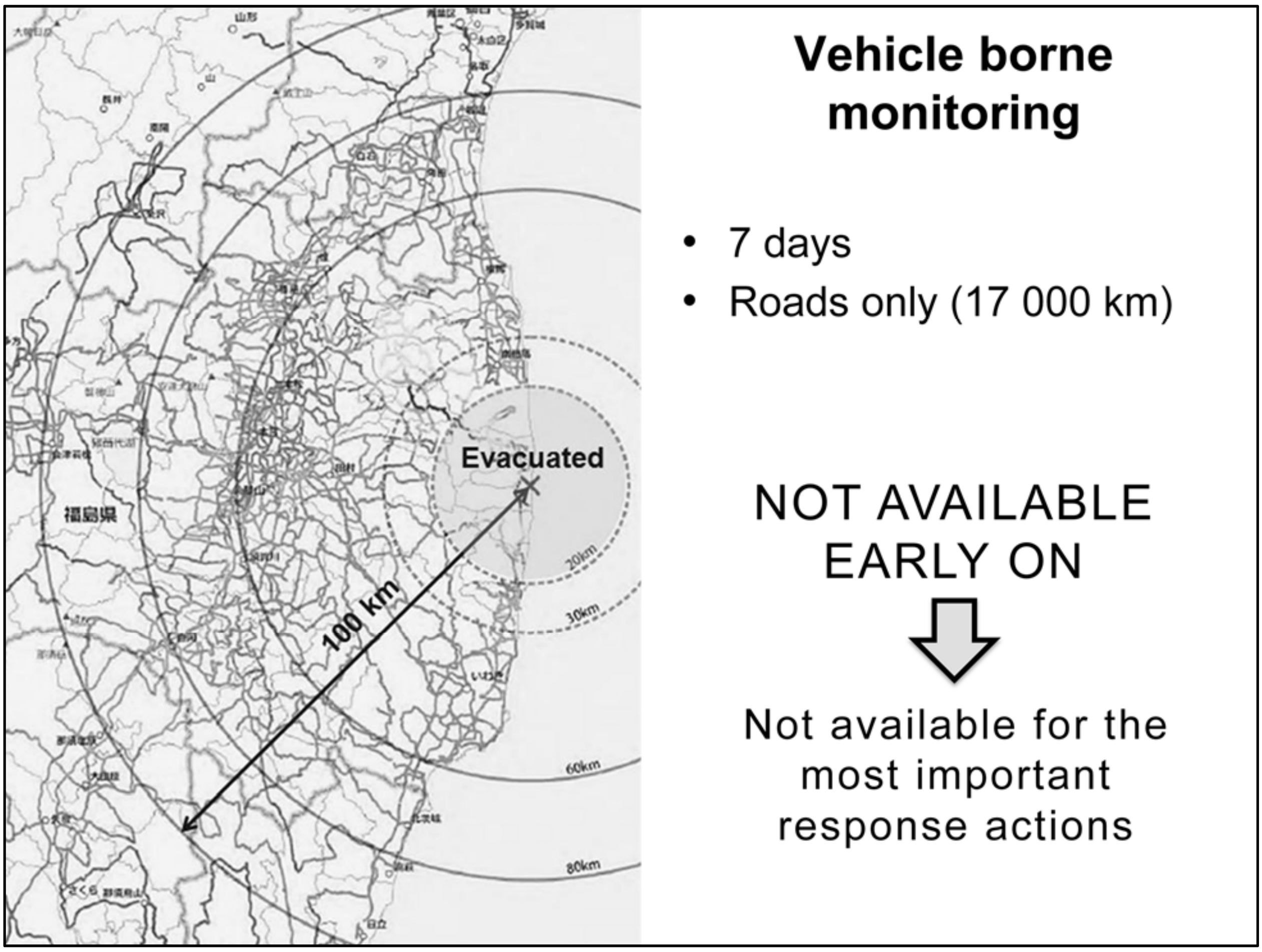
[17] NATIONAL NUCLEAR SECURITY ADMINISTRATION OF THE UNITED STATES OF AMERICA, posted at http://energy.gov/downloads/radiation-monitoring-data-fukushima-area .



Vehicle borne monitoring can be implemented in a relatively short time and with limited resources. This slide shows the vehicle borne monitoring performed after the Fukushima Daiichi accident. Monitoring was performed on national and prefectural roads within 100 km from the plant, and on municipal roads within 80 km from the plant. A total of about 17 000 km out of the targeted 20 000 km of roads could be monitored. A total of three people (two measurers and one driver) rode in each measuring vehicle. Measurements were conducted automatically every 10 seconds (approximately every 100 m). The data sent by the vehicles could be regularly monitored by the headquarters thanks to the mobile network [18].

Air dose rates were measured over the road and inside the vehicles using NaI (Tl) scintillation survey meters. Air dose rates measured by each survey meter were corrected and converted to air dose rates 1 m above the ground.

It took 7 days to develop this map, again too long for the implementation of urgent protective and other response actions. In addition the map only captures the detail of the distribution status of radioactive materials leaving most of the areas unmonitored.

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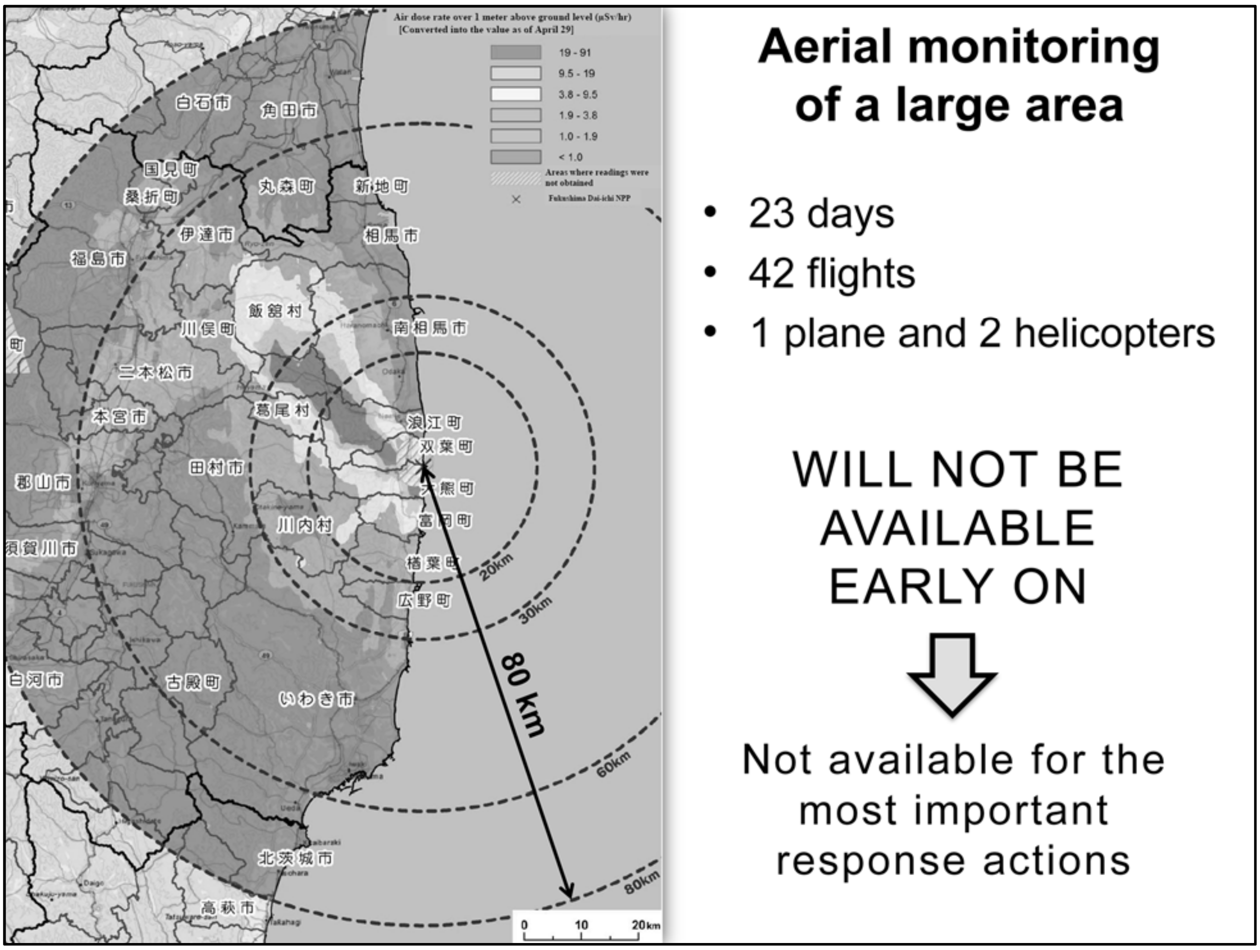
[18] NUCLEAR EMERGENCY RESPONSE HEADQUARTERS OF THE GOVERNMENT OF JAPAN, Additional report of the Japanese Government to the IAEA, The accident at TEPCO’s Fukushima Nuclear Power Stations (second Report) (2011) (September).



The previous slide showed that vehicle monitoring should not be considered as an option early on into an emergency. What about extended aerial monitoring?

This map, jointly developed by DOE (U.S. Department of Energy) and MEXT (Ministry of Education, Culture, Sports, Science and Technology of the Government of Japan), shows extended aerial gamma ray monitoring within 80 km of the Fukushima Daiichi plant. The data was obtained by 42 fixed wing and helicopter survey flights at altitudes ranging from 150 to 700 m during 23 days. Dose rates are averaged over areas of 300 to 1500 m in diameter. There is no data for the eastern part of the Town of Inawashiro because it is mountainous and not easily accessible by low-flying aircraft (as for this area, the dose rate was confirmed to be below 1 μSv/h as a result of the measurements by means of a monitoring car) [19].

Decision makers should be aware that detailed maps will not be available early on in an emergency. Decisions will have to be taken without this kind of information.

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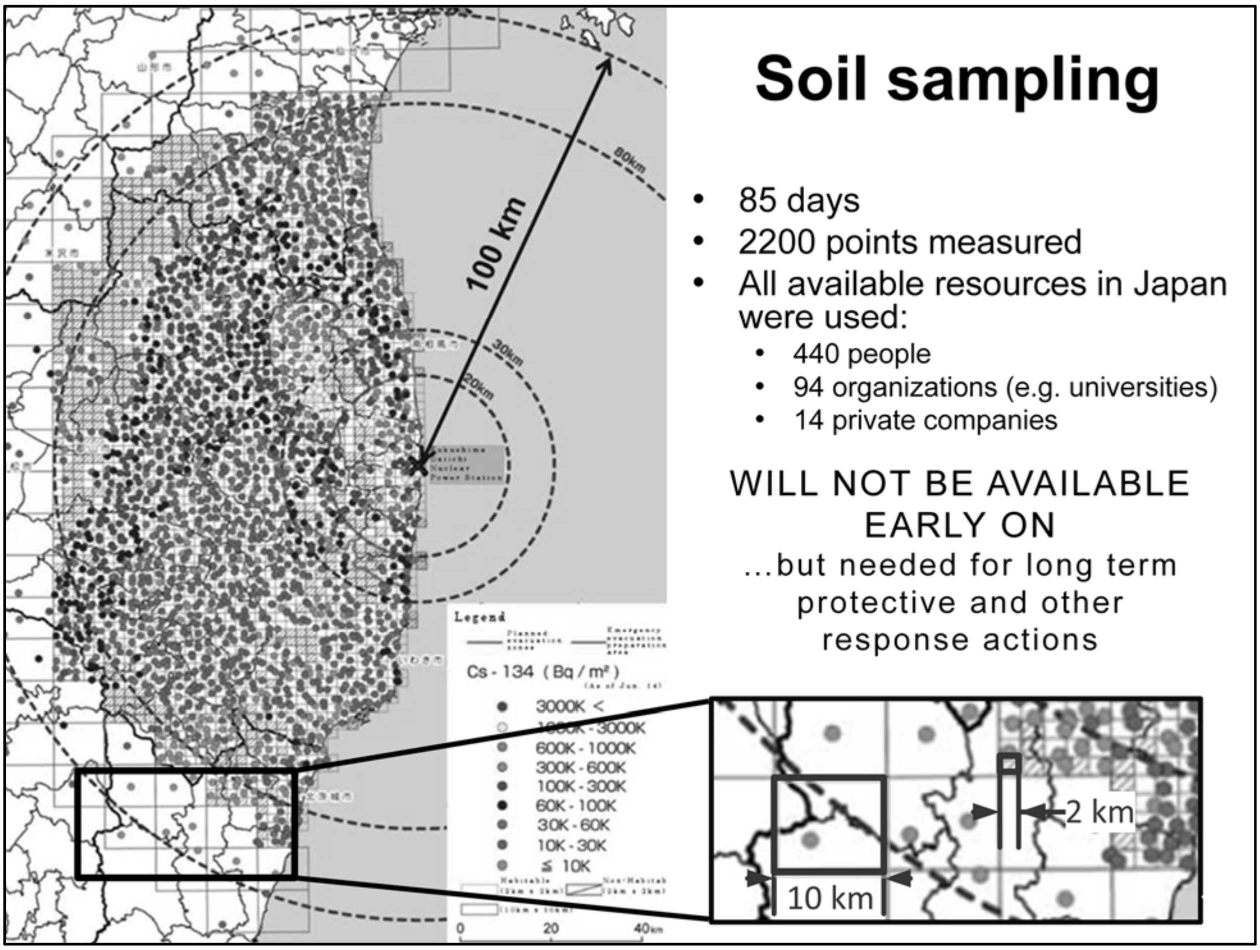
[19] MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE, AND TECHNOLOGY OF THE GOVERNMENT OF JAPAN, Results of Airborne Monitoring by the Ministry of Education, Culture, Sports, Science and Technology and the U.S. Department of Energy (2011) (May).



The resources and the time needed to analyse a fairly small number of soil samples lies far behind the possibilities available at the beginning of a severe emergency. A clear example of this is the map developed by MEXT after the Fukushima Daiichi accident showing the concentration of radioactive ^{134}Cs in soil [20]. More than 400 co-operators of 94 organizations, including universities, medical institutions and private companies, collaborated during 85 days to develop this map.

MEXT collected soil samples from the 5 cm surface layer at around 2200 locations within approximately 100 km from the Fukushima Daiichi plant to analyse nuclides by using germanium semiconductor detectors. Previous airborne monitoring revealed that spots showing high radiation doses were concentrated in areas within 80 km of the plant, therefore within this area measurements were conducted at one location per 2 km × 2 km, and at one location per 10 km × 10 km for the areas beyond 80 km of the plant. [21, 22].

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[20] NUCLEAR EMERGENCY RESPONSE HEADQUARTERS OF THE GOVERNMENT OF JAPAN, Additional report of the Japanese Government to the IAEA, The accident at TEPCO's Fukushima Nuclear Power Stations (second Report), Chapter IV, p. 24 (2011) (September).

[21] MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE, AND TECHNOLOGY OF THE GOVERNMENT OF JAPAN, Commencement of Air Dose Rate Monitoring and Soil Survey for Creating Maps of Distributions of Radiation Doses, etc. (2011) (June 3).

[22] MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE, AND TECHNOLOGY OF THE GOVERNMENT OF JAPAN, Preparation of Distribution Map of Radiation Doses, etc. (Map of Radioactive Cesium Concentration in Soil) (2011) (August 30).

1st problem:

Monitoring will take time and consume resources

Conclusion:

Initial urgent protective and other response actions should be implemented based on plant conditions, BEFORE monitoring and sampling

Monitoring and sampling is essential for later protective and other response actions

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2^{nd} Problem

Deposition patterns are complex over large and short distances

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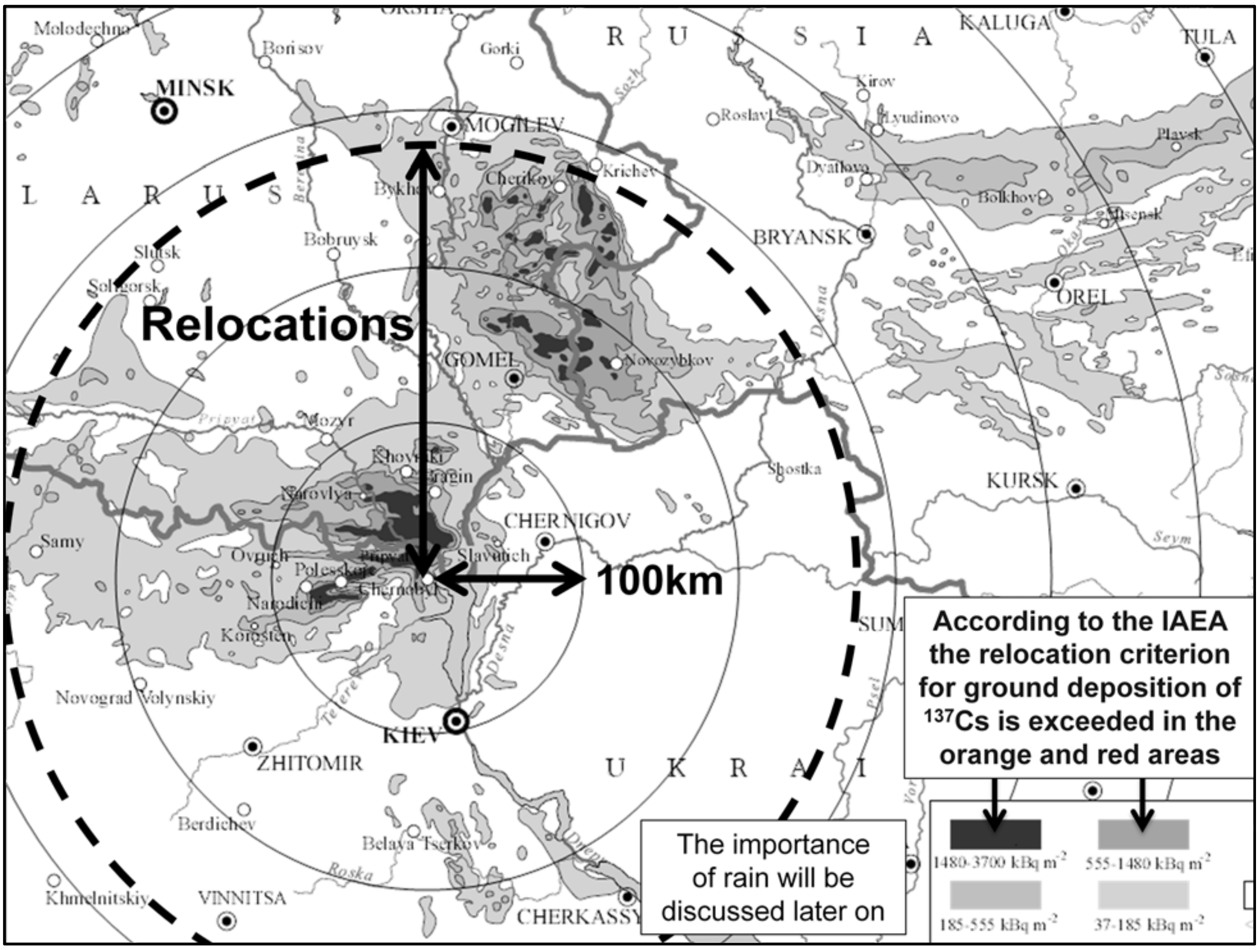
The pattern of deposition of radioactive material can be very complex and non-homogeneous over large and small areas, as shown in the following slides.



A severe accident involving core melt and major containment failure can cause significant and complex levels of contamination over very large areas. This can be seen from the ^{137}Cs contamination pattern resulting from the Chernobyl accident [23]. The hotspot to the north-west about 300 km from Chernobyl resulted from rain, warranting relocations at distances of more than 250 km from Chernobyl.

As mentioned, the plume resulting from an accident is relatively narrow, but for most accidents the release will last several hours, during which the wind direction will most likely change. As a result, it will be impossible to predict all the areas that will be affected by the accident. In fact, most reactor accidents have affected all areas near the plant. Consequently, **urgent protective and other response actions that are critical for preventing serious health effects should be taken in all directions around the plant.**

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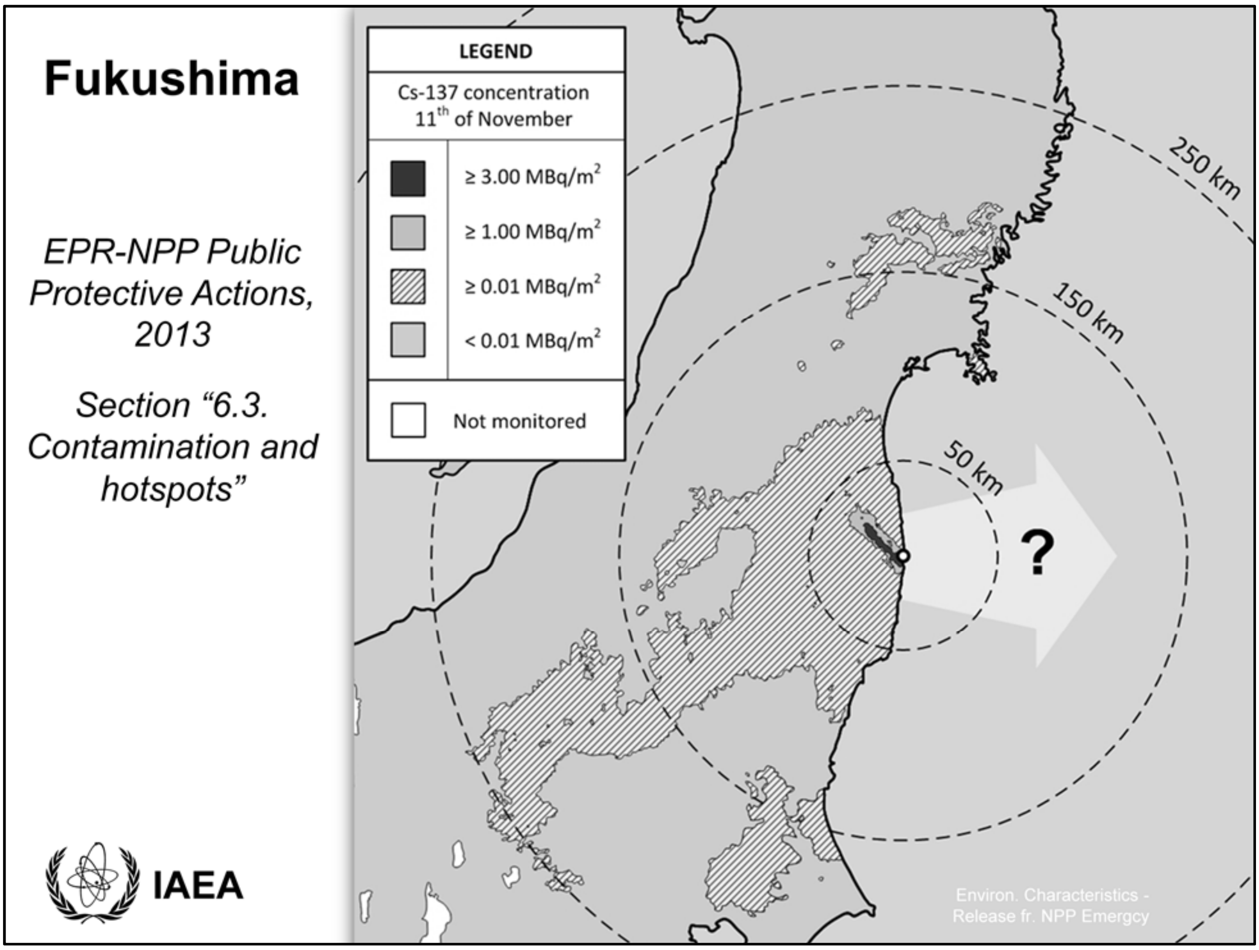
[23] UNITED NATIONS, Sources and Effects of Ionizing Radiation, 2000 Report to the General Assembly, Annex J: Exposures and Effect of the Chernobyl Accident, Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), UN, New York (2000) 460.



The deposition patterns following the release from the accident at the Fukushima Daiichi plant were also complex, as illustrated in this slide (data from Ref. [25]). This figure shows the ^{137}Cs deposition after the major releases.

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[25] MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE, AND TECHNOLOGY OF THE GOVERNMENT OF JAPAN, posted at http://ramap.jaea.go.jp/map/. Retrieved 5th June 2012.

2nd problem:

Deposition patterns are complex
over large and short distances

Conclusion:

Do not rely on models. Deposition patterns are not predictable. Urgent protective and other response actions that are critical for preventing serious health effects should be taken in ALL directions around the plant

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3rd Problem

Hotspots occur and are hard to find

More and more hotspots will be detected by the public and local authorities

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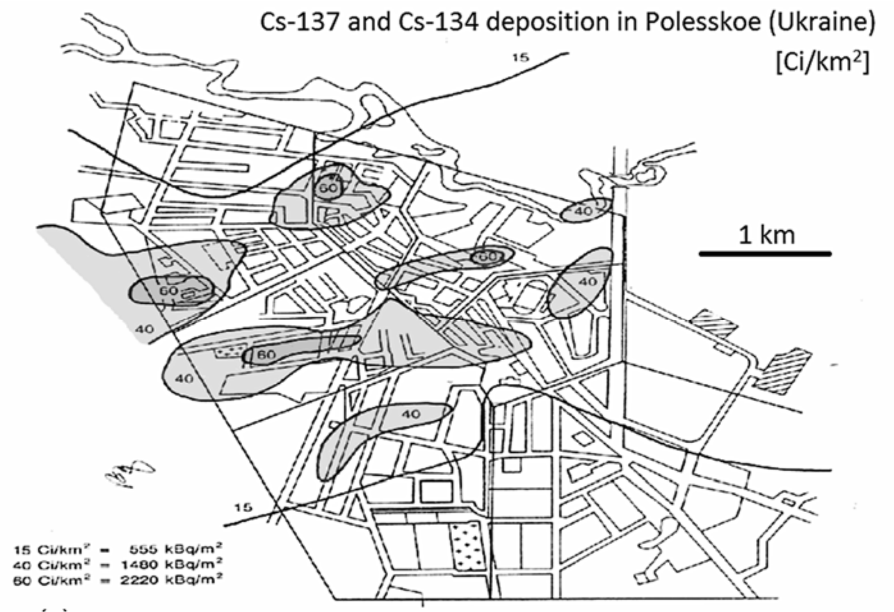
The use of the terms ‘contamination’ and ‘hotspot’ has been a source of considerable confusion and public concern. This has been of particular concern when hotspots and areas of contamination were shown on maps used to describe the impact of the emergency on the public and decision makers. In many cases, very low levels of radiation were shown that would not cause any health effects and would therefore not warrant any response actions; however, this was not clearly explained to the public and decision makers.

Following a release of radioactive material, the site levels of deposition can vary considerably, resulting in areas with higher concentrations of radioactive material or dose rates than those nearby. These higher concentrations are often called hotspots, which causes undue concern amongst the public. However, this variation in itself does not indicate that there is a radiation health concern and does not indicate that any response is needed unless an OIL is exceeded.

In an emergency a hotspot only needs to be used to refer to an area with ground deposition of radioactive material resulting in an OIL or other predetermined criteria being exceeded.

Hotspots occur and are hard to find

A hotspot is an area of any size with a ground deposition of radioactive material warranting response actions to protect the public



Tell local authorities and the public to expect hotspots and how to deal with them

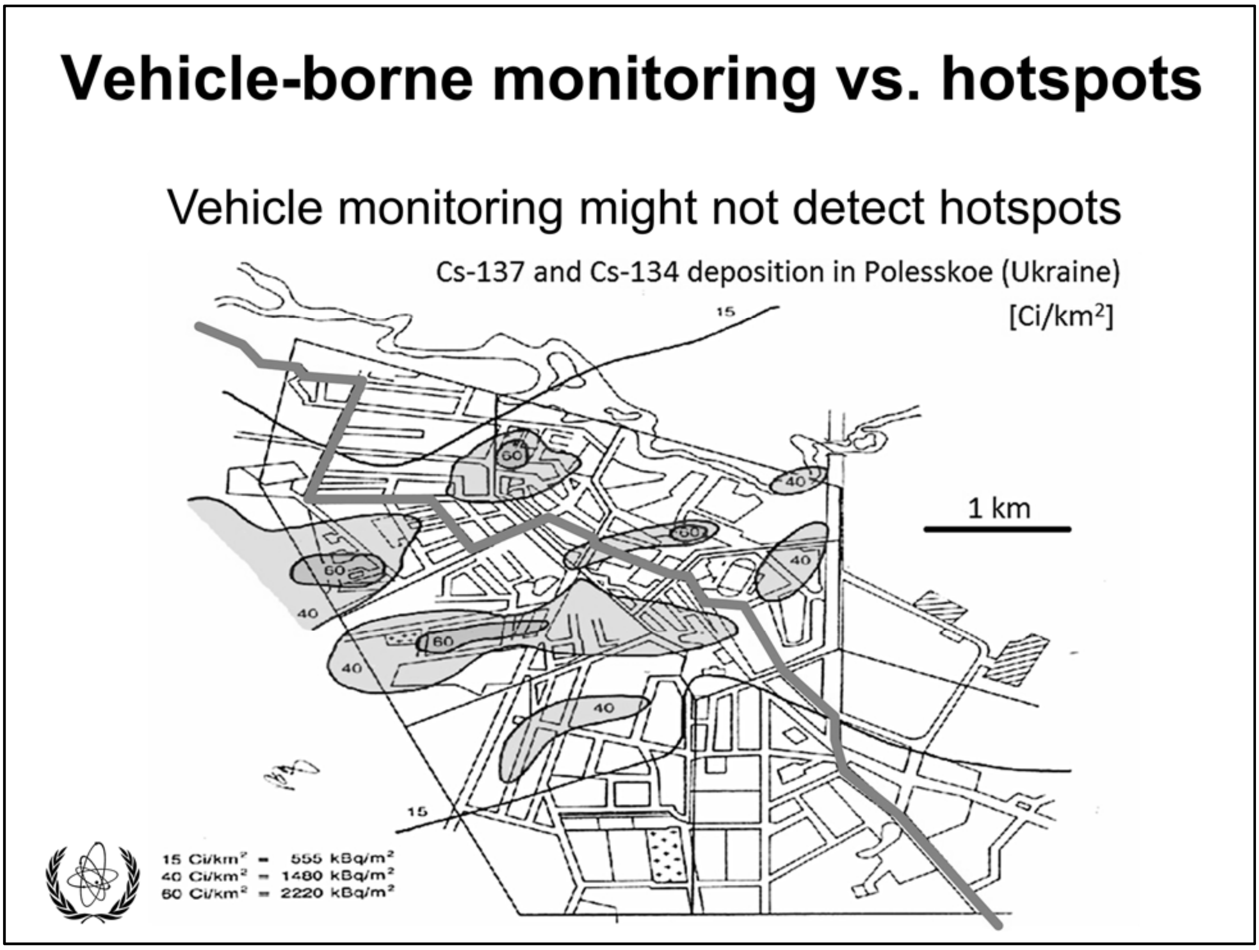
The increased availability of dosimeters by the public will quickly lead to public concerns

Hotspots will be found for days to weeks after deposition. When resources become available, extended and detailed monitoring is required and should be regarded as imperative.

As a matter of fact, most hotspots will be found by local authorities and the public, they should therefore be told to expect them and to implement corresponding response actions. As explained in Module 9 on Public and Media Response, the increased availability of dosimeters will lead to a relatively fast detection of hotspots. Decision makers should address these concerns in advanced to avoid unwanted reactions of the public.

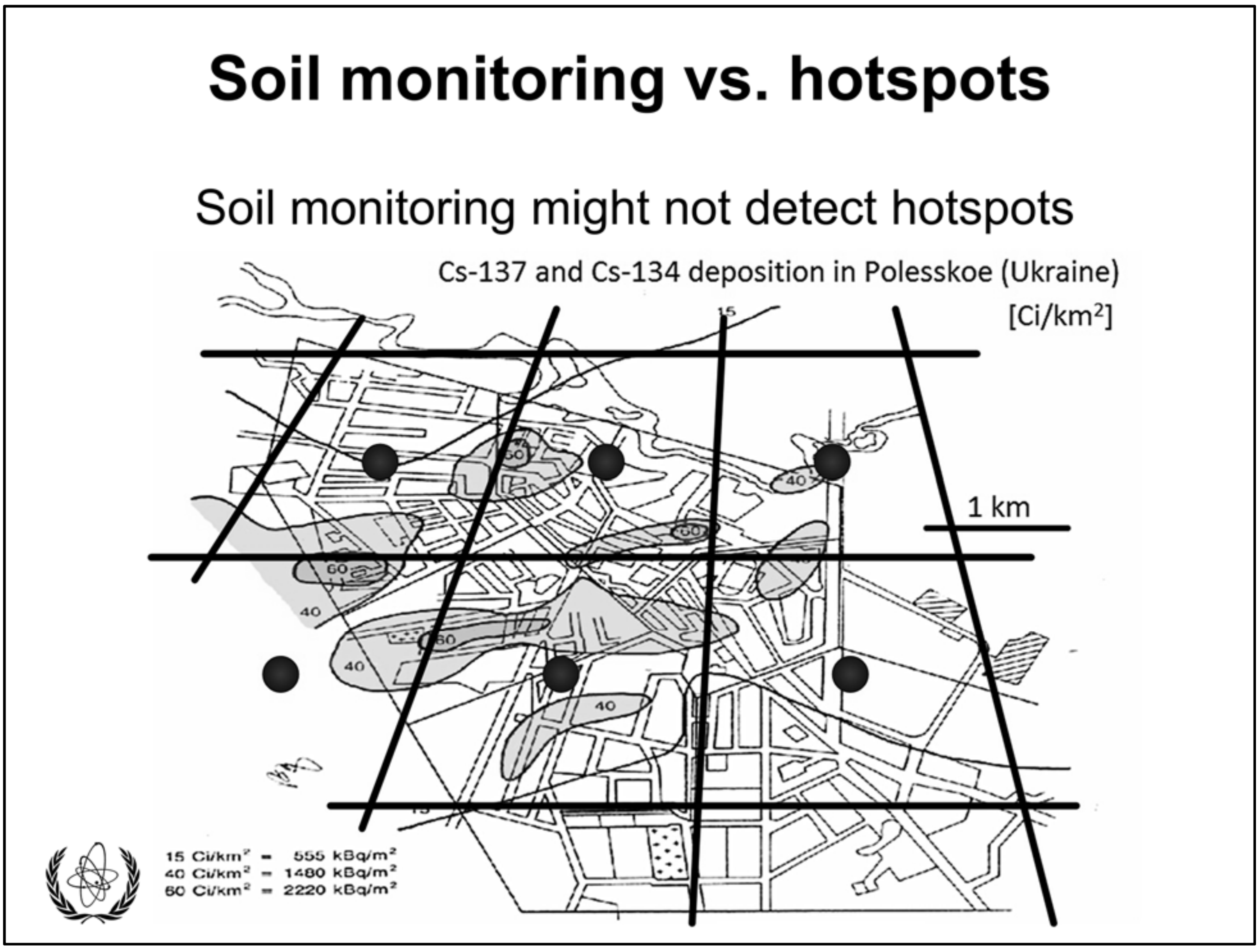
The size of hotspots is unpredictable. This map of the town of Polesskoe in the Ukraine shows considerable variations in the ^{137}Cs and ^{134}Cs surface concentrations and dose rate levels over short distances, resulting from the Chernobyl release. The deposition levels vary by more than a factor of four within a few hundred metres.

As will be show in the next slides the previously discussed monitoring and sampling techniques (vehicle-borne monitoring, sampling an aerial monitoring) are not reliable in the detection of hotspots.

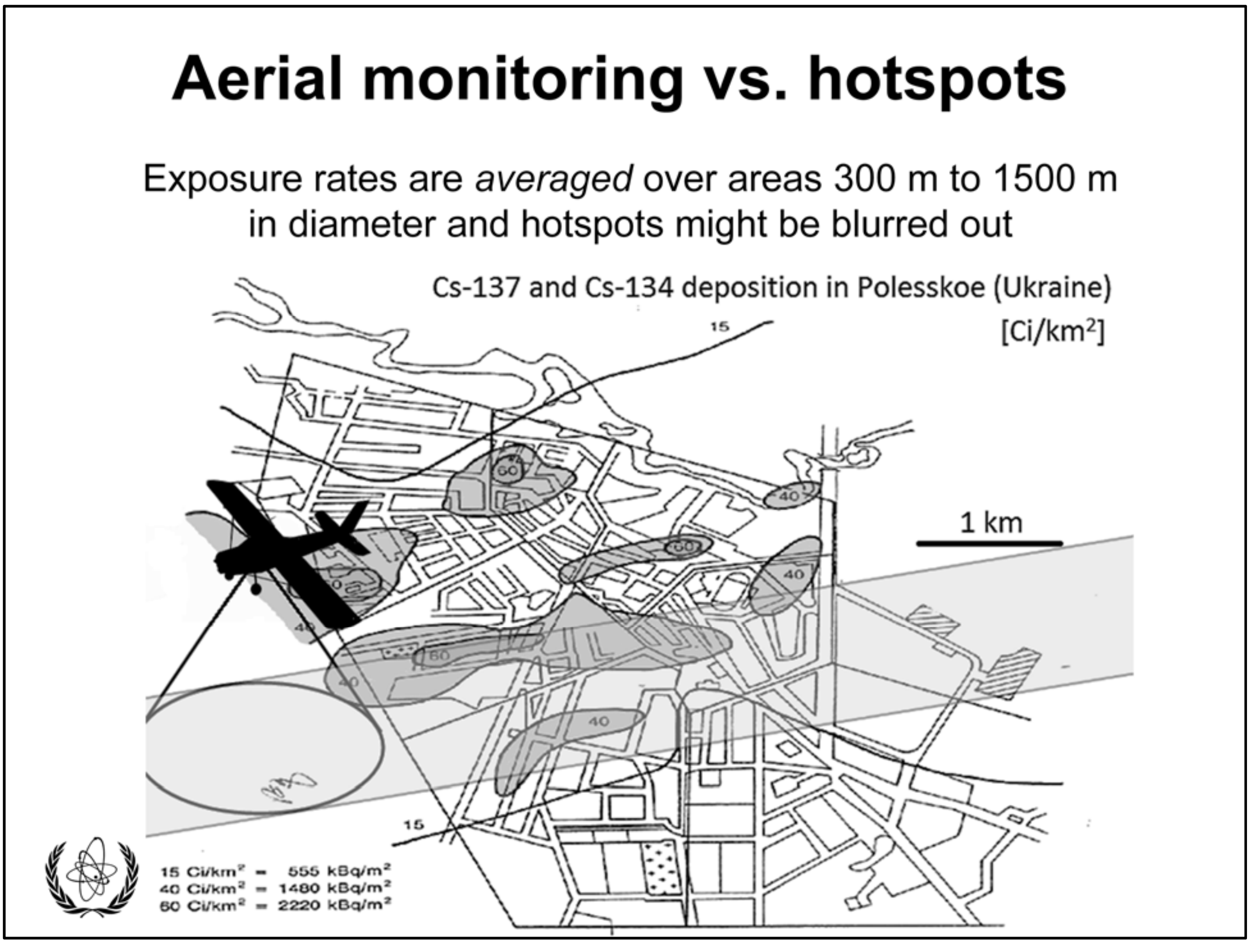


Vehicle-borne monitoring will not be effective in detecting hotspots. A monitoring vehicle driving through Polesskoe, following the “unlucky” route shown in the slide, would not have detected the real severity of the situation, leaving the population exposed to significant health risks.

If a hotspot is detected by vehicle monitoring, protective actions should be applied for the whole area. It is probable that the vehicle monitoring has not detected other hotspots.



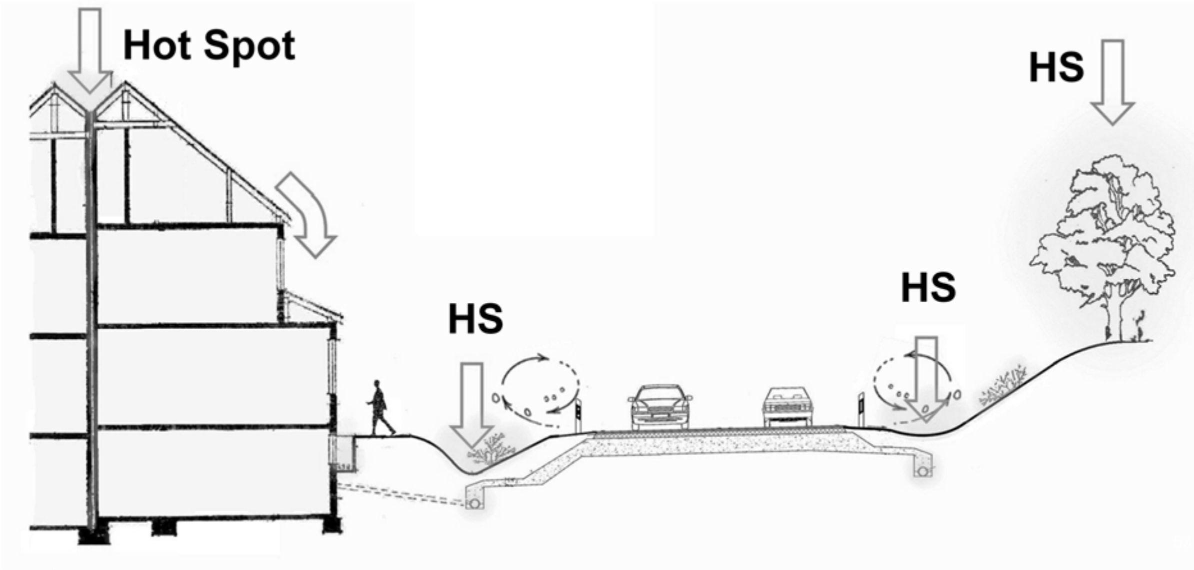
This slide shows the effectiveness of soil sampling at one location per 2 km × 2 km, such as the one implemented in the areas within 80 km from the Fukushima plant. The hotspots easily remain undetected.



This slide shows a simple representation of an aerial measurement. The measured exposure rates are averaged over wide areas (300 to 1500 m in diameter) blurring out smaller hotspots that are captured within the measured trajectory. Although initial aerial monitoring will not detect smaller hotspots, it will be effective in the detection of bigger deposition patterns in the order of magnitude of kilometres, including bigger hotspots.

Contamination concentrators

There are multiple ways in which hotspots are generated including: wet and dry deposition, weathering, shielding, resuspension, wash-off, runoff and wash-in



This slide tries to give an account of the formation of hotspots due to contamination concentrators. Radioactive fallout will be concentrated or attenuated by multiple effects such as wet and dry deposition, runoff, wash-off, weathering, shielding and resuspension.

Due to natural effects like gravity, rain or wind, and by human actions like traffic, cleaning or dust raising, radionuclides will be concentrated in areas such as roadside ditches, spaces between houses or water drains, while being removed from roofs, walls and roads.

Due to the vast number of variables relevant for these phenomena, it is nearly impossible to predict the formation of hotspots. Small changes in initial meteorological conditions can have huge effects on radionuclide deposition and therefore radionuclide concentration. A clear example of this is the deposition on trees; measurements during the Chernobyl accident have shown that the deposition rate on trees varies drastically for dry or wet deposition [26].

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[26] NORDIC LIASON COMMITTEE FOR ATOMIC ENERGY, Deposition and removal of radioactive surfaces in an urban area, Risø National Laboratory, Roskilde (1990)

3rd problem:

Hotspots occur and are hard to find

Conclusion:

Expect more and more hotspots to be detected over time (beyond the areas you have evacuated)

Expect public concern about hotspots, so inform the public to expect hotspots and to take response actions

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4^{th} Problem

Food, milk and water restrictions may be needed over long distances and are heavily influenced by rain

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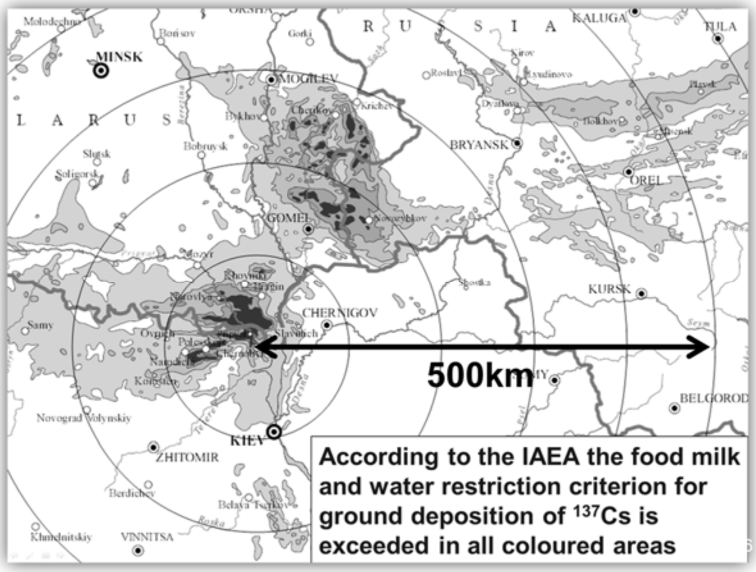
Precipitation is one of the most relevant causes for the formation of wider hotspots. On a smaller scale, the distribution pattern of fallout, specially in urban areas, is very dependent on whether the deposition took place in dry or wet weather. Radionuclides transported by air masses are “washed out” by rain leading to increased deposition rates on the ground.

Precipitation will lead to contamination over long distances

- Radionuclides transported by air masses are “washed out” by rain, leading to increased deposition rates on the ground: precipitation is one of the most relevant causes for the formation of hotspots
- Small plumes can lead to high doses on the ground due to rain
- This is especially important for food, milk and water restrictions
- Levels of radiation warranting restrictions can be exceeded at great distances (e.g. all the coloured areas of the map)



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Deposition from the plume may result in the radioactive material getting into local produce, milk from grazing animals and rainwater. This slide shows that areas exceeding OIL3 values warranting food restrictions observed over a complex area out to a distance of more than 500 km due to the release from the accident at the Chernobyl plant. The patterns of this deposition (hotspots) are so complex that it is impossible to monitor enough of the area in order to quickly identify all the locations for which food restrictions apply. Consequently, the consumption of non-essential local produce, milk, and rainwater within the ICPD needs to be restricted upon declaration of a General Emergency (i.e. before monitoring or sampling is carried out) and until it is assessed and found to be safe for consumption. Failure to implement these controls within a few days of a release could result in eventual radiation induced thyroid cancers, particularly among children, such as those which occurred after the accident at the Chernobyl nuclear power plant [27–29].

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[27] BUGLOVA, E., KENIGSBERG, J., McKENNA,T., “Reactor accidents and thyroid cancer risk: Use of the Chernobyl experience for emergency response”, Proc. Int. Symp. Radiation and Thyroid Cancer (THOMAS, G., KARAOGLOU, A., WILLIAMS, E.D., Eds), World Scientific (1999) 449–453.

[28] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, OFFICE FOR THE COORDINATION OF HUMANITARIAN AFFAIRS, UNITED NATIONS ENVIRONMENT PROGRAMME, UNITED NATIONS DEVELOPMENT PROGRAMME, UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION, WORLD HEALTH ORGANIZATION, WORLD BANK (THE CHERNOBYL FORUM 2003-2005), Chernobyl’s Legacy: Health, Environmental and Socio-Economic Impacts and Recommendations to the Governments of Belarus , the Russian Federation and Ukraine, Second revised version, IAEA/PI/A.87 Rev.2 / 06-09181, Vienna (2006).

[29] UNITED NATIONS, Sources and Effects of Ionizing Radiation, Report to the General Assembly, Vol. II: Scientific Annexes C, D and E, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2008), UN, New York (2011).

4th problem:

Precipitation will create large hotspots warranting protective actions over long distances, especially regarding food, milk and water restrictions

Conclusion:

Implement food, milk and water restrictions within predetermined distances from the NPP and monitor to expand and/or confirm these restrictions

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5th Problem

Monitoring results will have high uncertainties

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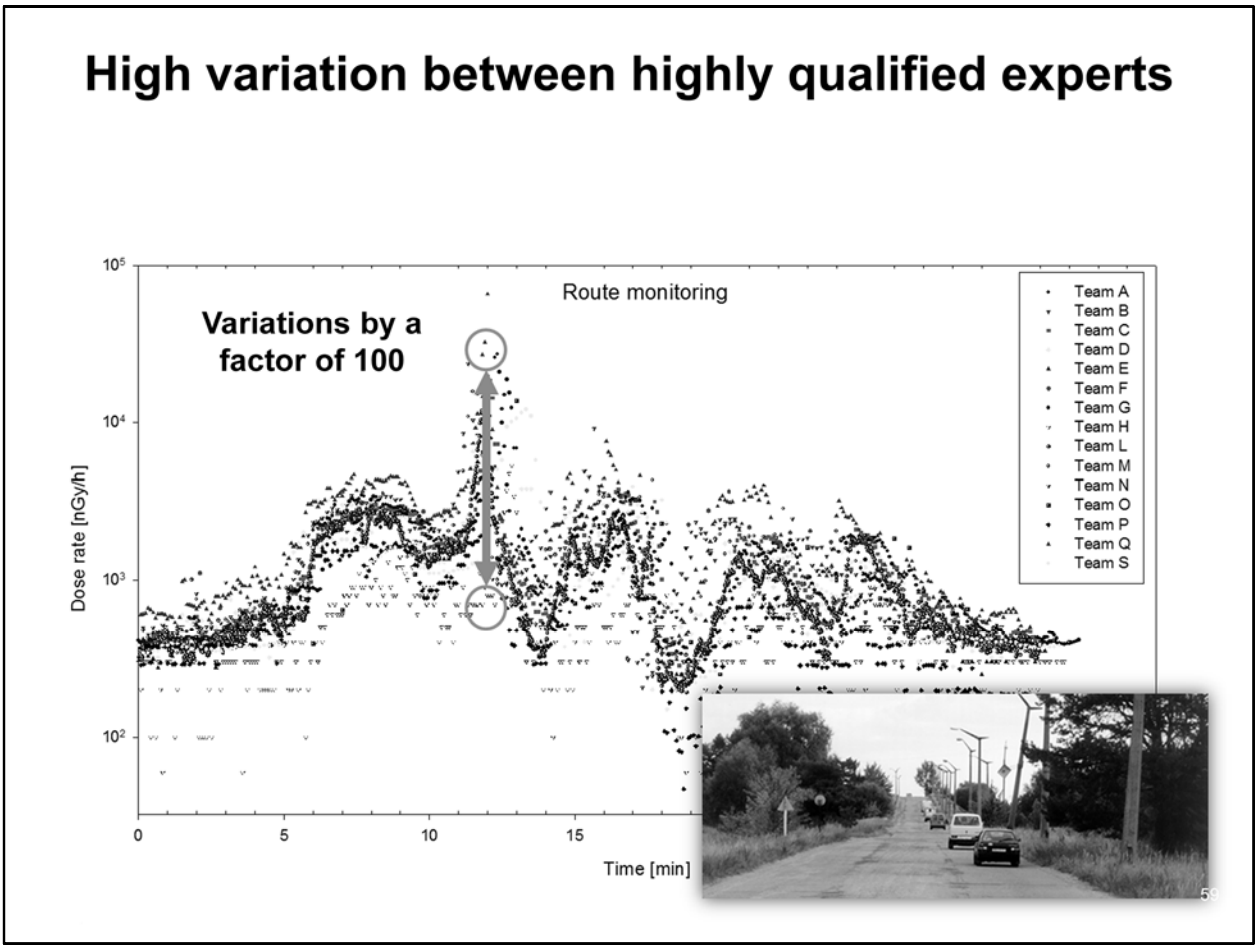
Arrangements need to be in place to take protective actions and other response actions promptly based on field monitoring data. However, early in an emergency there will only be limited monitoring data, and it may be confusing and inconsistent. This is due to the considerable variation in the dose rates, as well as variations in the monitoring team measurements. Even highly professional teams can be expected to report different dose rates and concentration levels when monitoring in the same areas. This will be particularly problematic early on in the emergency when decisions need to be made quickly in order to be effective. Therefore, arrangements need to be in place to enable decisions to be made promptly, based on early, limited and possibly inconsistent monitoring data.



These intercomparison measurements were held in 1999 in the exclusion zone of the Chernobyl plant in the Ukraine. Nineteen teams from nine countries and the IAEA participated in the workshop. In this specific exercise, a convoy was formed which travelled for about ½ hour (approximately 20 km) in the exclusion zone through different dose rate regions. The ambient dose rate was recorded from the vehicle while driving [30].

These highly qualified teams reported monitoring results with significant variations between them. The measurements were performed in the absence of a real emergency that could have introduced further uncertainties.

Past emergencies have shown that early on in a severe emergency, there will be very little good information available upon which to base protective action decisions. There is likely to be incomplete information; and even where there is duplicating information, it may well be conflicting and inconsistent. In many cases, the information may be plain WRONG.

Decision makers should expect these uncertainties early on in the emergency, and take reasonably conservative assumptions to protect the public. **An element of suspicion of the information is always encouraged.**

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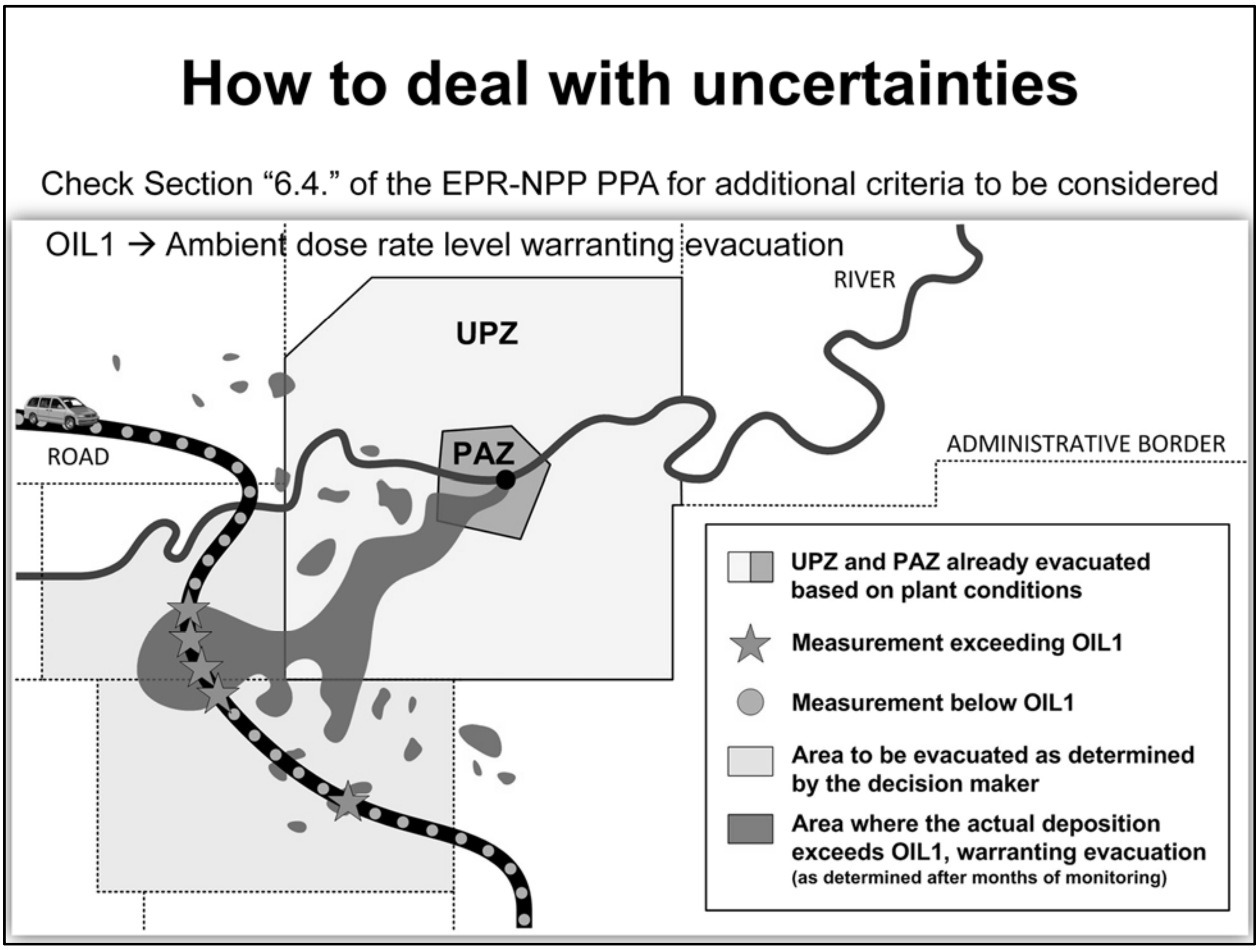
[30] GLAVIC-CINDRO, D., KORUN, M., PUCELJ, B., VODENIK, B., MORAL-12 Intercomparison Measurements 99, J. Stefan Institute, Ljubljana (1999)



Arrangements need to be in place to enable decisions to be made promptly, based on early, limited and possibly inconsistent monitoring data. A possible strategy for doing this is illustrated in this slide. In this example there was a General Emergency and the population within the PAZ and UPZ were evacuated. A major release has occurred and a monitoring team is deployed to determine if additional protective actions are needed beyond the UPZ. The figure shows in orange the areas of deposition of radioactive material that warrants evacuation, however it will take weeks for environmental monitoring to identify in detail all these areas. The monitoring team has taken the route depicted in black. Only a few of the monitoring team's measurements exceed the OIL1 levels (those shown as blue stars on the route taken by the monitoring team). These levels of dose rate indicate evacuation is warranted. However, as can be seen in the figure, most of the areas with deposition levels warranting evacuation were not identified by this monitoring team. The decision maker recommends that those living within the entire administrative area (light blue areas) where there were measurements that exceed OIL1 be evacuated. This decision was made in recognition that:

- the pattern of deposition could be very complex;
- those living where OIL1 is exceeded are a considerable risk and need to evacuate promptly;
- it will take days to weeks of monitoring to locate with accuracy all the areas that need to be evacuated.

How to deal with these uncertainties

Consider the characteristics of the measurements and the natural and social environment of the area, such as the following:

- the number of readings requiring a protective action, both in the same location and in the vicinity;
- the magnitude of the reading;
- the reliability of the measurement;
- the population in the area;
- the consequence for no action (or action);
- the use of the land and whether there are farms in the locality;
- conditions that may make implementation of protective actions hazardous (e.g. restricting essential food or water, movement of patients, hazardous evacuation or sheltering);
- social conditions;
- the ability to define the area in a way understandable to the public;
- administrative and jurisdiction boundaries.

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When determining if and where protective actions and other response actions need to be taken, decision makers need to consider the characteristics of the measurements and the natural and social environment of the area, such as the following:

- the number of readings requiring a protective action, both in the same location and in the vicinity;
- the magnitude of the reading and if it just over a level requiring some protective action or greatly in excess;
- the reliability of the measurement;
- the population in the area, since if there is no population nearby there is less need to make a quick decision;
- the consequence for no action (or action). For example immediate action is warranted where urgent actions need to be taken, but there could be days for further assessments to confirm the areas in which early actions need to be taken;
- the use of the land and whether there are farms in the locality;
- conditions that may make implementation of protective actions hazardous (e.g. restricting essential food or water, movement of patients without proper preparations, evacuation or sheltering under hazardous conditions);
- social conditions;
- the ability to define the area in a way understandable to the public;
- administrative and jurisdiction boundaries.

During the emergency a great number of actors will deal with the monitoring data obtained by the environmental monitoring teams. This will lead to confusion, to repeated and misinterpreted data sets. In order to implement effective protective actions, the information should be systematically ordered following predetermined criteria from the beginning of the emergency.

5th problem:

Monitoring results will have high variations,
even for well-trained teams

Conclusion:

Know how to deal with these uncertainties early on in the emergency, and take reasonably conservative assumptions to protect the public

An element of suspicion of the information is encouraged

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4. Conclusions and exercises

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Conclusions

- Core damage state, release pathways, release time, release duration, isotopic mixture and plume behaviour are unpredictable during a severe emergency
- Be prepared to deal with complex dynamics and fast changes during a severe emergency
- Models may not be a basis for the implementation of effective protective actions close in and early on (due to the associated uncertainties)
- Expect all directions around the plant to be affected

Therefore, take initial response actions based on plant conditions

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Conclusions

- Monitoring will take time and consume resources
- Deposition patterns will be complex, leading to hotspots
- Expect high variations in the monitoring results

The uncertainties related to a severe emergency have already been considered in the development of IAEA tools.

Make use of them.

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Questions Module 7-2

You are the off-site decision maker and there has been a major release at an NPP. Assuming that you have already taken response actions based on plant conditions:

1. Once there is a severe NPP emergency, can you predict the release time and plume behaviour? Explain your answer.
2. How long will it take to get extended soil-sampling, aerial survey and vehicle-borne dose rate maps? And what about simpler maps?
3. Where do you expect hotspots? Where do you expect higher dose rates?
4. Two monitoring teams provide notably different dose rate values for the same area. One requires some kind of protective action and the other does not. What do you do?

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1. No, you cannot. There are too many sources of uncertainty such as the core damage state, release route conditions, reduction mechanisms, wind direction, plume meandering, wind shear, rain and other meteorological phenomena. Core damage state, release pathways, release time, release duration, isotopic mixture and plume behaviour are unpredictable. Therefore, take initial response actions based on plant conditions. Be prepared to deal with complex dynamics and fast changes during an emergency. But keep in mind that these uncertainties have already been taken into account by the IAEA in the development of its tools.

2. In the aftermath of the Fukushima Daiichi NPP accident, it took one week to develop extended vehicle-borne maps, three weeks for extended air-borne maps and nearly three months for extended soil-sampling maps.

Past emergencies have shown that, in the best cases, it will take days to get very simple dose rate maps. This simple information does not show hotspots or other complex patterns, required for the implementation of effective protective actions.

3. The distribution of hotspots is not easily predictable. Radionuclides will be concentrated in areas such as roadside ditches, spaces between houses or water drains, while being removed from roofs, walls or roads.

Precipitation is the most relevant factor in the formation of greater hotspots. In areas with precipitation during or after the release, higher dose rates should be expected.

4. Previous emergencies have shown that this is a common situation! Additional measurements will require time and resources you will probably not have. To avoid health risks to the public, protective actions should be implemented.

Answers

1. Once there is a severe NPP emergency, can you predict the release and the plume behaviour?

No, you cannot. There are too many sources of uncertainty such as the core damage state, release route conditions, reduction mechanisms, wind direction, plume meandering, wind shear, rain and other meteorological phenomena.

Core damage state, release pathways, release time, release duration, isotopic mixture and plume behaviour are unpredictable. Therefore, take initial response actions based on plant conditions.

Be prepared to deal with complex dynamics and fast changes during an emergency. But keep in mind that these uncertainties have already been taken into account by the IAEA in developing the tools.

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Answers

2. How long will it take to get extended soil-sampling, aerial survey and vehicle-borne dose rate maps? And what about simpler maps?

In the aftermath of the Fukushima Daiichi accident, it took one week to develop extended vehicle-borne maps, three weeks for extended aerial survey maps and nearly three months for extended soil-sampling maps.

Past emergencies have shown that, in the best cases, it will take days to get very simple dose rate maps. This simple information does not show hotspots or other complex patterns that are required for the implementation of effective protective actions.

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Answers

3. Where do you expect hotspots? Where do you expect lower dose rates?

The distribution of hotspots is not easily predictable. Radionuclides will be concentrated in areas such as roadside ditches, spaces between houses or water drains, while being removed from roofs, walls or roads. Precipitation is the most relevant factor in the formation of greater hotspots. In areas with precipitation during or after the release, higher dose rates should be expected.

4. Two monitoring teams provide notably different dose rate values for the same area. One measurement requires some kind of protective action the other does not. What do you do?

Previous emergencies have shown that this is a common situation! Additional measurements will require time and resources you will probably not have. To avoid health risks to the public, protective actions should be implemented.

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Exercise – Vehicle-borne monitoring

The next slide will show vehicle-borne monitoring results. Areas with more than 25 μSv/h require the relocation of the public (IAEA's OIL2*)

Where would you relocate the public?

INSTRUCTOR GUIDELINES:
Provide the audience with a printout of the Following slide and give some minutes to mark the areas to be relocated.

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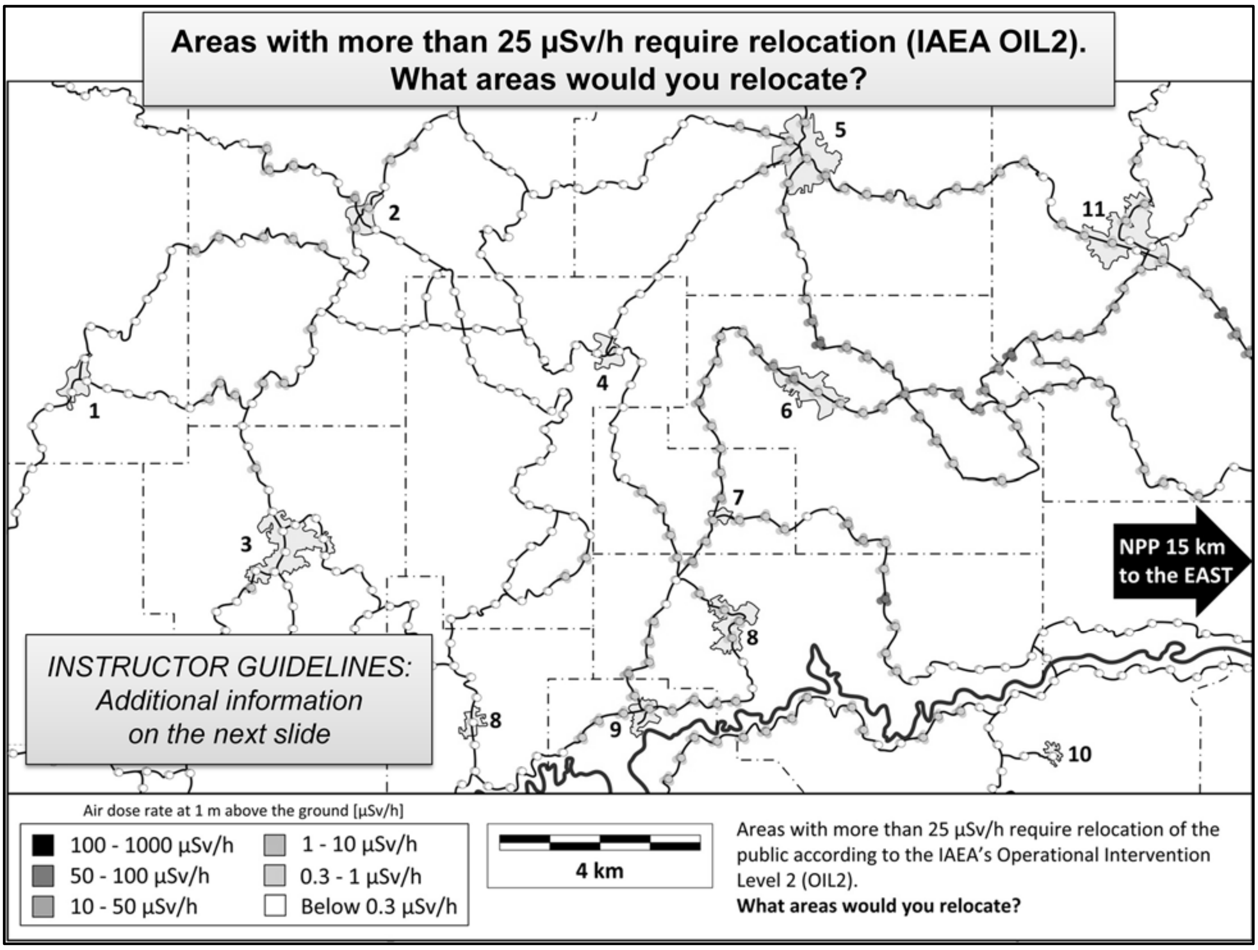
*Operational Intervention Level 2 warranting relocation of the public.

The purpose of the exercise is to show the complexity of effective decision making in the absence of detailed information.

INSTRUCTOR GUIDELINES*: Provide the audience with a printout of the following slide and give some minutes to mark the areas to be relocated (high resolution jpg file available in the electronic package).*



INSTRUCTOR GUIDELINES: *Additional information on the next slide*

The OIL2 value for the ambient dose rate at 1 m above ground level was developed for the protection of someone living in an affected area. When developing the OILs, all the important exposure pathways were considered. It is assumed that everybody (including pregnant women) are living normally in an area affected by a release and are being exposed to ground shine (external exposure from deposition) and inadvertent ingestion, for example, from dirt on hands. Inhalation of resuspended radioactive material and external exposure from resuspended radioactive material were also considered, but these are not important sources of exposure. However, it is assumed that the person is not eating or drinking food, milk or water from the affected area because protective actions have been implemented to restrict consumption.

OIL2 is based on generic criteria for taking early protective actions and other response actions when the effective dose of 100 mSv or equivalent dose of 100 mSv to the fetus is projected to be exceeded in one year. Two values are provided by the IAEA for OIL2: 100 µSv/h for measurements that are taken less than 10 days after the shutdown of a reactor and 25 µSv/h for measurements that are taken more than 10 days after shutdown of a reactor. This is in order to account for the short-lived radionuclides that cause a high dose rate measurement over the first 10 days after shutdown of the reactor, but do not contribute significantly to the dose.

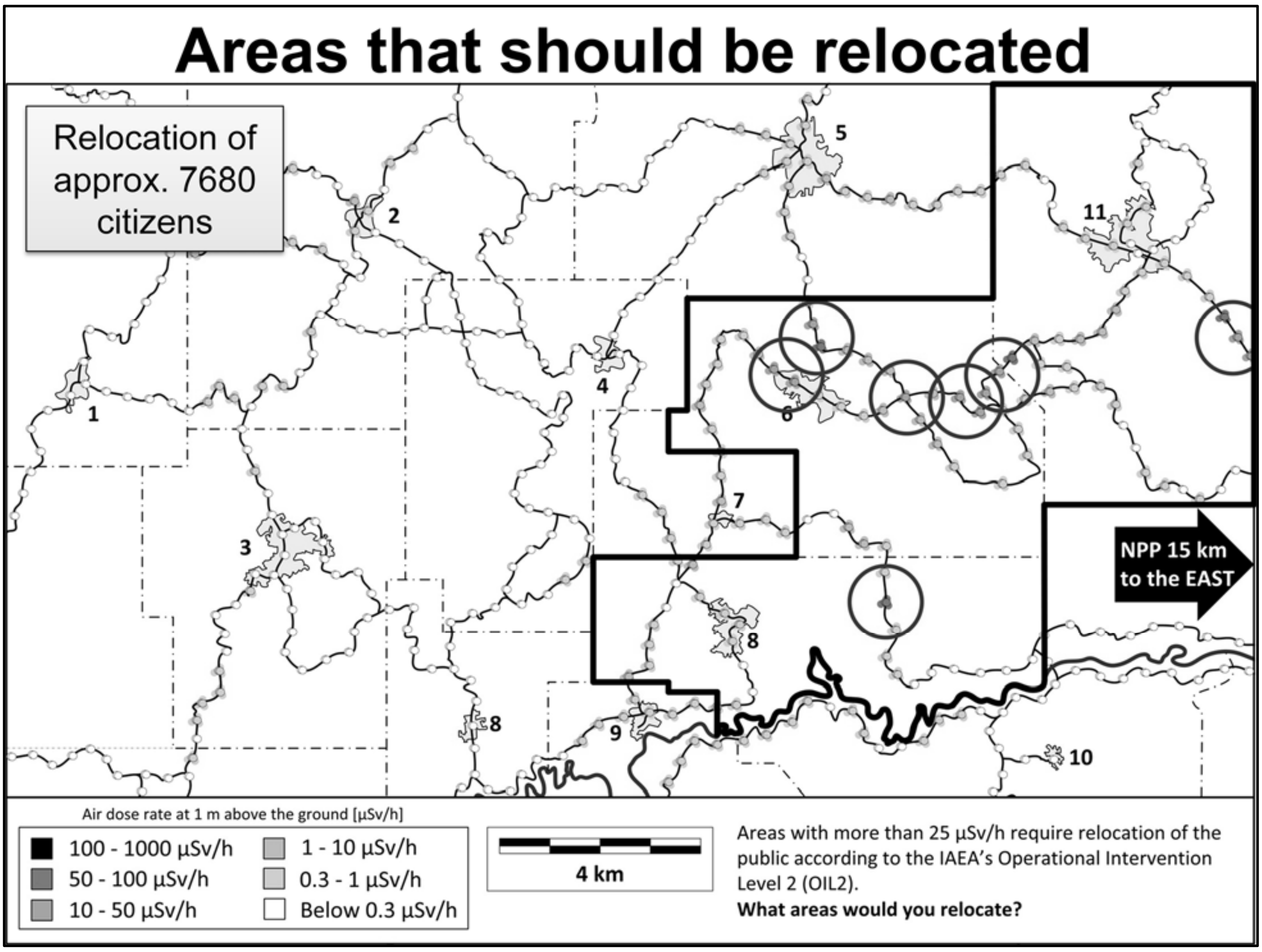
Additional information

- Data obtained during the second week after declaration of the general emergency
- Typical humid continental late summer with occasional storms in the evenings and wind shifts in all directions (climate classification – Dfb = warm summer subtype) (no detailed meteorological data available)
- Meteorological prediction for the area: normal summer days with occasional mild summer storms
- All roads are operational and the public is calm

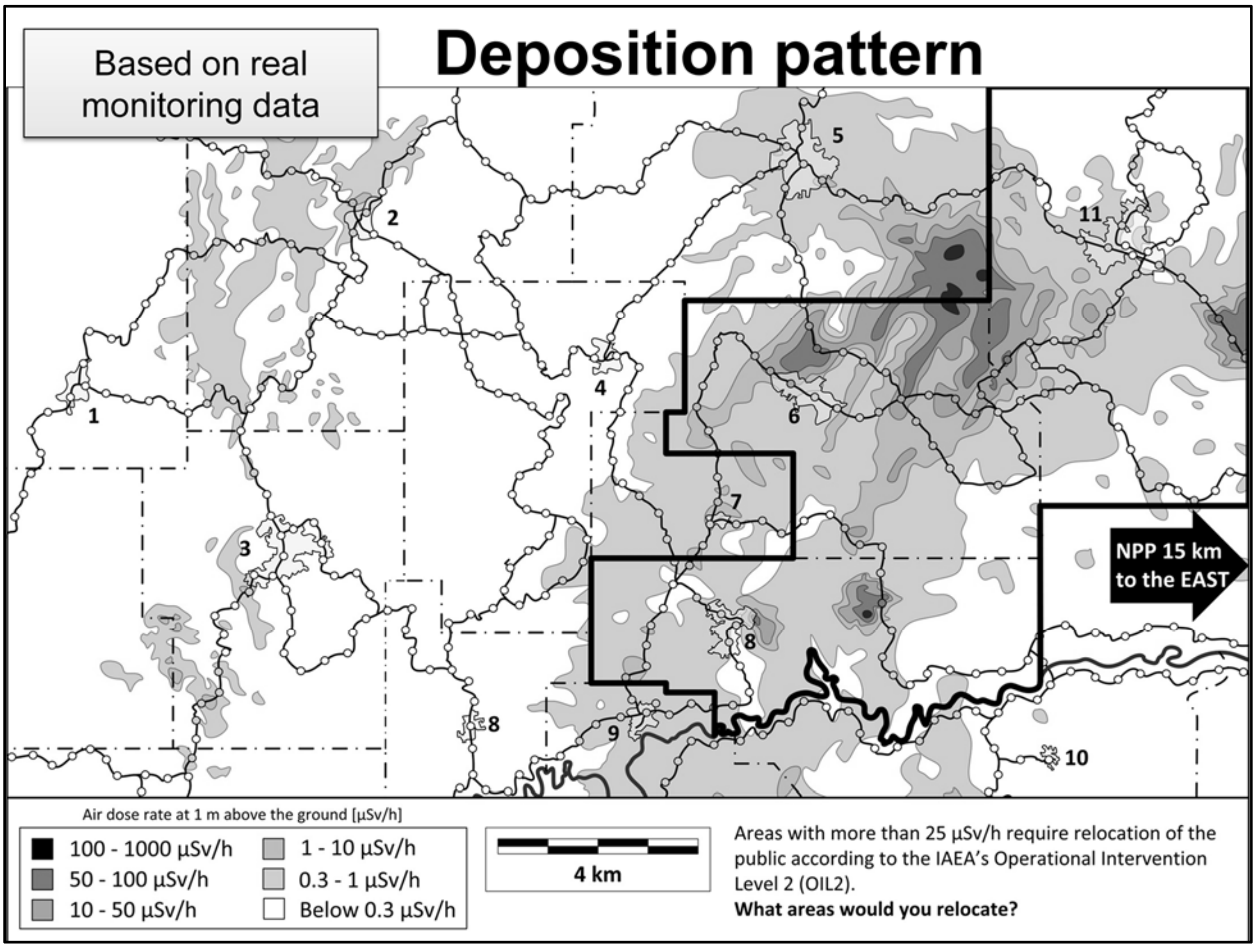
Village	No. of inhabitants
1	958
2	1003
3	2505
4	934
5	3214
6	2154
7	523
8	1965
9	856
10	210
11	3561

Map:

[31] PEEL, M.C., FINLAYSON, B.L., McMAHON, T.A., Updated world map of the Köppen-Geiger climate classification, Hydrol. Earth Syst. Sci. Discuss., **4** 439–473 (2007) posted at www.hydrol-earth-syst-sci-discuss.net/4/439/2007/



Based on the previously discussed strategy and available information the areas indicated in the figure should be evacuated.



A comparison with a real deposition pattern clearly shows the strengths and weaknesses of this strategy.

Protective Actions for an Emergency at a Nuclear Power Plant

Module 8
Part I

Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

IAEA
International Atomic Energy Agency

Lecture:

L-08 Protective Actions for an Emergency at a Nuclear Power Plant – Part I

Purpose:

To explain the actions required to protect the public for a severe emergency at a nuclear power plant.

Learning objectives:

On completion of this lecture participants will:

- Describe the risk to the public posed by a severe emergency at a nuclear power plant or spent fuel pool
- Decide on the protective actions and other response actions needed to protect the public based on:
  - Conditions at the plant
  - Environmental monitoring and sampling data

Author: Thomas MCKENNA **Revisions:** Phillip VILAR WELTER, Brian DODD, Eduardo LURASCHI

Duration: 2 hours

Learning objectives

*Upon completion of this module participants will be able to use the publication: **EPR-NPP PUBLIC PROTECTIVE ACTIONS** to:*

- *Describe the risk to the public posed by a severe emergency at a nuclear power plant or spent fuel pool*
- *Decide on the protective actions and other response actions needed to protect the public based on:*
  - *Conditions at the plant*
  - *Environmental monitoring and sampling data*

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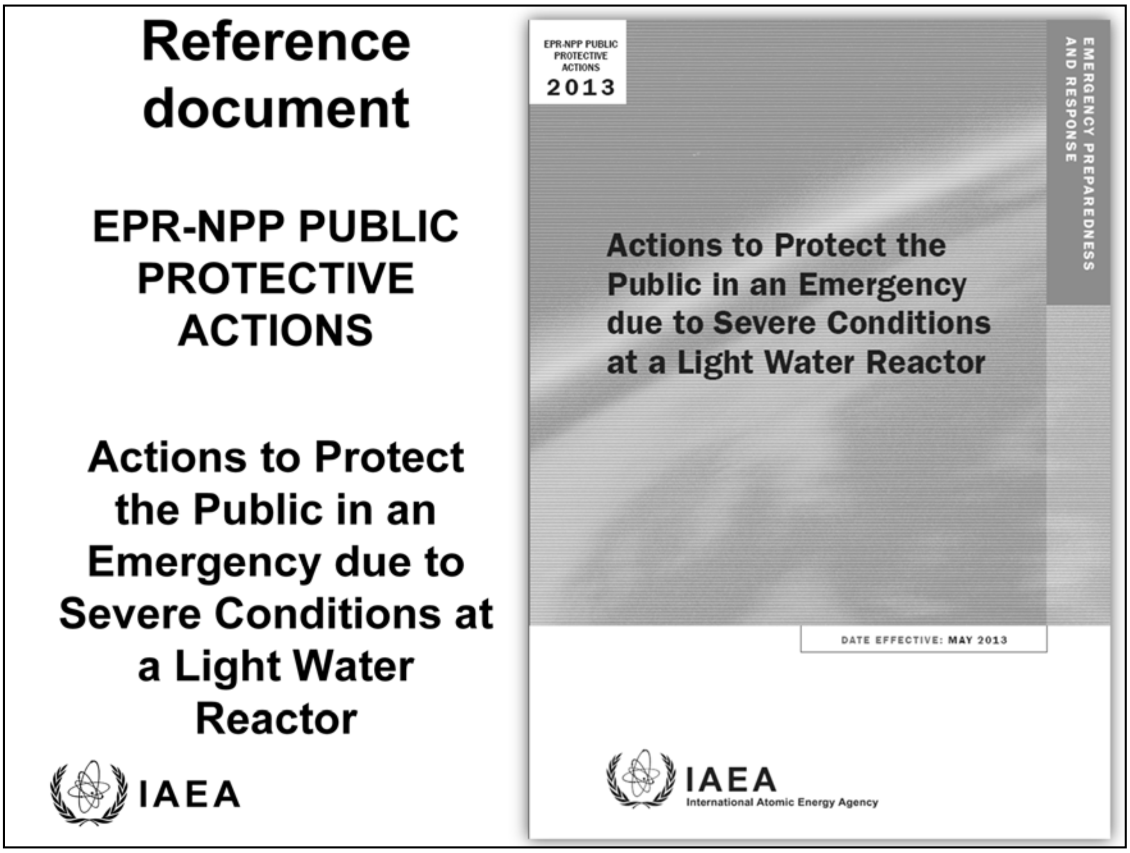

This presentation is based on the material contained in the EPR publication entitled Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor, EPR-NPP PUBLIC PROTECTIVE ACTIONS. References to pages, tables and figures in square brackets in this presentation are to this publication.

Objectives of the protective actions:

- To prevent injuries and deaths
- Keep the doses to the public below the generic criteria at which actions are justified to reduce the risk of stochastic effects (cancers)
- To prevent or reduce economic impact
- To prevent or reduce psychological and sociological effects

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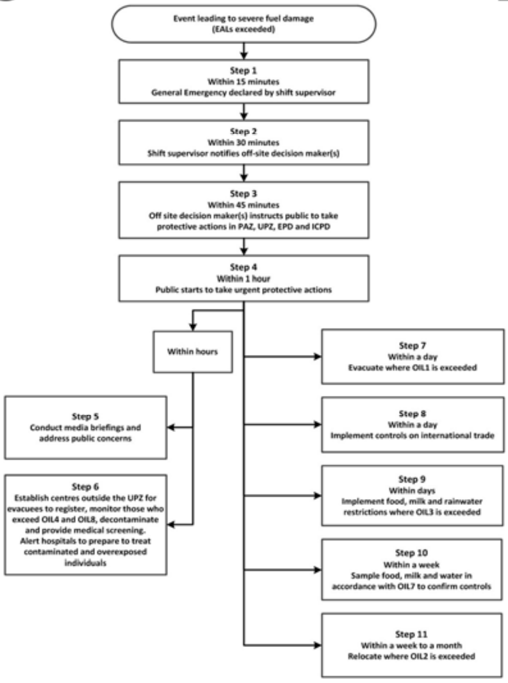
Module 8 is based on:

[Fig. 1, EPR-NPP PPA]

- The steps presented in Figure 1
- Following these for a severe emergency allows you to meet the objectives outlined in the previous slide



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This module is based on Fig. 1 *STEPS TO TAKE FOR AN EVENT THAT IS PROJECTED TO RESULT IN SEVERE DAMAGE TO THE FUEL IN A REACTOR CORE OR A SPENT FUEL POOL (GENERAL EMERGENCY)* of EPR publication entitled Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor, EPR-NPP PUBLIC PROTECTIVE ACTIONS.

Who is at greatest risk ?

- Pregnant women and children
- The public wants to know that they are being protected
- Protective actions are for their protection

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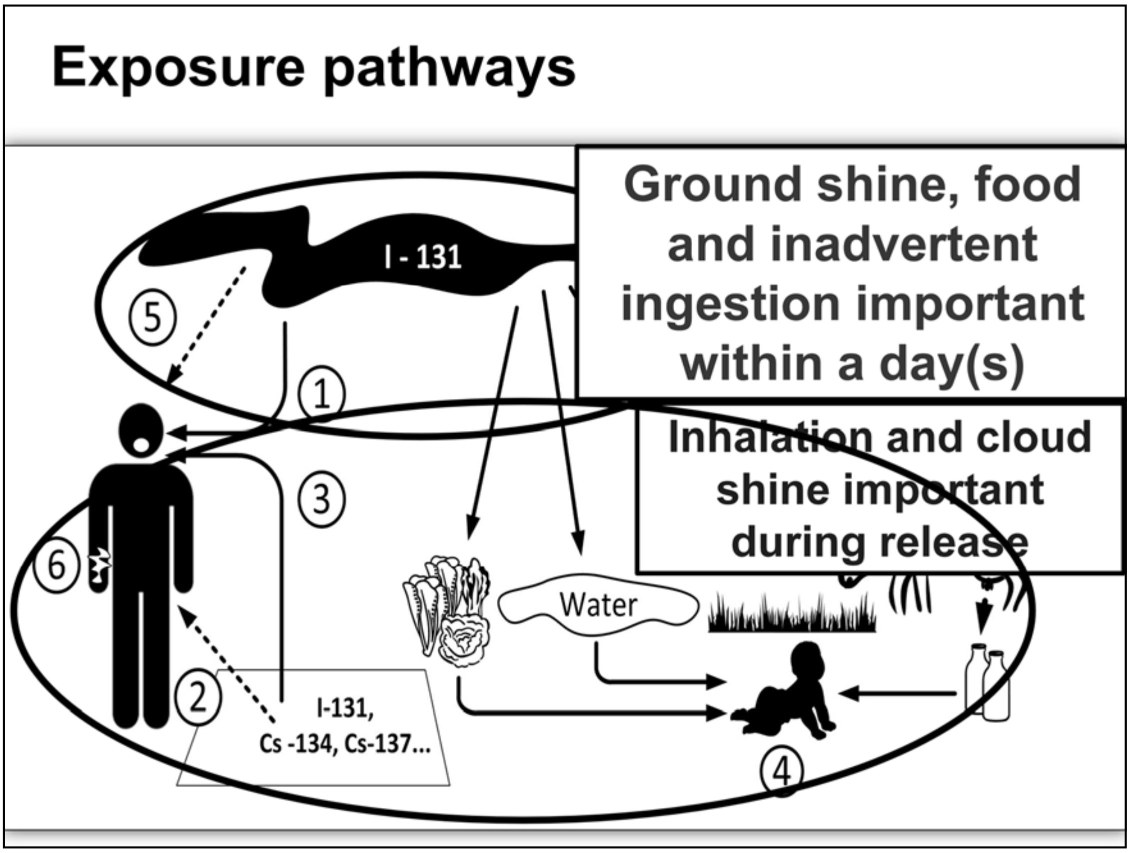
As we saw earlier, pregnant women and children are at greatest risk from a release from a nuclear power plant. Past emergencies have also showed that the public wants reassurance that these members of the public are being protected. Therefore, protective actions are taken to protect pregnant woman and children.



During a release, inhalation (1) and external exposure from the radioactive material in the cloud – called cloud shine (5) are the most important sources of dose. Inhalation of iodine would be the most important source of severe health effects to the thyroid and to the fetus. After a release, the ground shine (2) from material deposited on the ground becomes an important contributor to severe health effects within a day. Another important source of exposure after a release is inadvertent ingestion of contaminated dirt (3), for example by children playing on the ground. Within days, ingestion of food, milk or rainwater contaminated by deposition (4) can be a major concern even at more than 300 km away.

Response action to be taken to be effective

- **Based on plant conditions** (before monitoring)
  - Prevent/reduce doses from inhalation, cloud shine and short term ground shine and possibly ingestion before monitoring can be used as a basis for actions that would be effective
- **Based on monitoring and sampling**
  - Prevent or reduce impact (doses or other effects) from a release.

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Response actions will be discussed for two different situations depending on when actions need to be initiated in order to be effective:

- **Based on plant conditions.** In this case actions are taken before or shortly after a release to prevent or reduces doses directly from the plume (inhalation, cloud shine) and deposition (short term ground shine and possibly ingestion) before monitoring can be an effective basis for an effective response.

- **Based on monitoring and sampling.** In this case actions are taken to prevent or reduce: (a) dose from ground shine over days or longer, (b) dose from ingestion of food, milk and water contamination, (c) effects of received exposure and (d) effects on trade.

Where to prepare or act?

- Emergency zones and distances where arrangements are made in advance for prompt response

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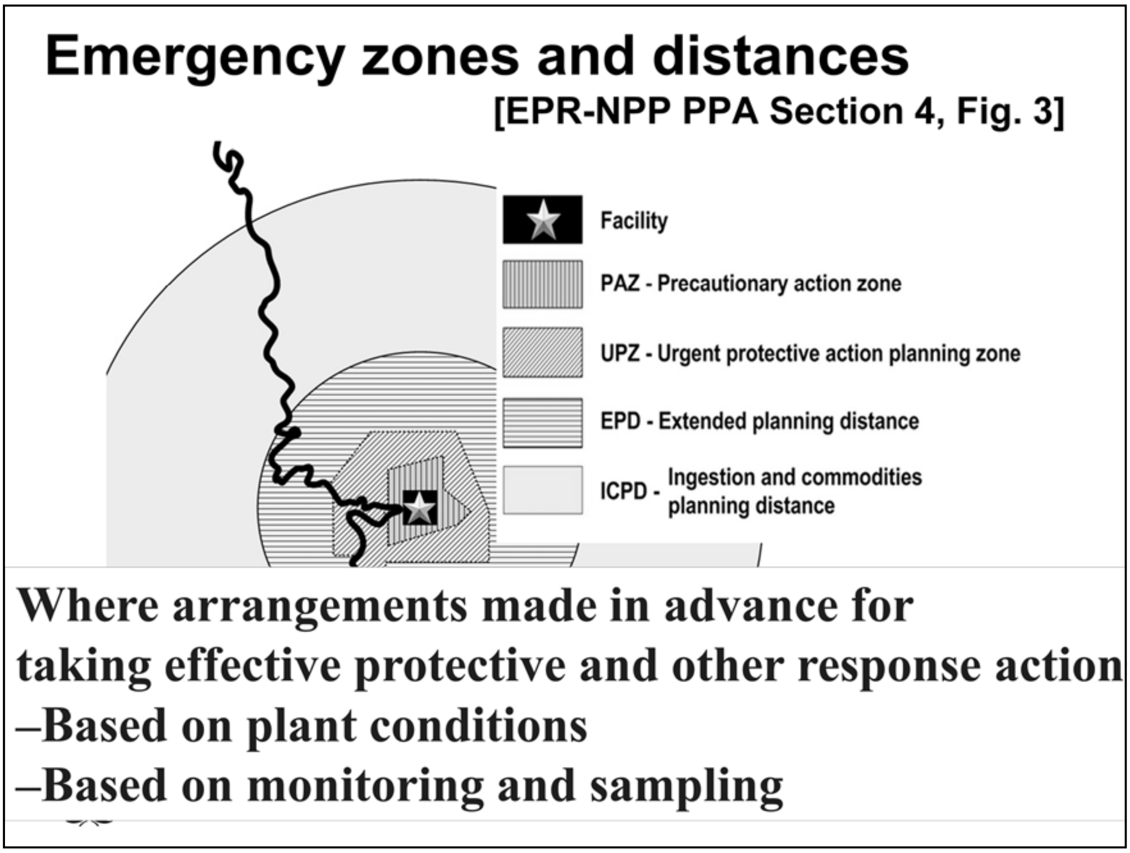

Section 4 of EPR-NPP PUBLIC PROTECTIVE ACTIONS discusses emergency zones and distances. Figure 3 shows graphically the areas that should be established and the protective actions that would be taken within each area.

Based on plant conditions (immediately upon detection of severe conditions in the plant – declaration of a general emergency) the following would be accomplished:

- Within the **precautionary action zone (PAZ)** arrangements should be in place to promptly take urgent protective measures when conditions are detected in the plant that can result in a severe release. Here, the aim is to act before a release in order to prevent severe deterministic effects.
- Within the **urgent protective action zone (UPZ)** arrangements will be made to take urgent protective measures when conditions are detected in the plant that can result in a severe release. Here, the aim is to act before or shortly after release in order to reduce stochastic effects (keep the below the Generic Criteria).
- Within the **ingestion and commodities planning distance (ICPD)**, when conditions are detected in the plant that can result in a severe release, announcements will be made to restrict consumption and distribution of vegetables and milk from grazing animals, consumption and distribution of rainwater and distribution of commodities until further assessment. These restrictions are intended to reduce the risk of stochastic effects (i.e. keep the dose below the generic criteria) and protect the economy by reassuring all trading partners that international trade is safe.

Based on monitoring:

- within the **extended planning distance (EPD)** arrangements will be made for prompt monitoring to locate hotspots requiring relocation.
- within all affected areas sampling and monitoring is conducted to ensure the adequacy of controls on ingestion and commodities.

Risk Posed by Severe Reactor Emergencies and Need for Action Before Monitoring

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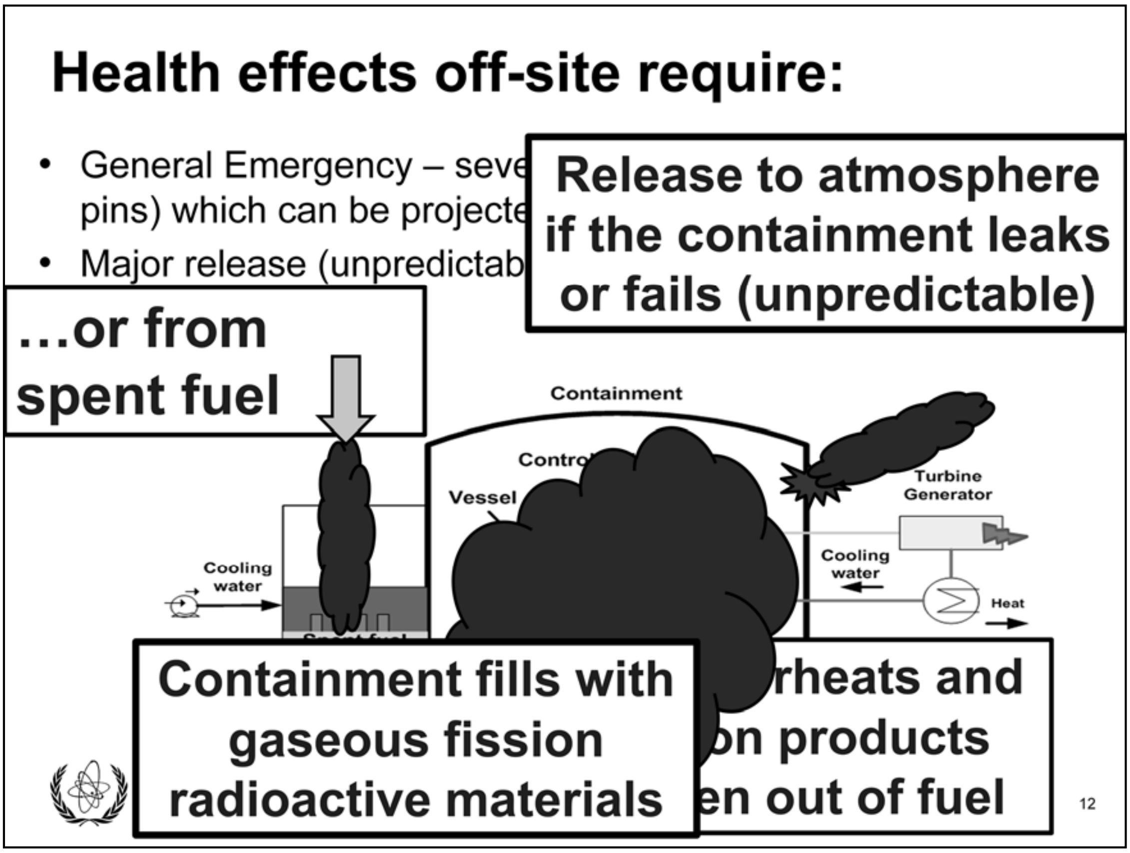

As we saw earlier, in order to have health effects off-site, damage to the fuel in the reactor core or spent fuel pool needs to have occurred, along with a major release. The threat to the public comes from the release of radioactive material from reactor fuel in the core or spent fuel pool due to overheating. When the fuel is no longer being covered with water it promptly overheats (temperature can increase at more than 2°C per second) and ultimately melts, driving out large amounts of radioactive material, in a gaseous form, into the containment. This gaseous radioactive material can be released directly to the atmosphere if there is any type of failure or leakage of the containment. Release of even a small fraction of this radioactive material can result in health concerns off-site.

As we have seen, the operating staff in a reactor should be able to detect conditions that will lead to fuel damage. However, containment leakage and failure are unpredictable.

An emergency that can result in fuel damage would be classified as a GENERAL EMERGENCY under the IAEA classification system [1].

For severe off-site health effects to take place, either the fuel in the core or the fuel in the spent fuel pool must have been severely damaged. In addition, there must have been a major release. Damage to the fuel in the spent fuel pool or the core can be predicted based on instrumentation in the control room; however, releases following fuel damage are unpredictable.

[1] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS OFFICE FOR THE COORDINATION OF HUMANITARIAN AFFAIRS, WORLD HEALTH ORGANIZATION, Preparedness and Response for a Nuclear or Radiological Emergency, Safety Standards Series No. GS-R-2, IAEA, Vienna (2002).

Support for sizes of PAZ and UPZ and associated protective actions in Appendix I

Where actions need to taken based on plant condition before monitoring in order to be effective:

- **PAZ** – to prevent the occurrence of severe deterministic effects;
- **UPZ** – to keep the doses below the generic criteria at which protective actions and other response actions are justified to reduce the risk of stochastic effects.

IAEA 13

Appendix I of EPR NPP PUBLIC PROTECTIVE ACTIONS discusses the basis for the PAZ and UPZ sizes and the recommended protective actions to be taken within these zones. Actions need to be taken in the zones before monitoring to be most effective:

– PAZ | actions to prevent the occurrence of severe deterministic effects

– UPZ | actions to keep the doses below the generic criteria in order to minimize stochastic effects.

Appendix I

Calculations to Support Zone Sizes

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TABLE 19 DOSIMETRIC CRITERIA USED FOR DETERMINING THE SIZE OF THE ZONES

Lowest threshold for all organs from external

Zone	Actions t… based on condition… prevent			Most important exposure pathway and considered in the calculations		
				Inhalation	Cloud shine	Ground shine
PAZ	Severe deterministic effects	$AD_{red\ marrow}$	1 Gy	X	X	1 day
		$AD_{fetus,inh}$	1 Gy	X		
UPZ	Stochastic effects (cancers)	E_{inh}	100 mSv	X		
		$H_{fetus,inh}$	100 mSv	X		

Pathways important before monitoring could be effective basis for action

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Turn to Table 19 of EPR-NPP PUBLIC PROTECTIVE ACTIONS. This table lists the dosimetric criteria used for the calculations to determine the suggested size of the PAZ and UPZ, together with the exposure pathways considered. These are exposure pathways that are the primary sources of exposure that can result in severe deterministic effects and stochastic effects that could be received before off-site monitoring can be used as an effective basis for protective actions.

Note the dose criterion for the $AD_{Red\ marrow}$ is used to assess effects from external exposure and is the lowest threshold for severe deterministic effects in any organ except the fetus (e.g. red marrow, lung, small intestine, gonads, thyroid, lens of the eye) [see Ref. [2]].

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Development of an Extended Framework for Emergency Response Criteria: Interim Report for Comments, IAEA-TECDOC-1432, Vienna (2005).

Release and meteorological assumptions

Release characterized considered to be a reasonable estimate for the worst possible release:

- 10% of volatile fission products
- Multi-hour release
- Typical meteorological conditions (D-Stability class, no wind, no rain)

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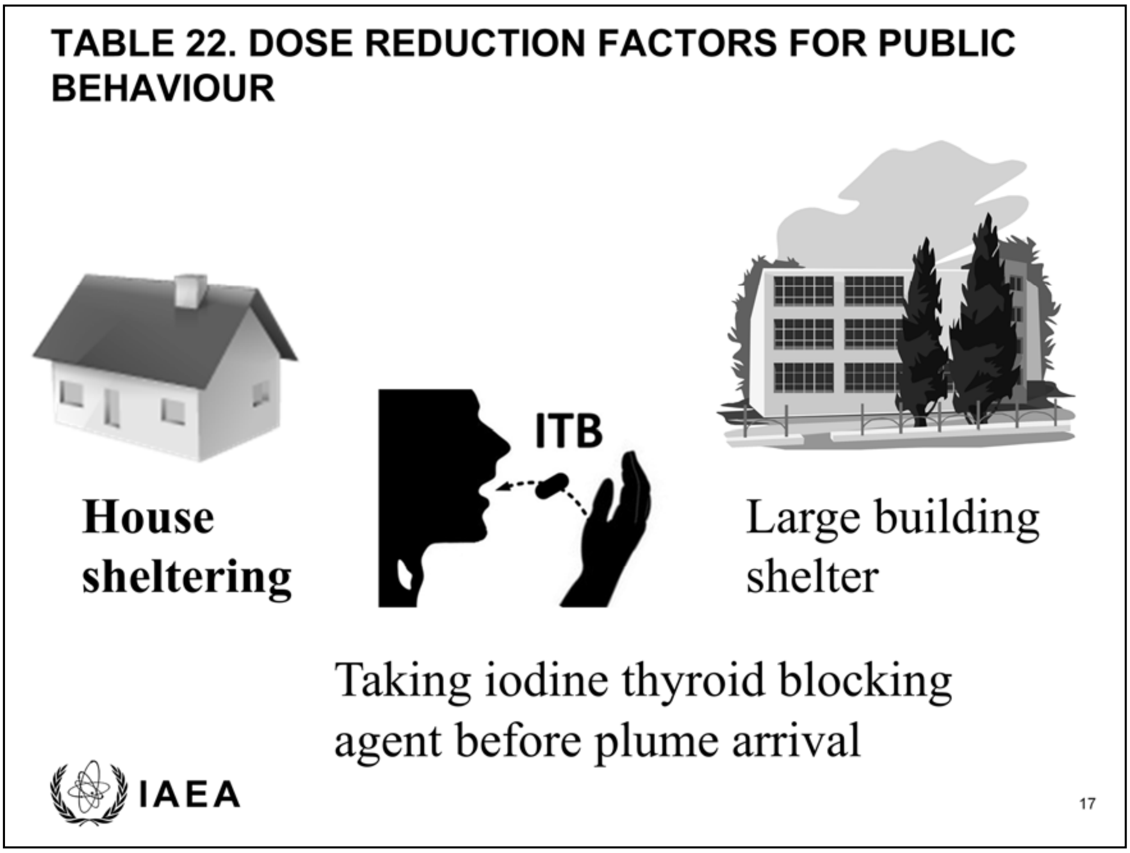
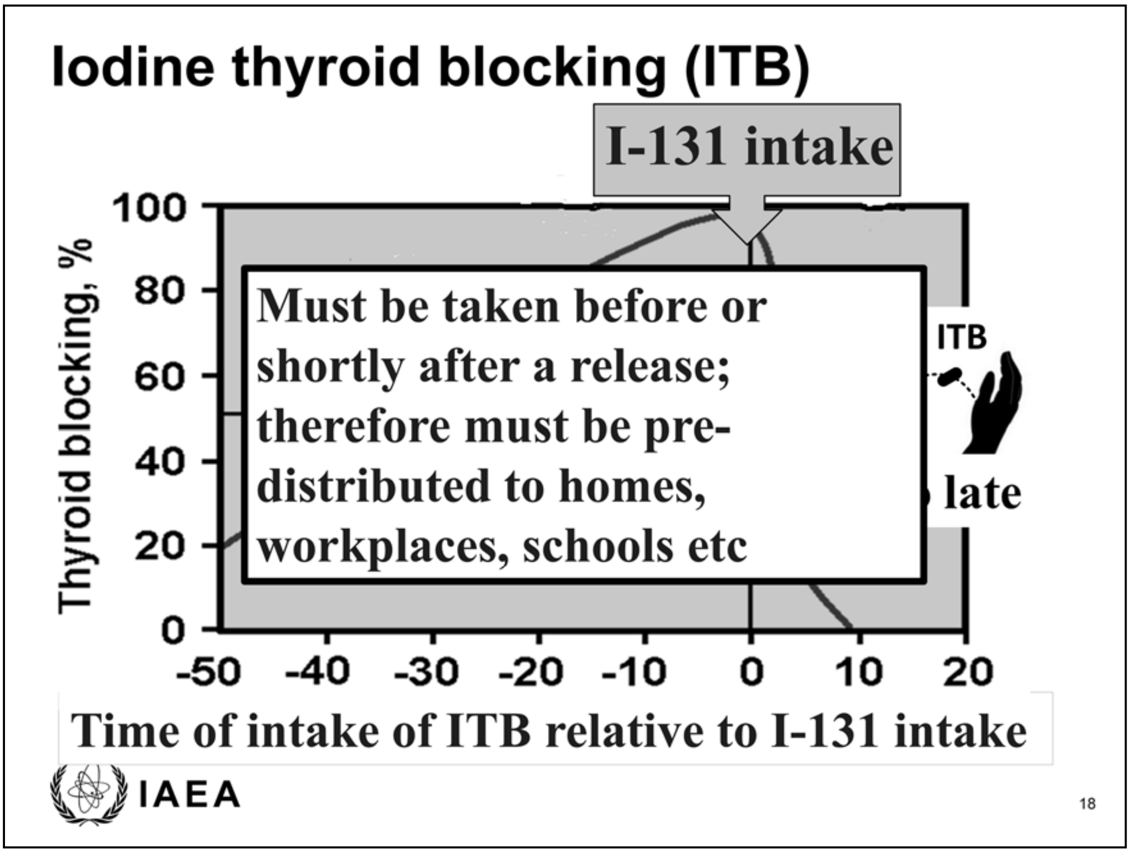
As discussed in Tables 20 and 21 in EPR-NPP PUBLIC PROTECTIVE ACTIONS.



Let us now turn to Table 22 of EPR-NPP PUBLIC PROTECTIVE ACTIONS, which provides the dose reduction factors used in the calculations to determine the suggested size of the PAZ and UPZ. The dose reduction factors in Table 22 are intended to be representative for:

- House sheltering: this case assumes the public is sheltered in a house during and after the release;
- Large building sheltering: this case assumes the public is sheltered inside a large multi-storey building during and after the release;
- Taking an iodine thyroid blocking (ITB) agent before or within two hours of inhalation of the radioiodine arising from a release.



The dose to the thyroid from inhalation can be greatly reduced by taking (ingesting) stable (non-radioactive) iodine, called iodine thyroid blocking (ITB) or iodine prophylaxis. However, as shown in this figure, the effectiveness of a single dose of ITB decreases rapidly after intake (inhalation or ingestion) of radioactive iodine. Therefore ITB agents must be taken before, or shortly after (within 1–2 hours) inhalation of radioactive iodine contained in the plume that is released from a nuclear power plant. Consequently, to be effective, iodine thyroid blocking agent must have been distributed beforehand to homes near the site as part of the preparedness process and the public instructed to immediately take it when damage to fuel is projected (= when a General Emergency is declared).

Taking an iodine thyroid blocking agent cannot prevent other severe effects such as deaths from a release: therefore distribution of iodine thyroid blocking agent must not delay other protective actions such as evacuation or sheltering.

Iodine thyroid blocking (ITB) [EPR-NPP PPA, Section 5.1]

- Must be administered before the release
- Must be immediately available
- No time for distribution during emergency
- Requires considerable logistical effort and clear instructions to be effective
- Therefore typically used in the area of greatest risk near the plant (30 km UPZ)

IAEA 19

An iodine thyroid blocking (ITB) agent, as discussed in Section 5.1 of EPR NPP PUBLIC PROTECTIVE ACTIONS, needs to have been distributed beforehand in a way that it can be taken immediately by the public living near the plant. This would require considerable administrative effort, logistical coordination and training for the public on what steps to take for the medicine to be effective. Therefore, provisions for providing iodine thyroid blocking are typically limited to within 30 km of the plant (UPZ).

Results of the calculations
[EPR-NPP PPA, Figs 18-23]

PAZ (severe deterministic effects)

- Fig. 18. $AD_{red\ marrow}$ without rain
- Fig. 19. $AD_{red\ marrow}$ with rain
- Fig. 20. $AD_{fetus,inh}$ with ITB agent
- Fig. 21. $AD_{fetus,inh}$ without ITB agent

UPZ (generic criteria – cancers)

- Fig. 22. E_{inh}.
- Fig. 23. $H_{fetus,inh}$ with ITB agent

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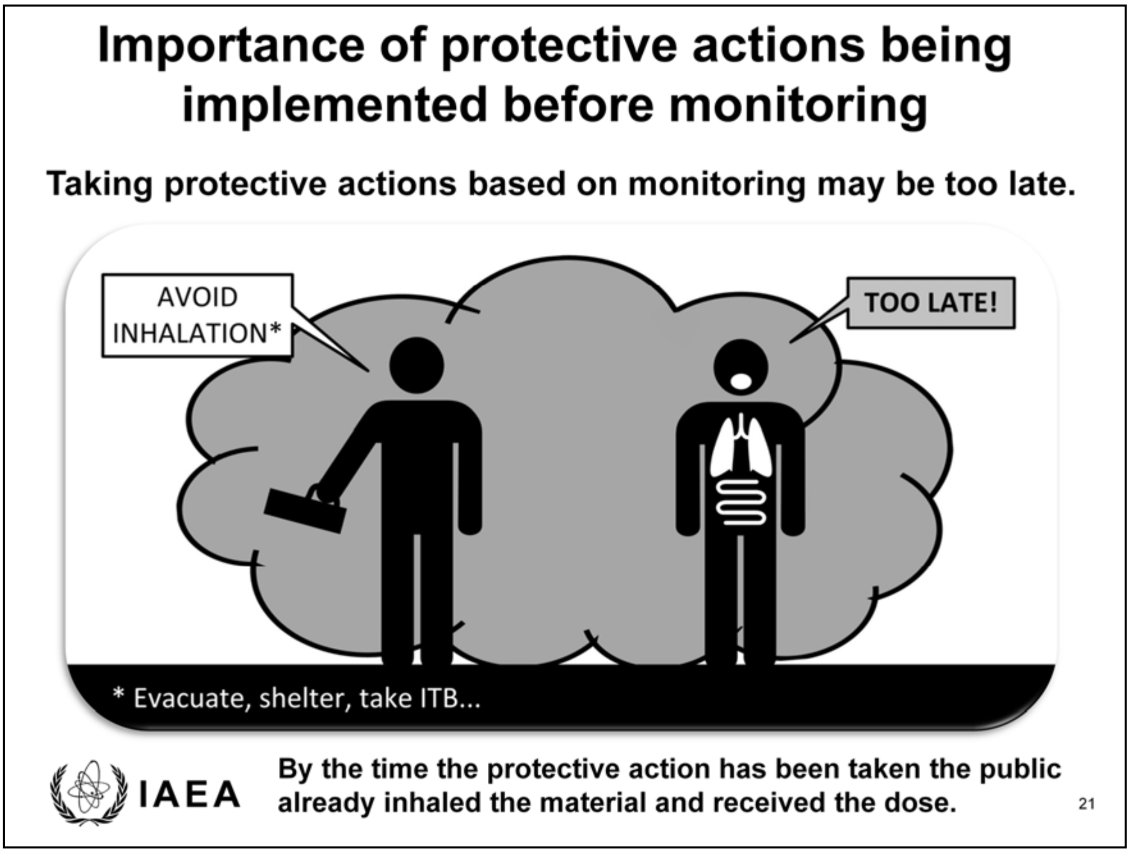
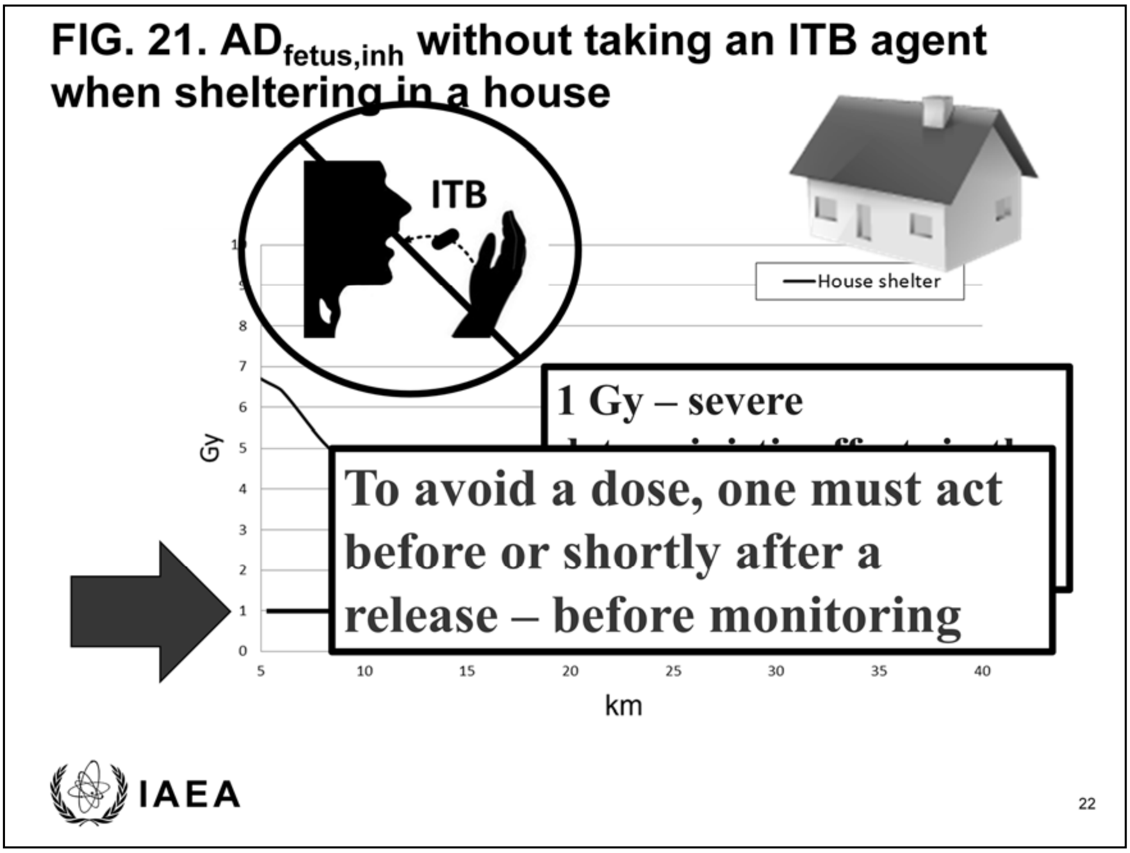
These figures in EPR-NPP PUBLIC PROTECTIVE ACTIONS show the results of the calculations used to support the suggested distance for the PAZ and UPZ.



The dose resulting from inhalation of the passing plume can be a very important source of dose during the emergency, especially to the fetus and the thyroid.

If protective actions, such as evacuation, sheltering or ITB are taken based on environmental monitoring results, and not on plant conditions, it may be too late for them to be effective.



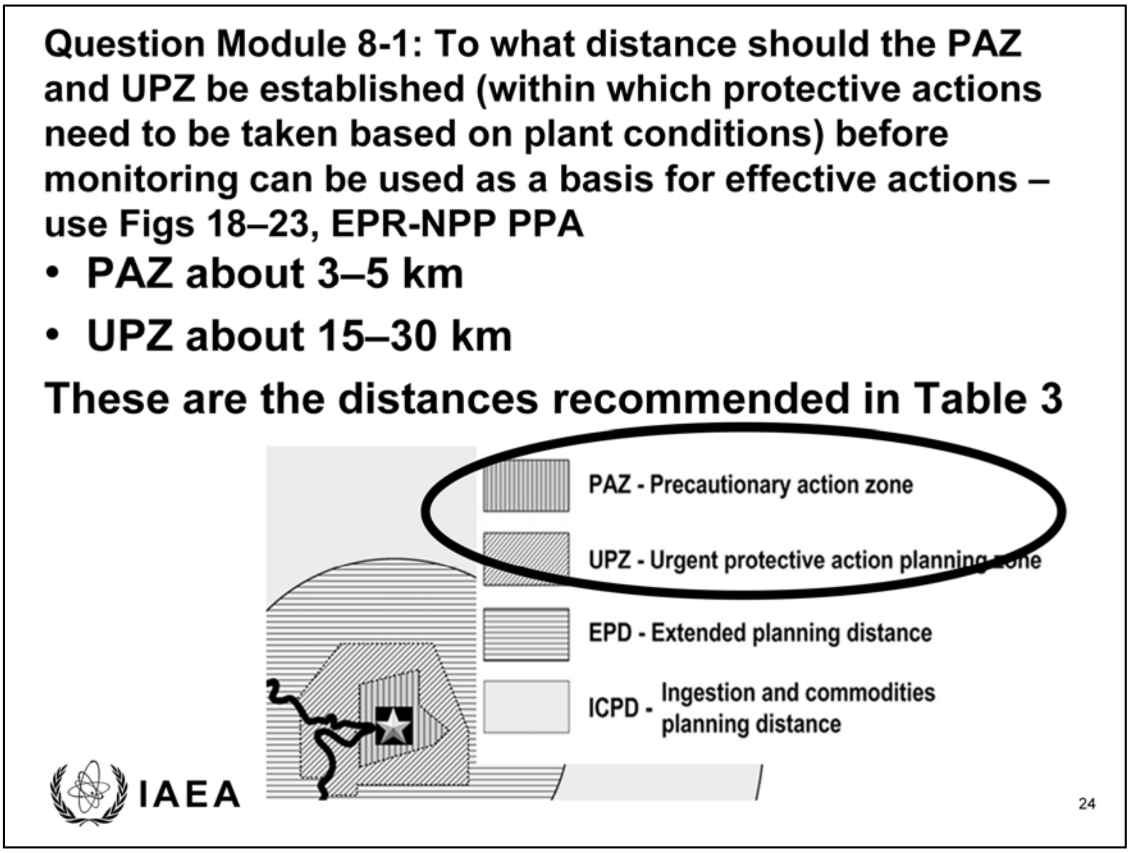
Turn to Fig. 21 of EPR-NPP PUBLIC PROTECTIVE ACTIONS. This shows the dose to the fetus from inhalation assuming ITB is not taken. If an **ITB agent is not taken** before or shortly after inhalation, a dose of 1 Gy (AD$_{fetus, inh}$, Table 19), for which there is a high probability of severe deterministic effects being seen in the fetus, is projected to be exceeded out to a distance of about 30 km for a pregnant woman sheltering in a house. Any protective actions to avoid doses arising from inhalation (e.g. taking ITB agent) must be implemented before or shortly after the release and thus before monitoring can be performed.

Question Module 8-1: To what distance should the PAZ and UPZ be established (within which protective actions need to be taken based on plant conditions) before monitoring results can be used as a basis for effective actions – use Figs 18–23, EPR-NPP PPA

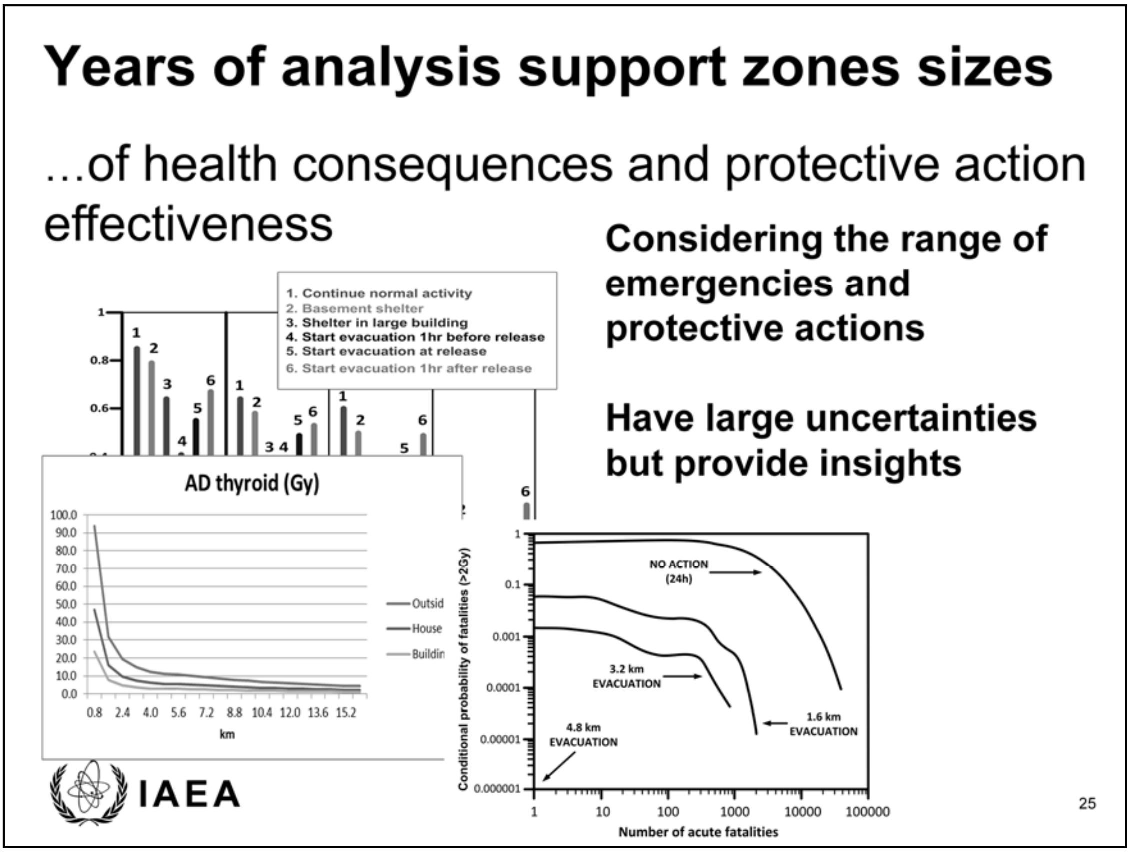
- **PAZ** – to prevent the occurrence of severe deterministic effects; and
- **UPZ** – to keep the doses below the GC at which protective actions and other response actions to reduce the risk of stochastic effects need to be taken

IAEA 23

Ask participants to use Figs 18–23 in EPR-NPP PUBLIC PROTECTIVE ACTIONS to decide to what distance the PAZ and UPZ should be established within which protective actions need to be taken before monitoring results can be used as a basis for effective actions.



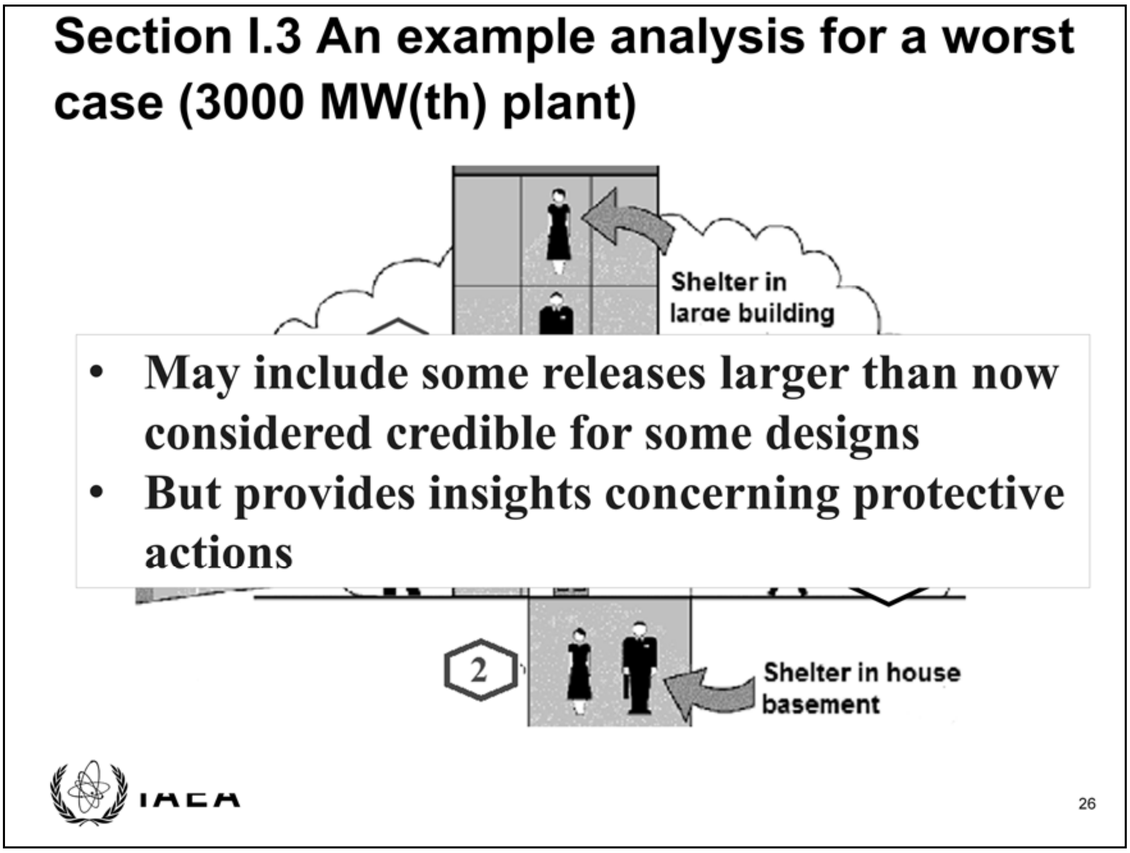
See discussion of the basis in Sections I.2.1 and I.2.2 of EPR-NPP PUBLIC PROTECTIVE ACTIONS. These are the distances recommended in Table 3 of this publication.



The suggested sizes for the zones is supported by a large number of studies conducted over the past 30 years.

These studies considered the full range of possible reactor and spent fuel emergencies and the protective action strategies that could be reasonably used to protect the public.

There is a great deal of uncertainty in these analysis but they consistently arrived at some basic insights that can provide the foundation for a protective action strategy.



Let us look at an example of other analyses [3] that is discussed in Appendix I of EPR NPP PUBLIC PROTECTIVE ACTIONS. This is for what is considered the worst possible emergency at a large nuclear power plant (3000 MW (th)) involving melting of the fuel in the core of the reactor and a failure of the containment. This analysis was for very severe emergencies involving melting of the fuel in the core and a large early release from the containment. This includes a spectrum of releases, some of which are no longer considered credible for many reactor designs. However, this analysis provided valuable insights into the effectiveness of various protective actions.

This analysis examined the following protective action strategies given a severe release resulting from damage of the fuel in reactor core (core melt) and containment failure.

1. Not taking any protective actions carrying on normal activity.

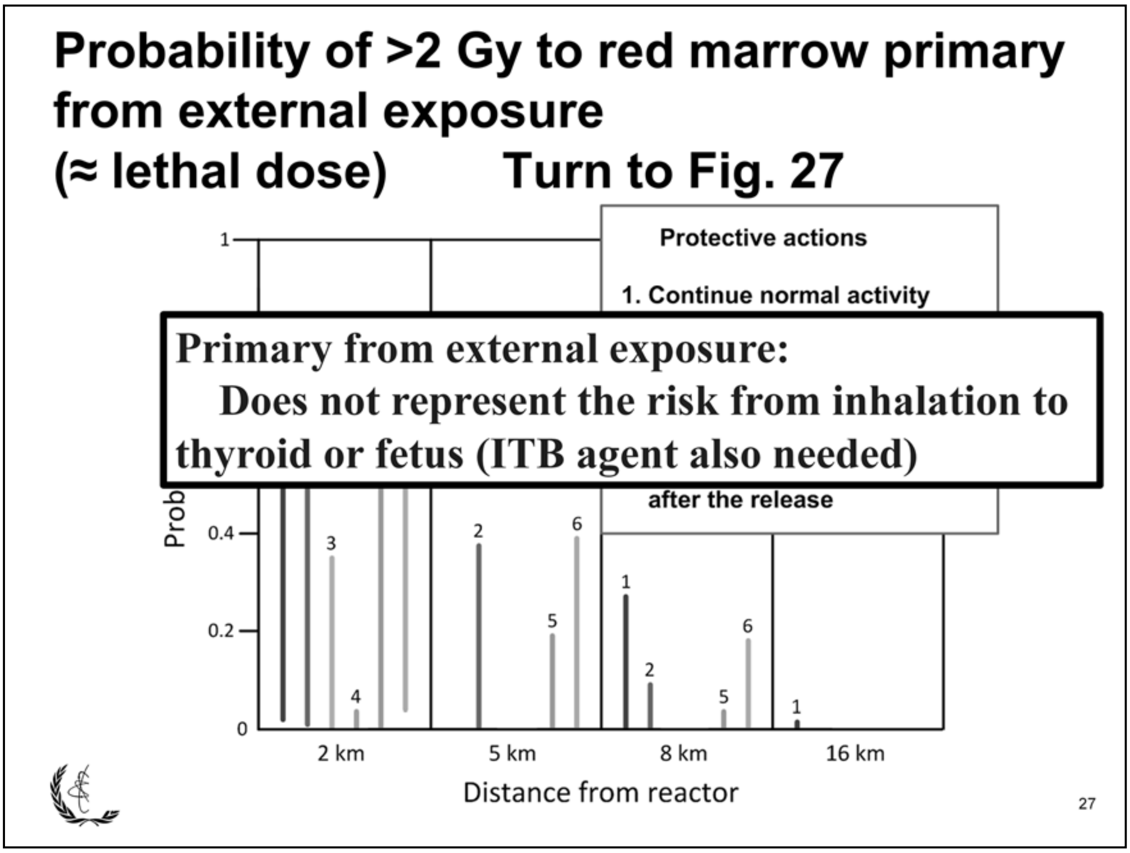
2. Home sheltering. This assumed sheltering in a masonry house or basement of a wood frame house.

3. Large building shelter. This assumed the protection provided by a large building, for example, an office building, hospital, apartment building or school.

4. Evacuation starting 1 hour before start of release at ≈ 4 km per hour (walking speed).

5. Evacuation starting when the release begins at ≈ 4 km per hour (walking speed).

[3] US NUCLEAR REGULATORY COMMISSION, Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants, NUREG-1150, USNRC, Washington, DC (1990).



Turn to Fig. 27 in Appendix I of EPR-NPP PUBLIC PROTECTIVE ACTIONS. This figure shows the results of the analysis. The bars show the probability of a person receiving, primary from external exposure, an RBE weighted dose to the bone marrow of greater than 2 Gy which is near the threshold for deaths. The bars in the figures represent the uncertainty resulting from the size of the release and weather conditions. An ITB agent was not considered since it would not affect the red marrow dose. Therefore in using these figures to examine the effective of the various protective actions it should be assumed that ITB agent was given before or shortly after the plume arrived in each case.

Within about 5 km from the nuclear power plant the only response that greatly reduces the chance of receiving 2 Gy is to start to evacuate before the start of the release (Case 4).

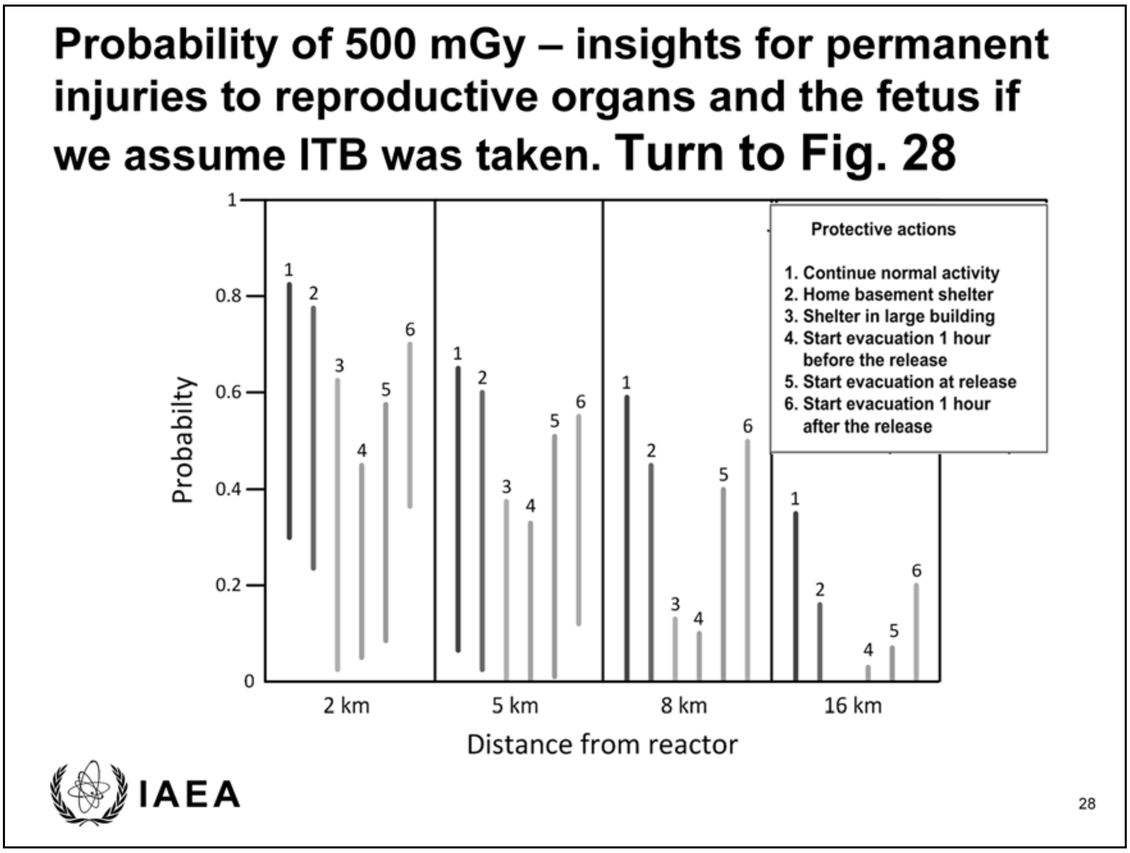
At 5–8 km people can greatly reduce their probability of receiving a dose exceeding 2 Gy either by starting to evacuate before the start of the release (Case 4) or by sheltering in large buildings (Case 3).

At 16 km, in most cases, no protective action except relocation from hotspots (areas with high dose from deposition) would be necessary to avoid 2 Gy to the red marrow.

More recent studies of release amounts and timing (source terms) that were considered more creditable show that evacuations at speeds greater than 7 km per hour starting at time of the release reduce risk of early fatalities to essentially zero.

Even walking out in the plume is better than basement shelter in a normal home. This analysis assumes that the *evacuation is conducted at walking speed* and all people in areas with significant levels of contamination are evacuated within 6 hours.

Remember: this does represent the risk from inhalation, so to protect the fetus and thyroid an ITB agent would need to be taken before the plume arrives.



Turn to Fig. 28 in Appendix I of EPR-NPP PUBLIC PROTECTIVE ACTIONS.

Figure 28 shows the probability of exceeding 500 mGy to the red marrow. This provides insights concerning prevention of non-fatal severe deterministic effects such as permanent injuries to the reproductive organs (threshold 1000 mGy) or the fetus (threshold 1000 mGy). However, for protection of the fetus we must also assume that an ITB agent was taken before intake to protect the foetal thyroid.

Within 8km starting to evacuate one hour before a release combined with ITB is the most effective strategy (Case 4) and

Beyond about 16 km all the strategies substantially combined with ITB reduce the risk of exceeding 500 mGy, and thus the probability of having severe effects in the fetus or reproductive organs.

Question Module 8-2: Beyond what distance (km) would these actions be effective?

[Figs 27 & 28, EPR-NPP PPA]

…in protecting the public in a severe emergency? Assume ITB was taken.

Action	2 Gy (Deaths)	500 mGy (Other severe deterministic effects)
Continue normal activity		
Home basement shelter + ITB		
Shelter in large building + ITB		
Start evacuation 1 h before release + ITB		
Start evacuation at time of release + ITB		
Start evacuation 1 h after start of the release + ITB		

Ask the participants based on Figs 27 and 28 of EPR NPP PUBLIC PROTECTIVE ACTIONS to fill out this table with the distance **beyond** which these actions would be effective in protecting the public from severe deterministic effects by keeping the dose below 2 Gy (near the death threshold) and below 0.5 Gy (dose above that resulting in permanent injuries to the fetus and reproductive organs). **Tell them to assume that ITB was also taken to protect the fetal thyroid.**

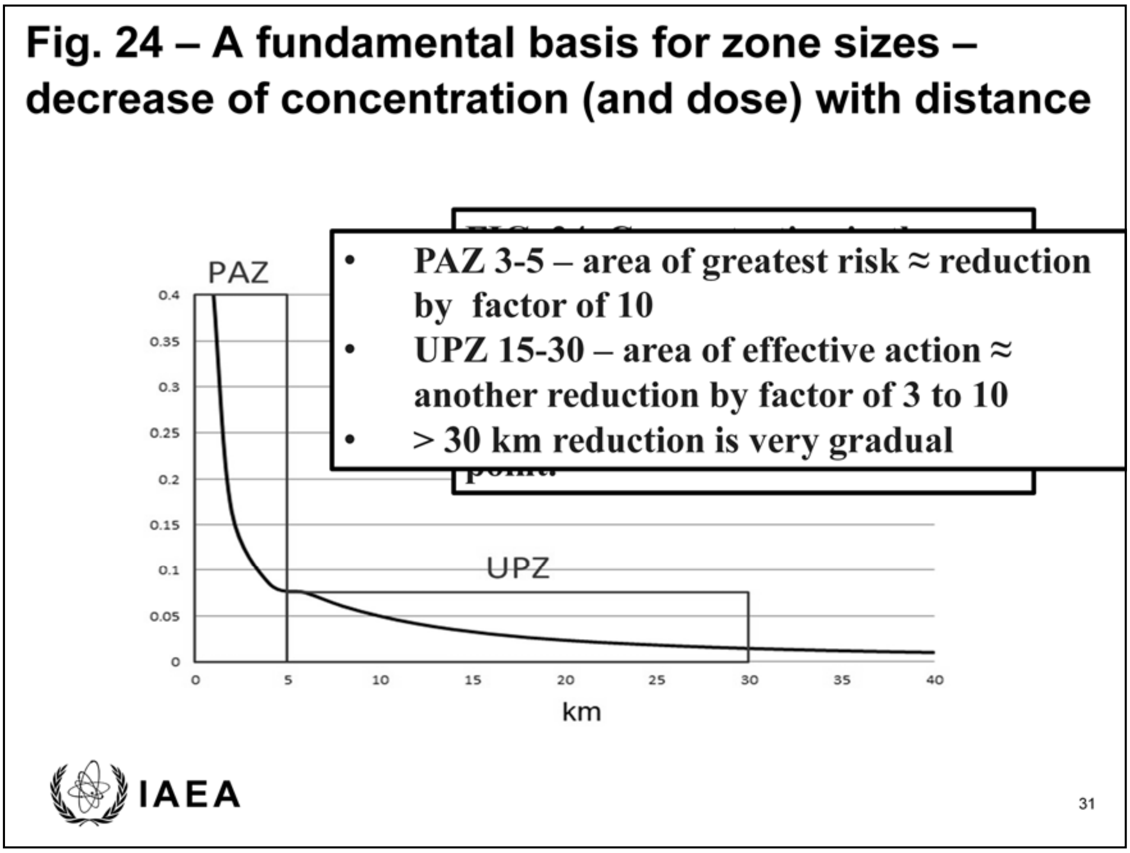
Answer Module 8-2: Distance beyond which action would be effective in protecting the public?

…assuming a P of <0.2 – what did you assume?

Action	2 Gy (Deaths)	500 mGy (Other severe deterministic effects)
Continue normal activity	>8	>16
Home basement shelter + ITB	> 5	>16
Shelter in large building + ITB	>2	>8
Start evacuation 1 h before release + ITB	> Site boundary	> 5 - 8
Start evacuation at time of release + ITB	> 5	>8
Start evacuation 1 h after start of the release + ITB	>16	>16

Remember: this assumes an evacuation at walking speed (4 km/h)
At higher evacuation speeds – evacuation is more effective

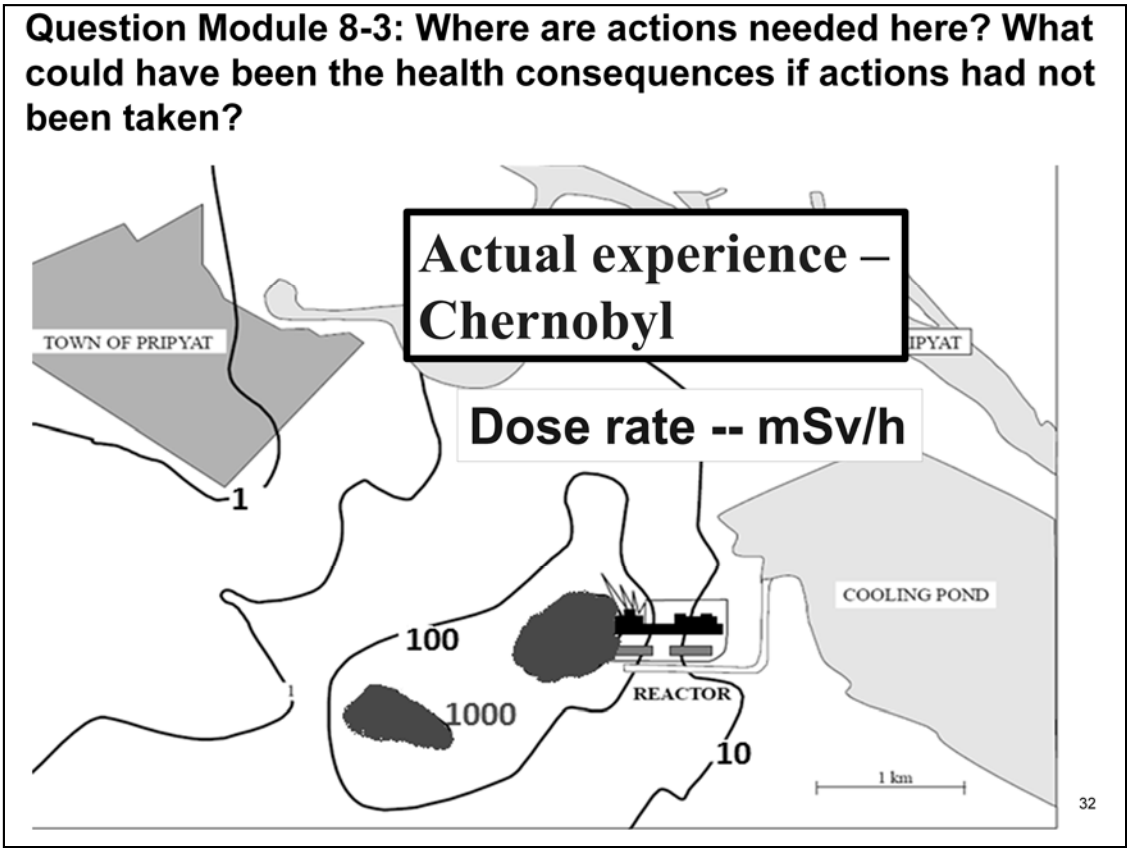
This shows approximately the distances beyond which these protective action would be effective in keeping the probability below 0.2.



Turn to Fig. 24 of EPR-NPP PUBLIC PROTECTIVE ACTIONS. This figure shows and Section I.2.3 discusses a fundamental basis for the zone sizes – reduction of the concentration and thus the dose with distance. Figure 24 shows that within about 3 to 5 km there is a reduction by a factor of 10 and another reduction of a factor of 3 after the plume has travelled about another 10 km. However, a further reduction by a factor of 3 is not observed until the plume has travelled an additional 25 km (out to about 40 km).

Establishing a PAZ with a boundary less than about 3 km should be avoided because it could greatly increase the risk to the public and establishing the boundary at significantly more than 5 km should be carefully considered to ensure it will not reduce the effectiveness of the protective actions for those close to the plant who are at greatest risk.

Beyond about 3 to 5 km it would be most efficient to concentrate on taking protective actions within approximately 15 to 30 km, which is the suggested starting point for establishing the boundary of the UPZ. Establishing the boundary of the UPZ at substantially less than 15 km should be avoided because of the increased risk to the public. However, establishing the boundary of the UPZ at significantly more than 30 km should also be carefully considered since: (a) it provides very little additional benefit because of the very gradual decrease in dose with distance and (b) may delay implementation of protective actions for those at greatest risk close to the plant.

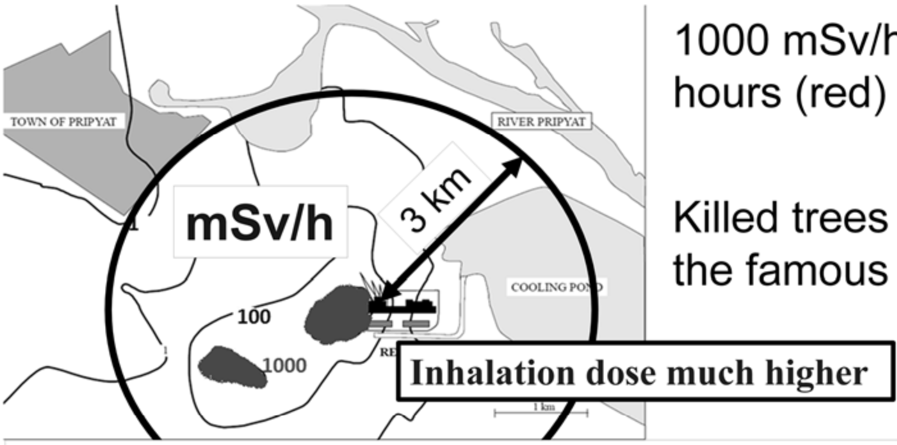


This shows the dose rate measured near Chernobyl in April 1986.

Ask the participants: Where are actions needed here? What could have been the health consequences if these actions had not been taken?

Image credit: UNITED NATIONS, Sources and Effects of Ionizing Radiation, 2000 Report to the General Assembly, Scientific Committee on the Effects of Atomic radiation (UNSCEAR), Vol. II: Effects, Annex: Exposures and Effect of the Chernobyl Accident, UN, New York (2000) p. 468

Answer Module 8-3: Where are actions needed here? What could have been the health consequences if actions had not been taken?



1000 mSv/h lethal in hours (red)

Killed trees – forming the famous red forest

- **Lethal dose rates at 2 km**: Needed to act on plant conditions within 3-5 km – evacuating or sheltering + ITB
- **All other areas:** with >1 mSv/h, this exceeded OIL1 requiring evacuation or sheltering, but action should have taken based on plant conditions and not awaiting monitoring

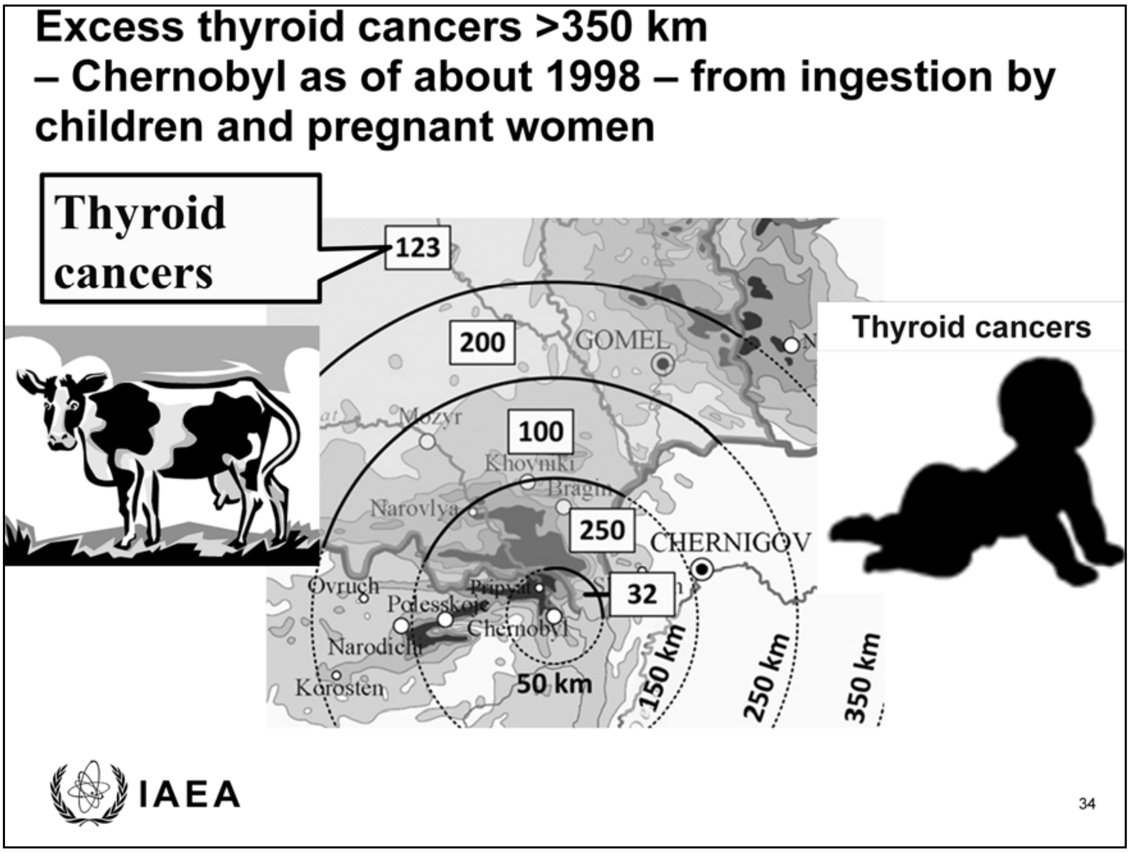
The areas shown in red had dose rates in excess of 1000 mSv/h (some at about 2 km from the plant). Someone in those areas could have received a lethal dose in less than an hour due to the external dose from the passing plume and ground deposition. There were no fatalities because this was a forest and no one lived there; however, this release did kill the trees, resulting in the famous "red forest". If the wind had been blowing towards the town of Pripyat (where many people were outdoors watching the fire at the plant) when this release occurred, there could have been fatalities and very large doses from inhalation.

This shows that the actions based on monitoring would have been too late to prevent severe health effects among those who may have been in the plume caused by the first release near the plant. Hence the importance of taking protective actions based on plant conditions. As discussed earlier, all those located within 3 to 5 km of the plant should have been sheltered (since provisions from prompt evacuation were not available) and should also have been administered iodine thyroid blocking means as soon as severe conditions were detected in the plant.

The OIL1 calling for evacuation or sheltering is exceeded for areas with > 1 mSv/h (1000 μSv/h), well beyond 3 km; however, those in all the area shown should have also sheltered and taken ITB and not waited for monitoring since dangerous doses could have been received before monitoring could be performed.

Abbreviation:

OIL – operational intervention level



Deposition of radioactive material in the plume from a severe core damage accident could contaminate vegetables, rainwater and milk from animals grazing on contaminated pasture, rainwater or wild products (mushrooms or game) to levels that would result in doses exceeding the generic criteria beyond 300 km.

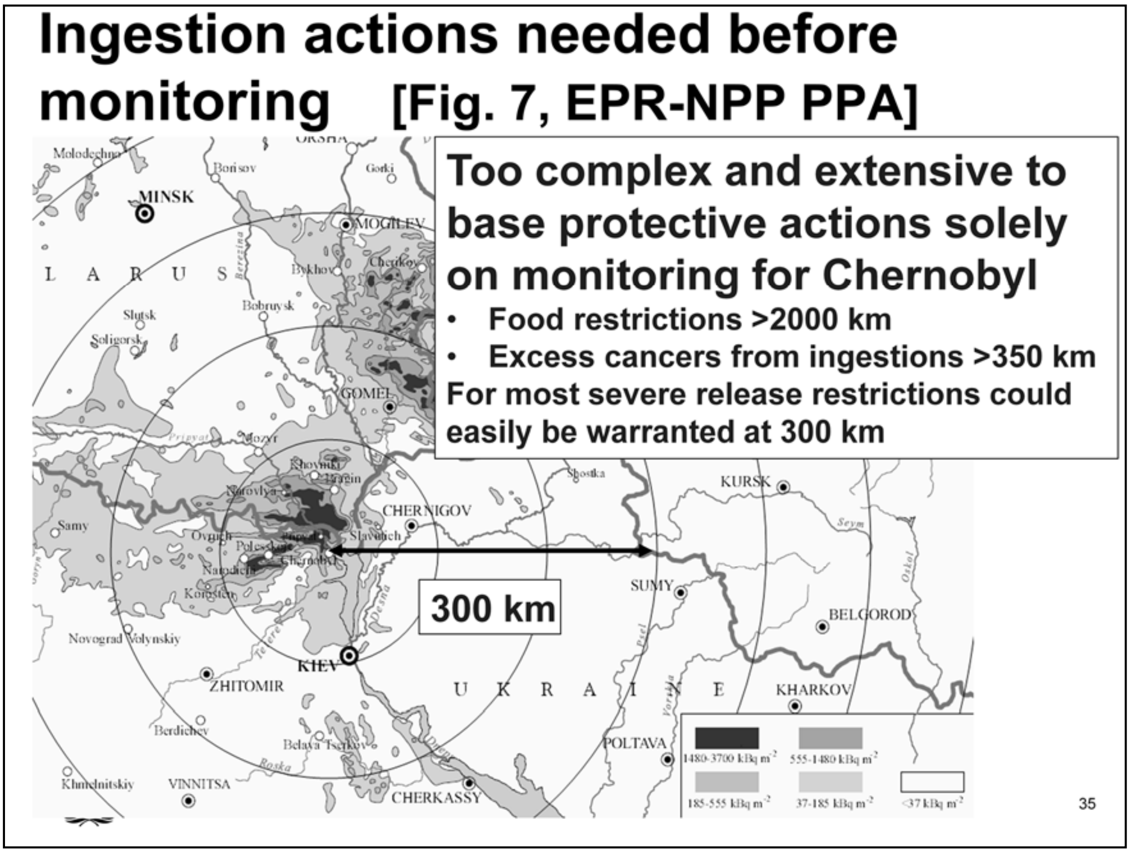
This figure shows the numbers of excess thyroid cancers in Belarus after Chernobyl as of about 1998. Note that most were beyond 50 km and occurred at >350km. The Belarussian border is located about 7 km from the Chernobyl plant and the country was seriously affected by the accident. Since 1990, there has been a large increase in the incidence in thyroid cancer among Belarussian children who were aged between 0 and 18 at the time of the accident. Over 6000 thyroid cancers had been diagnosed by 2010. Thyroid cancer in children is very rare and therefore these cancers can easily be attributed to the iodine releases from the power plant.

The principal cause is the dose to the thyroid from eating leafy vegetables contaminated with radioactive iodine and drinking milk from cows grazing on contaminated pasture. Most of these cancers were among children less than six years old at the time of the accident and the vast majority were diagnosed in those living more than 50 km from the plant; excess cancers from ingestion were seen at distances of more than 350 km from the plant.

Cows were typically grazing in Belarus at the time of year when the accident occurred, and yet no efforts were taken to restrict the consumption of privately produced contaminated milk for the first days following the accident. The vast majority of these excess cancers could have been prevented by instructing the population not to drink potentially contaminated milk.

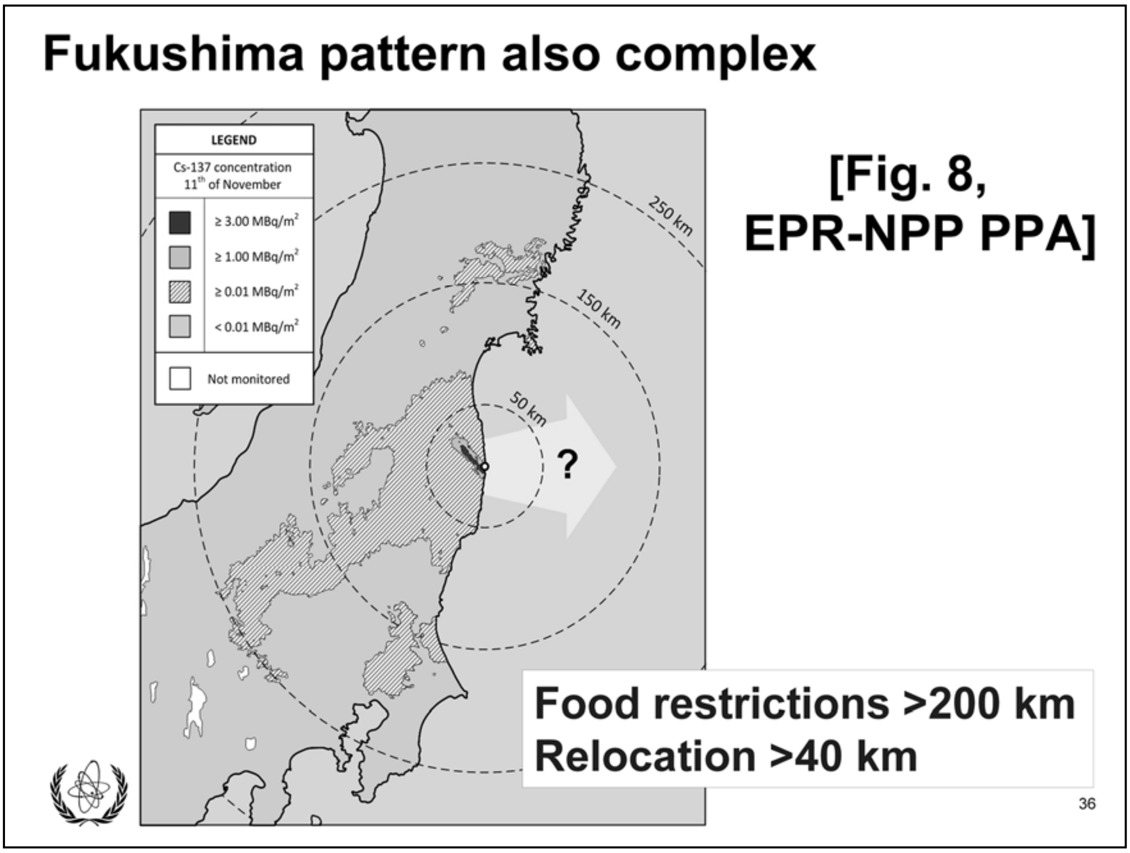
These cancers respond favorably to early treatment and to date only a few of the children diagnosed in Belarus with thyroid cancer have died as a result of the cancer. This shows the importance of identifying children who may have received high thyroid doses for medical monitoring starting about 2 years after a severe release.

JACOB, P., et al., Thyroid cancer risk in Belarus after the Chernobyl accident: Comparison with external exposures, Radiat. Environ. Biophys. 30 (2000) 25–31.

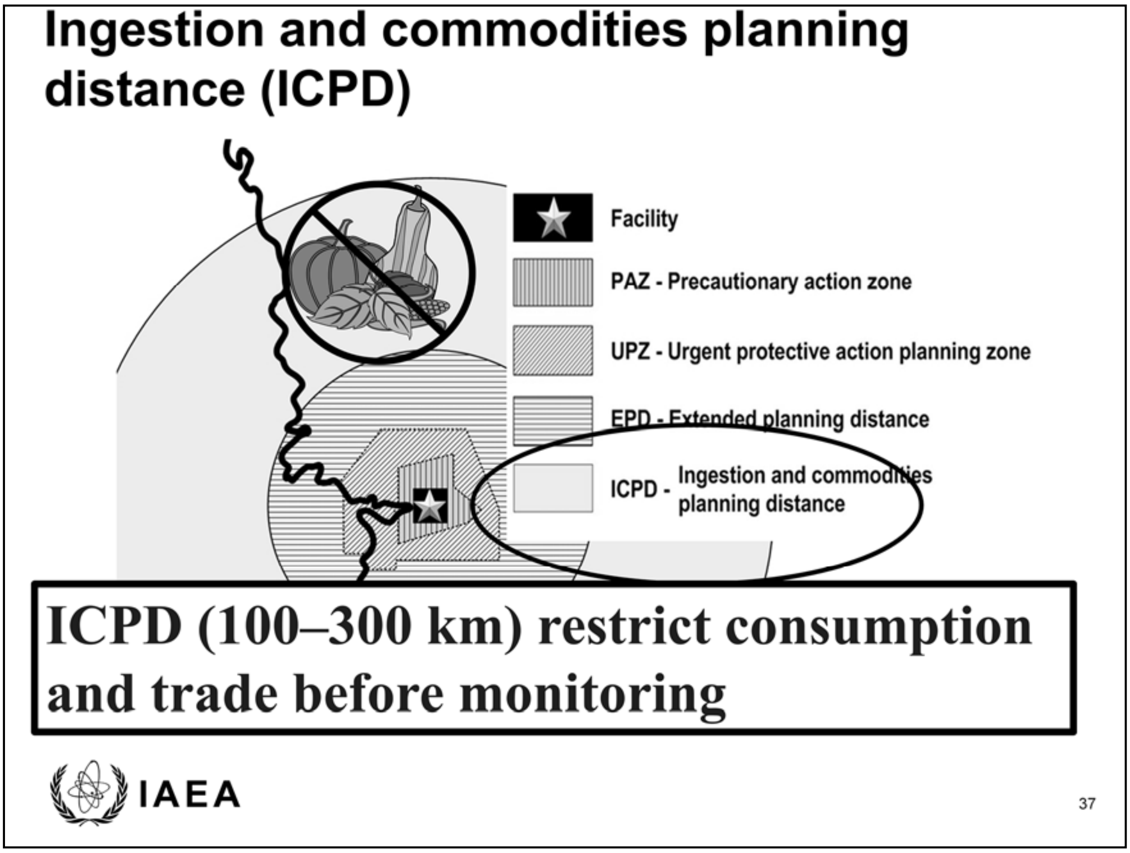


Turn to Fig 7. As shown in Fig. 7 (for Chernobyl) of EPR-NPP PUBLIC PROTECTIVE ACTIONS, a severe emergency involving fuel melt and major containment failure can cause significant and complex levels of contamination over very large areas that require various protective actions to be taken. It is clear from the figure that the area impacted is too complex and extensive to be promptly monitored and sampled to provide a basis for effective restrictions on potentially contaminated food, rainwater and milk. The Chernobyl release resulted in hotspots warranting restrictions on food at more than 2000 km (for example in the UK) and excess thyroid cancers from ingestion were detected at more than 350 km. Clearly for smaller releases, as are expected for most plants, contamination warranting relocation could easily occur within a few hundred kilometres.

Source: UNSCEAR UNITED NATIONS, Sources and Effects of Ionizing Radiation, Vol. I Sources, Vol. II Effects, Report to the General Assembly (with scientific annexes)



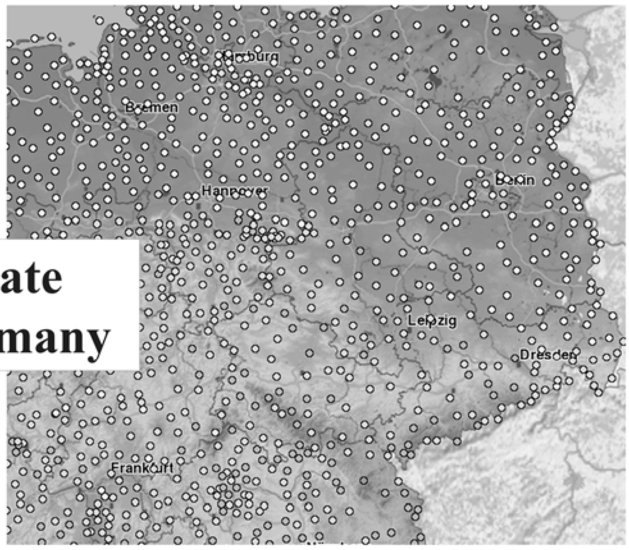
As shown in Fig. 8 of EPR-NPP PUBLIC PROTECTIVE ACTIONS, the deposition patterns following the Fukushima release are also complex and caused mostly by rain. People living in areas more than 40 km away from the plant were relocated and food was restricted in some cases more than 200 km from the plant.



As we saw from the Chernobyl and Fukushima emergencies, areas of deposition warranting restrictions on food can be very complex. It might take weeks and even months before all the areas with contamination can be located and for a system of sampling and analysis to be put in place to ensure that all the food, milk and rainwater that could be contaminated by a release is safe (with levels of radiation below the generic criteria warranting restrictions). Therefore, in order to ensure that the food, milk and rainwater that could be directly contaminated from a release are safe, restrictions should be placed within the **ingestion and commodities planning distance (ICPD)** when there is a potential for a severe release (based on plant conditions before monitoring).

Based on the Chernobyl experience and calculations discussed in Appendix I of EPR-NPP PUBLIC PROTECTIVE ACTIONS, the suggested size for the ICPD is between 100 and 300 km, depending on the size of the plant.

Restrictions within ICPD could taken after a release where there is a dense system of dose rate monitors to identify where actions are needed



System of dose rate monitors in Germany

IAEA

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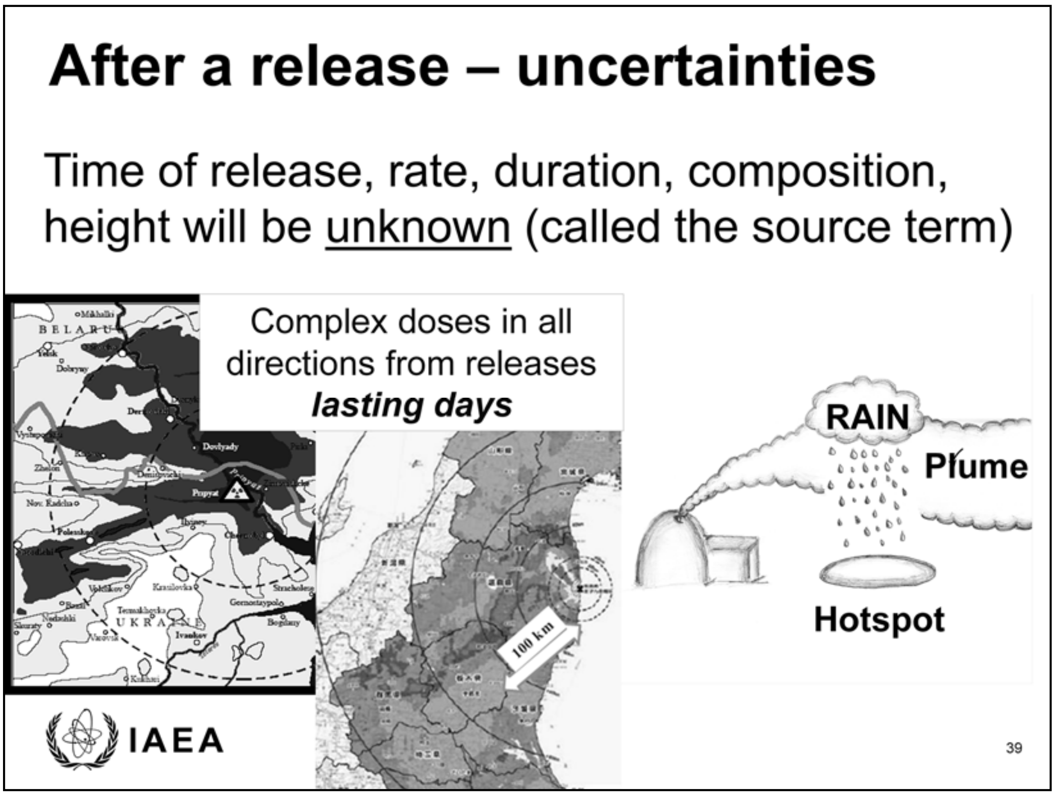
Restrictions on food, milk and rainwater could be applied after a release if the country involved has a dense network of dose rate monitors. These monitors could serve to identify areas where operation intervention levels are exceeded and to promptly apply restrictions within the ICPD during or following a release. This illustration shows the network of dose rate monitors in Germany.



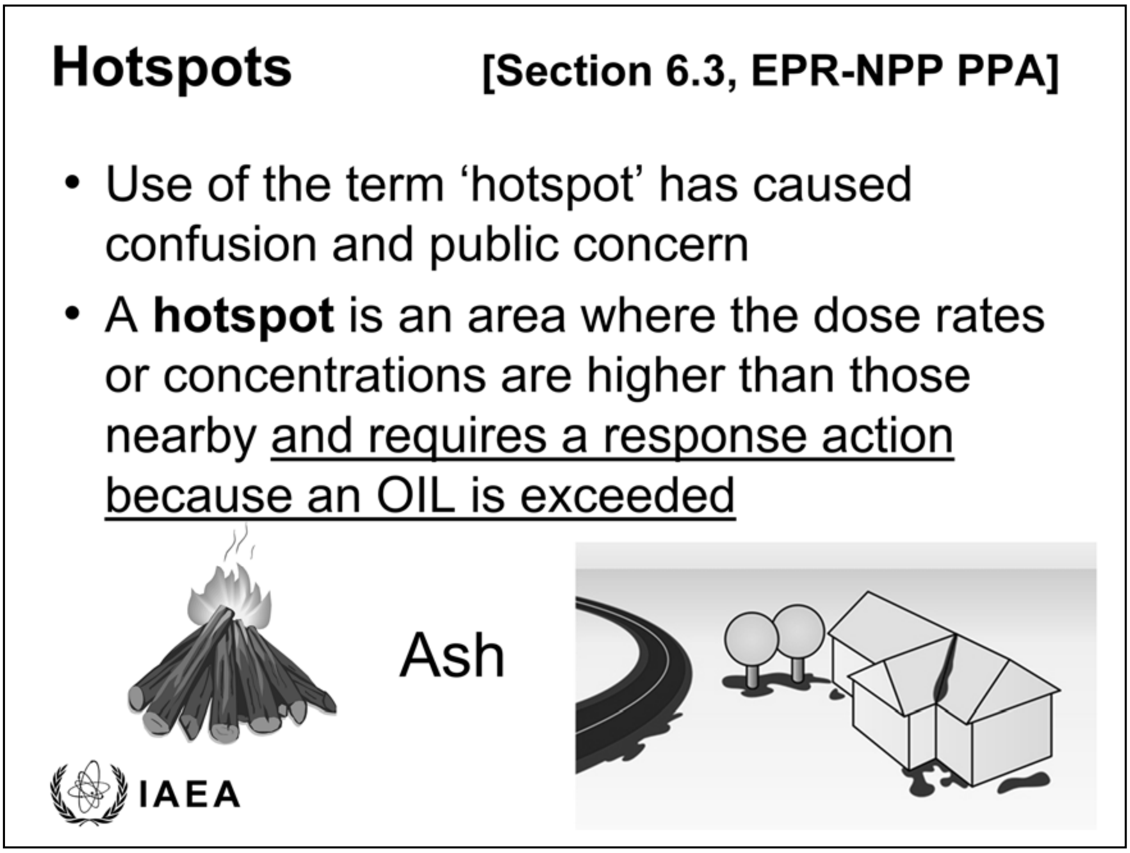
As discussed earlier, the time, rate, duration, size and composition of a release will most likely be unpredictable. The estimated sizes and compositions of the Fukushima and Chernobyl releases (called the 'source term') were being revised years after the emergencies.

A release from damaged fuel in a reactor or spent fuel pool will form a plume. The plume could be close to the ground, called a ground-level release, or elevated. If the release is close to the ground, then the public will be enveloped by the plume and can receive very high doses from inhaling the radioactive material in the plume.

The release will probably last for days and as the plume travels, radioactive material in the plume is deposited on the ground, structures and vegetation. The deposition of radioactive material can be increased by rainfall and can form complex patterns of hotspots in all directions, which require protective actions.

To the left you can see the deposition pattern resulting from the Chernobyl release that lasted many days and affected areas in all directions. In the middle of the slide you can see the deposition pattern from the Fukushima release, which also lasted several days. The deposition from the Fukushima release occurred primarily when the plume encountered rain.

The important point is that a severe release most likely will last for several days and affect areas in all directions.



As discussed in Section 6.3 of EPR-NPP PUBLIC PROTECTIVE ACTIONS, the use of the term 'hotspot' has caused a lot of confusion and unwarranted concerns among the public in past emergencies. An the area should be described as a hotspot only if the dose rates or concentrations are higher than those nearby and exceed an OIL or other criterion requiring action.

You should also expect localized hotspots resulting from various factors that concentrate the deposition. The most important is probably rain which can concentrate deposition in ditches or around houses from the runoff from the roof. Burning contaminated material can also result in hotspots from the ash.

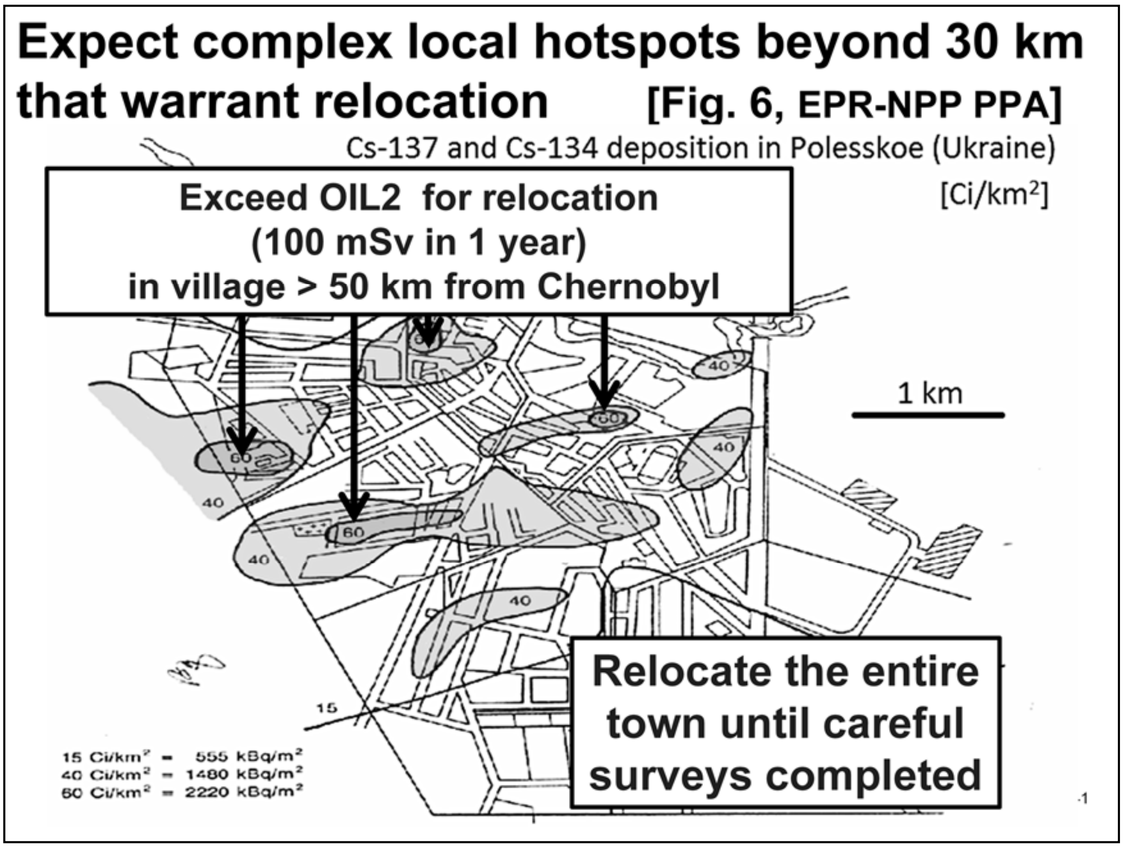
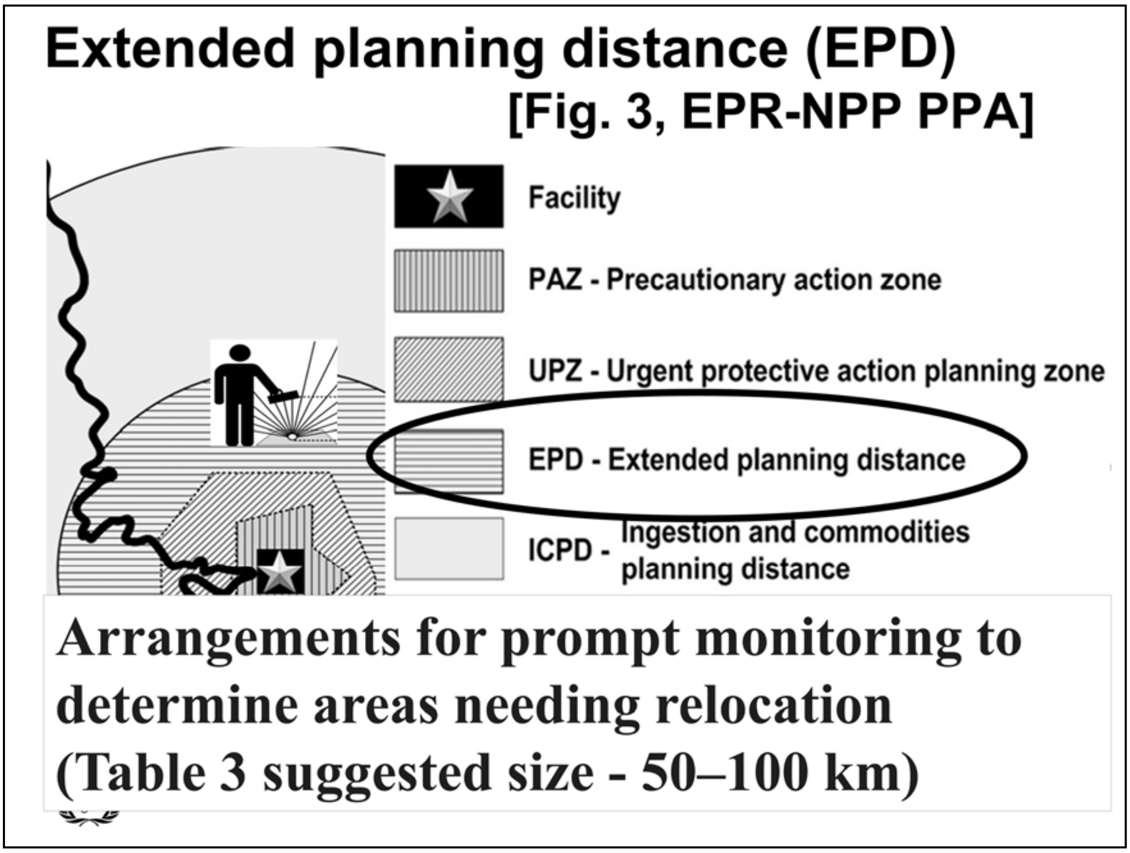


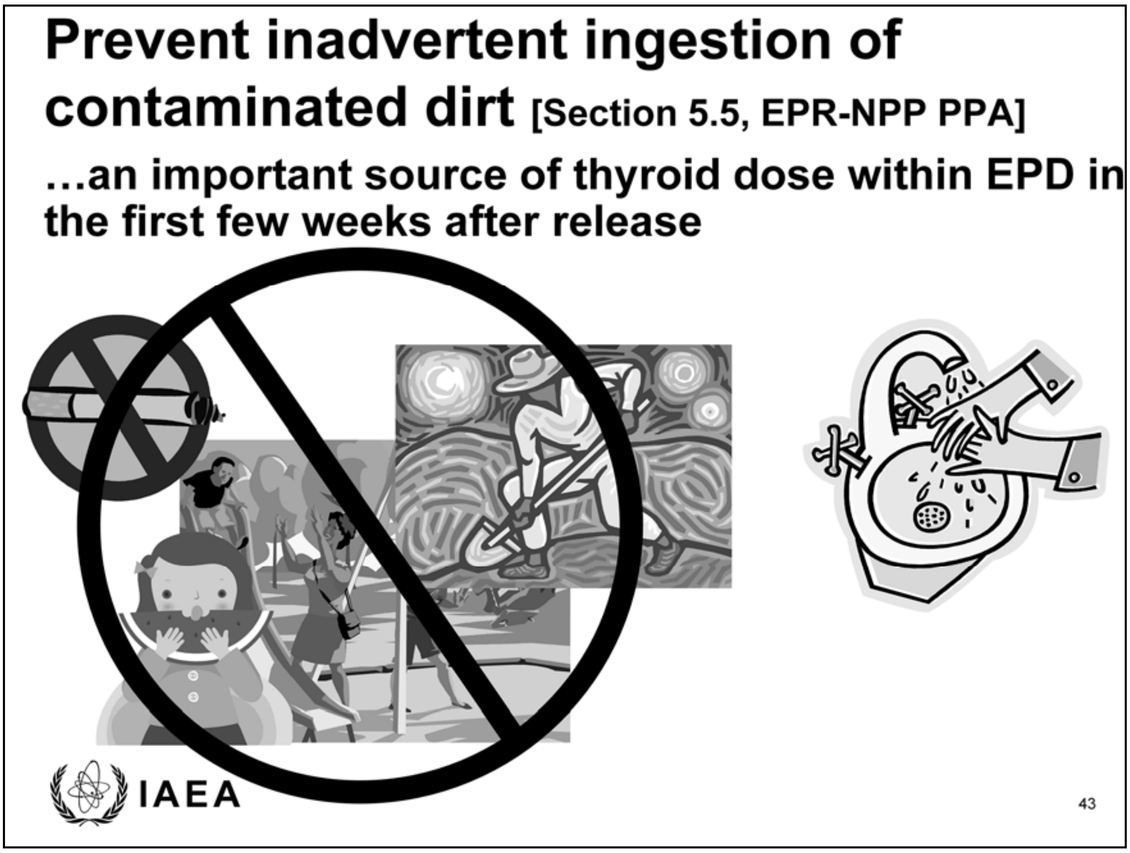
Figure 6 of EPR NPP PUBLIC PROTECTIVE ACTIONS shows the considerable variations in the Cs-137 and Cs-134 surface concentrations over short distances. The deposition levels vary by more than a factor of four within a few hundred metres. This demonstrates the difficulty in determining areas that must be relocated and the fact it may be most effective to relocate entire areas such as a town before more careful surveys are completed.

This illustration shows the layout of the town of Polesskoe in the Ukraine, approximately 50 km from the Chernobyl nuclear power plant. Highlighted areas exceed the IAEA OIL2 in Table 8 that call for relocation. Which means that people living normally in these areas could receive an effective dose of more than 100 mSv in the first year.

Source: INTERNATIONAL ATOMIC ENERGY AGENCY, The International Chernobyl Project Technical Report, IAEA, Vienna (1991).



EPR-NPP PUBLIC PROTECTIVE ACTIONS recommends establishing an **extended planning distance (EPD) where** arrangements are made for prompt monitoring to locate hotspots requiring relocation. The suggested size of the EPD in Table 3 is 50–100 km based on Chernobyl and the analysis discussed in Appendix I.



Prevention of inadvertent ingestion is discussed in Section 5.5 of EPR-NPP PUBLIC PROTECTIVE ACTIONS. Inadvertent ingestion of contaminated dirt, for example from eating with dirty hands, can be an important source of thyroid dose within the first 50 km during the first few weeks following a release. Therefore within about EPD (50 km) the public should be advised to take actions to reduce inadvertent ingestion by (a) not eating, smoking or putting their hands near the mouth unless they have been washed, (b) not playing outside or (c) not conducting activities that could produce dust.

Summary – actions to prevent severe health effects

≈ Radius* (km)	General Emergency	Zone/ Distance
3–5	Immediate evacuation + ITB	PAZ
15–30	Evacuation or large building sheltering + ITB	UPZ
50–100	Monitoring and relocation where OILs are exceeded within days to weeks – reduce inadvertent ingestion	EPD
100–300	Protect/restrict ingestion and commodities	ICPD

IAEA * Sizes depend on size of reactor

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The size of the zones and distances and actions to be taken with the zones and distances is based in part on the analysis described in Appendix I, which shows that taking the following protective actions most effectively prevents or reduces severe health effects off the site.

Upon declaration of a General Emergency (upon detection of conditions in the plant leading to severe damage to the fuel in the core or spent fuel pool) the following urgent protective actions should be taken (hopefully before a release) in all directions:

- Within about 3 to 5 km the public should immediately take iodine thyroid blocking (ITB) agents and safely evacuate* – this distance is called the precautionary action zone (PAZ).
- Within about 10 to 30 km (depending on the size of the reactor) the public should immediately take ITB agents and be evacuated* or take short term shelter in large buildings. These actions should done in such a way that it will not delay evacuation of an area within 3 to 5 km of the plant. This distance is called the urgent protective action planning zone (UPZ).
    - **If safe evacuation is delayed or not possible (e.g. due to snow, floods, or lack of transport, special facilities such as hospitals), the public should shelter until speedy evacuation is possible*.
- Within about 100–300 km (depending on the size of the reactor) take actions to protect and restrict ingestion and distribution of vegetables, milk, rainwater, and commodities that may be contaminated by the release. The effectiveness of these actions should be confirmed by monitoring and sampling analysis based on OILs after a release. This distance is called the ingestion and commodities planning distance (ICRP).

After a release:

- Within about 50–100 km (depending on the size of the reactor) conduct monitoring to locate and evacuate/relocate from hotspots that exceed the OILs calling for early or urgent actions. Also within this distance action will be taken to reduce inadvertent ingestion. This distance is called the extended planning distance (EPD).

Table 3 - suggested sizes for emergency zones and distances as a function of reactor size

Emergency zones and distances	Suggested maximum radius (km)	
	≥ 1000 MW(th)	100 to 1000 MW(th)
Precautionary action zone (PAZ)	3 to 5	
Urg… zon…		
Ext…		
Ingestion and commodities planning distance (ICPD)	300	100

This is a first approximation that needs to be adjusted to specific plant designs, emergency scenarios and local conditions

IAEA

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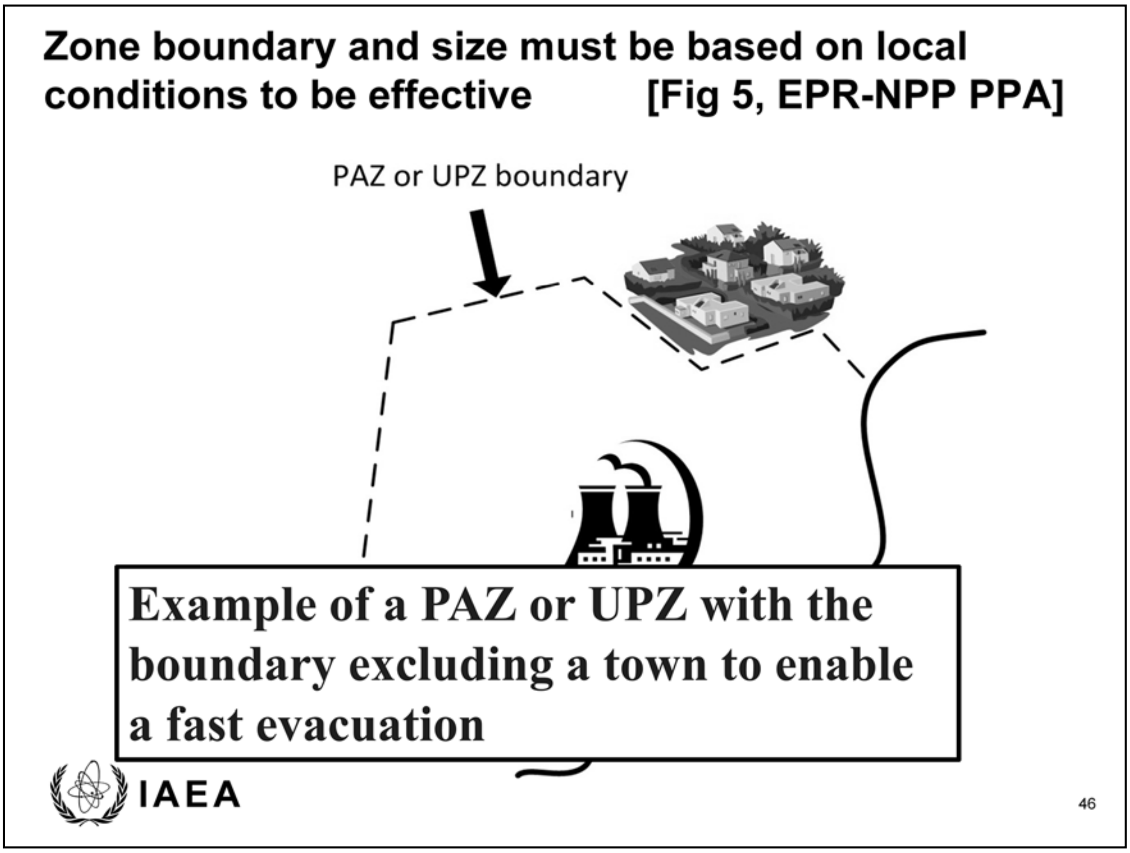
Table 3 of EPR-NPP PUBLIC PROTECTIVE ACTIONS suggested sizes for the zones and distances are given in Table 3. The size and boundaries of zones need to be site specific and due to the large variations in site and nuclear power plant characteristics, it is beyond the scope of this publication to provide a single set of specific distances that would be most effective for all nuclear power plants. Therefore, the sizes of the zones and distances given in Table 3 are to be considered as a first approximation that needs to be adjusted to specific plant designs, emergency scenarios and local conditions.



Turn to Fig. 5 of EPR-NPP PUBLIC PROTECTIVE ACTIONS. The boundaries of the PAZ and UPZ need to be established to ensure the most effective protective actions. For example, if the area within 3–5 km of the nuclear power plant can be evacuated faster if a town is excluded, the boundary of the PAZ needs to be established to exclude the town, as shown in Fig. 5 of EPR-NPP PUBLIC PROTECTIVE ACTIONS.

Basis for Actions Before Monitoring

Emergency Classification

IAEA
International Atomic Energy Agency

Let us now review the classification system and emergency action levels (EALs) discussed earlier. They form the basis for taking protective action before monitoring.

IAEA classification system [Section 3, Table 1, EPR-NPP PPA]

Class	Plant conditions	Protective actions off-site
General Emergency	May not be safe off-site • Actual or projected severe damage to fuel • Loss of control	Immediate urgent protective action
Site Area Emergency	One more failure will result in severe damage to fuel	• Alert officials and public to prepare to take actions • Off-site monitoring
Alert	Degraded or uncertain conditions – no danger to fuel	None

IAEA

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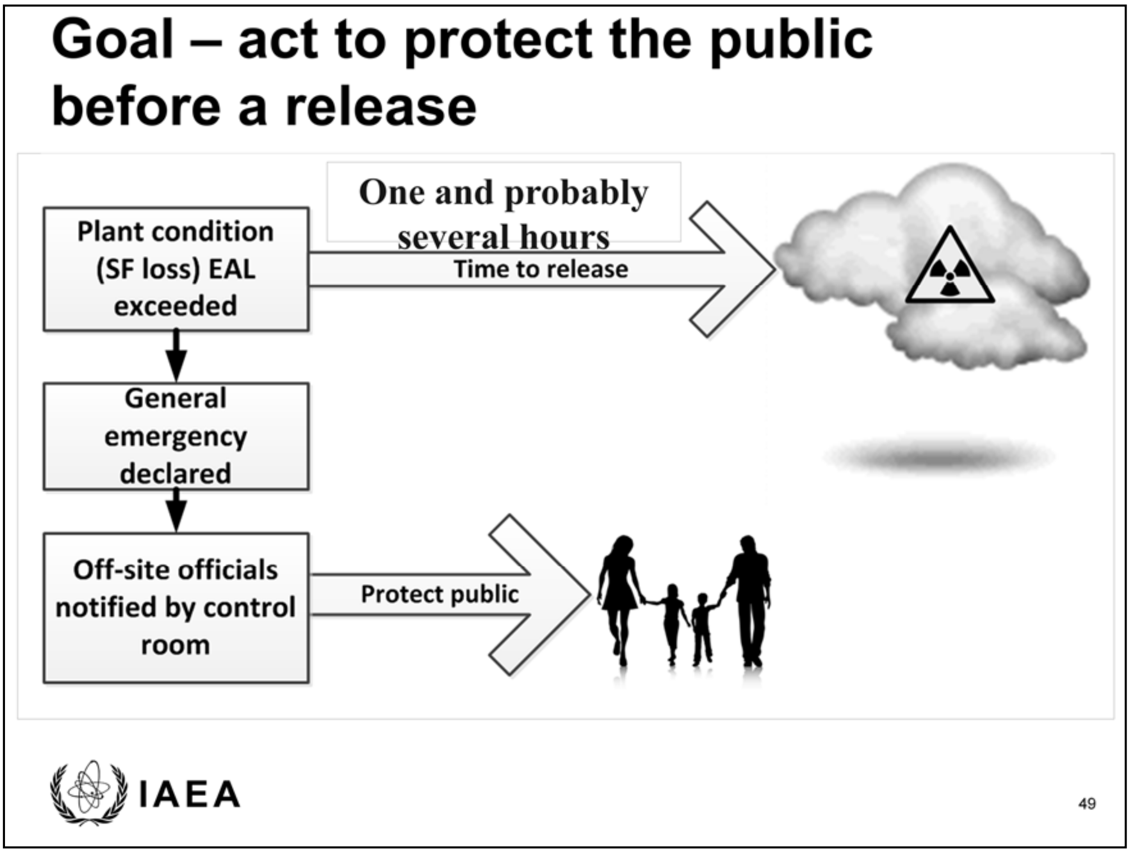
The IAEA emergency classification system is described in Table 1 of Section 3 of ERR-NPP PUBLIC PROTECTIVE ACTIONS.

The declaration of a **General Emergency** means that it may not be safe off-site because either: (a) events have occurred at the nuclear power plant that will lead to severe damage to the fuel in the reactor core or the spent fuel pool, (b) severe damage to the fuel has been detected or control over the facility has been lost. Therefore, the declaration of a General Emergency triggers immediate implementation of urgent protective actions and other response actions to protect the public. Upon declaration of a General Emergency, the shift supervision should promptly notify and recommend protective actions to the off-site decision maker (within less than 30 minutes). The off-site decision maker should implement protective actions immediately when notified by the plant.

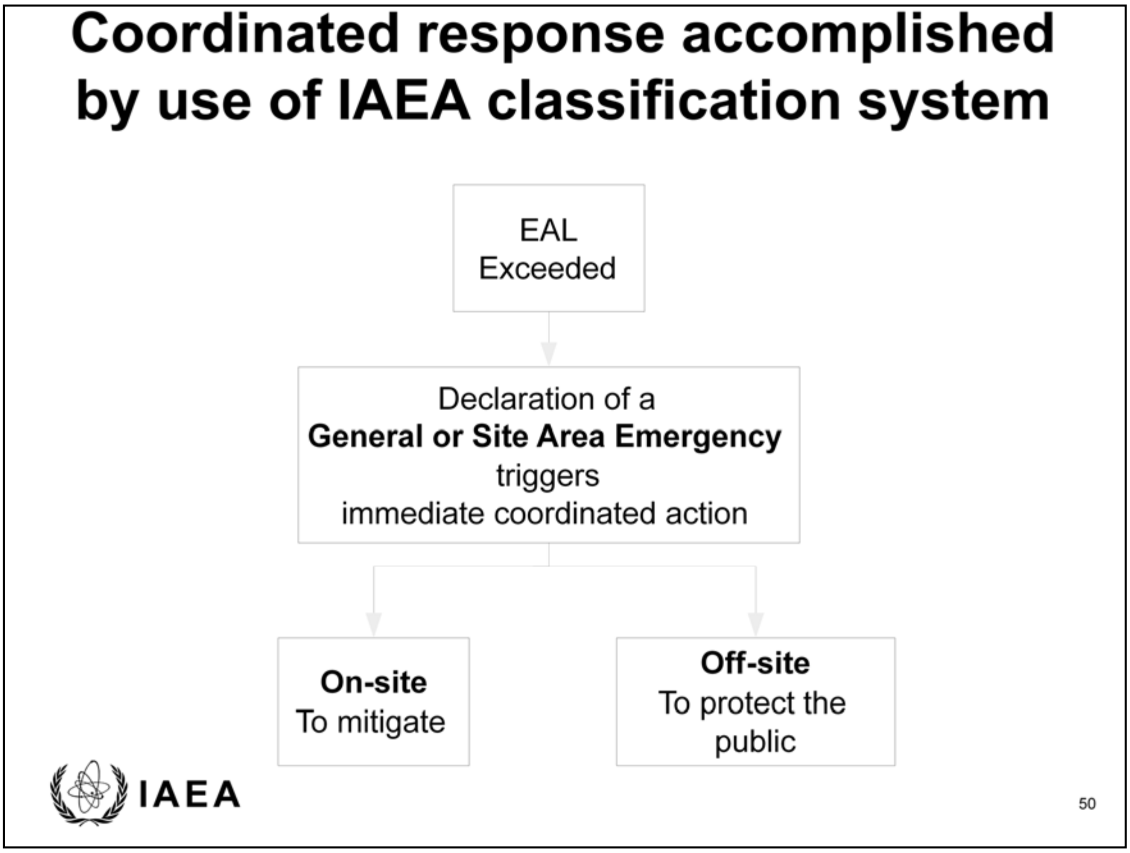
The declaration of a **Site Area Emergency** means that any additional failures at the nuclear power plant will result in severe damage to the fuel in the reactor core or in the spent fuel pool. Thus one more failure would result in declaration of a General Emergency. Therefore, upon declaration of a Site Area Emergency it is prudent to advise the public to prepare to take protective actions and other response actions, to activate emergency response organizations and conduct radiological monitoring in the vicinity of the nuclear power plant.

The declaration of an **Alert** is not an emergency; the declaration means that something unusual has occurred that may degrade conditions on-site but does not represent a danger to the fuel in the core or spent fuel pool and thus does not represent a risk to those off-site.



The goal is to classify the emergency as soon as possible, thus allowing the greatest amount of time to take effective protective and other response actions before the public is exposed.

If the control room notifies off-site officials of a General Emergency within minutes when an SF is lost (or the EAL is exceeded), off-site officials should have one or more hours to initiate public protective actions before a release.

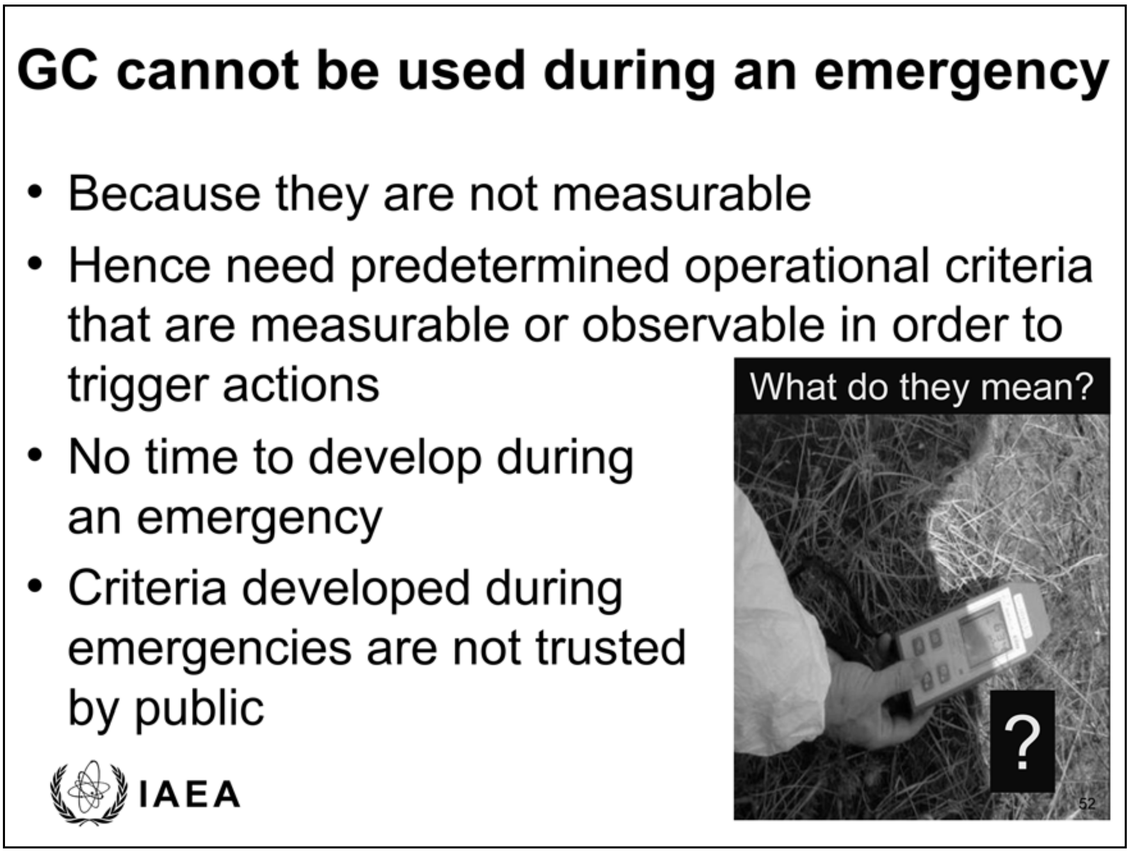


Under the IAEA classification system, only a Site Area Emergency and General Emergency warrant an off-site response. A Site Area Emergency means that any additional failures at the nuclear power plant will result in severe damage to the fuel in the reactor core or in the spent fuel pool. Therefore, upon declaration of a Site Area Emergency it is prudent to advise the public and off-site officials to prepare to take protective actions and other response actions. A General Emergency means that events have occurred at the nuclear power plant that will lead to severe damage to the fuel in the reactor core or the spent fuel pool and triggers immediate implementation of urgent protective actions and other response actions to protect the public.

Basis for Action After a Release

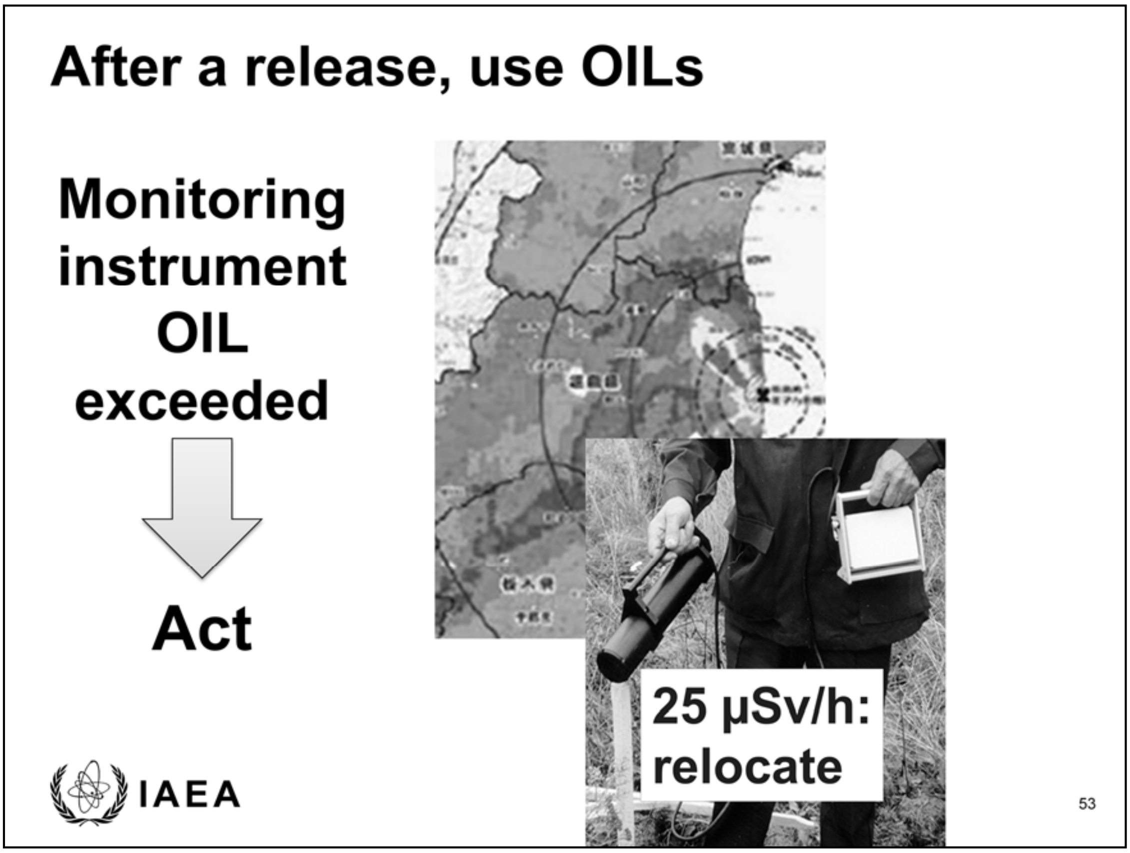
Monitoring and Sampling with Operational Intervention Levels (OILs)

IAEA
International Atomic Energy Agency



Generic criteria cannot be used during an emergency because they are **not** conceived in terms of things that can be seen (e.g. observable condition in the nuclear power plant) or measured (e.g. dose rate). Therefore, operational criteria must be developed that can be observed or measured during an emergency that will trigger a particular response action consistent with the generic criteria.

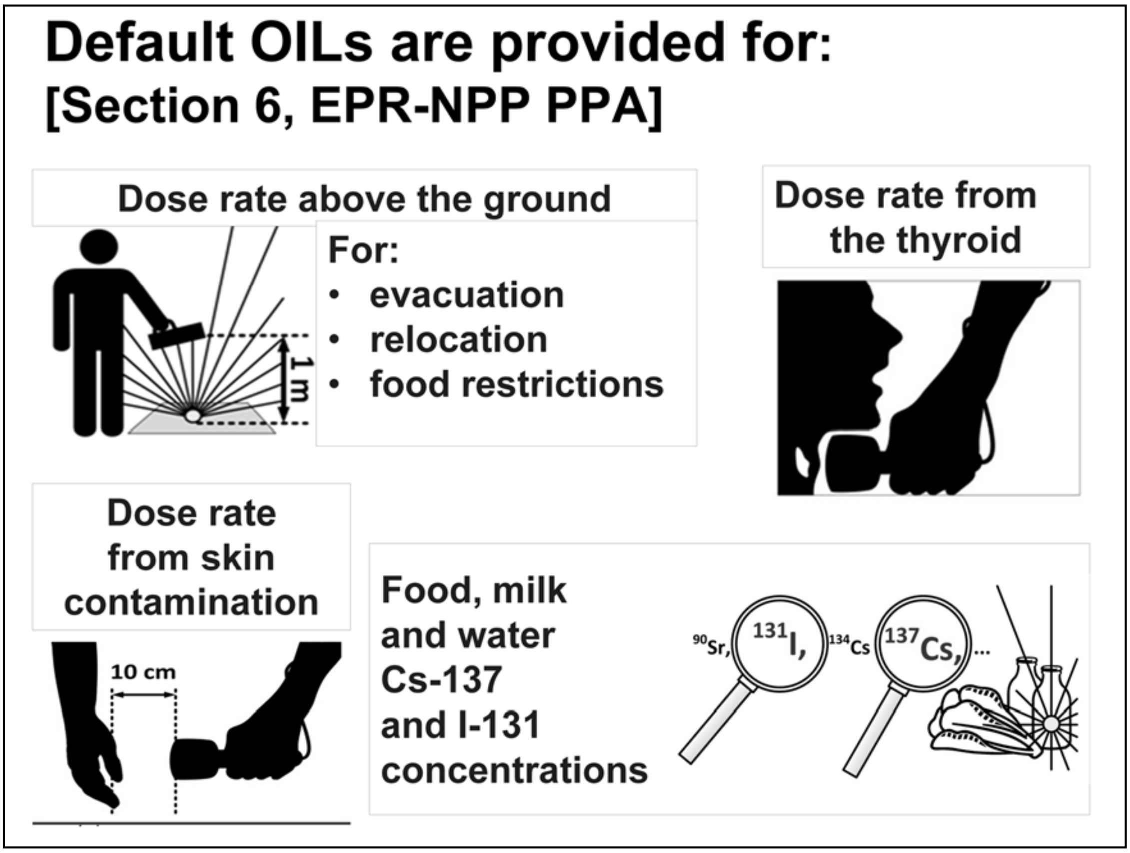
Operational criteria must be developed before an emergency in order to be available for immediate use. Past experience also shows that it is difficult to develop and justify operational criteria during an emergency because of intense public concerns. Criteria developed after the start of an emergency are often not trusted by the public.



After a release, operational criteria are used to quickly determine, based on monitoring and sampling results, where protective and other response actions need to be taken.

Operational Intervention Levels (OILs) are used immediately and directly (without further assessment) to determine appropriate protective and other response actions based on environmental measurements. For each OIL the actions to be taken will be predetermined as shown in the slide.

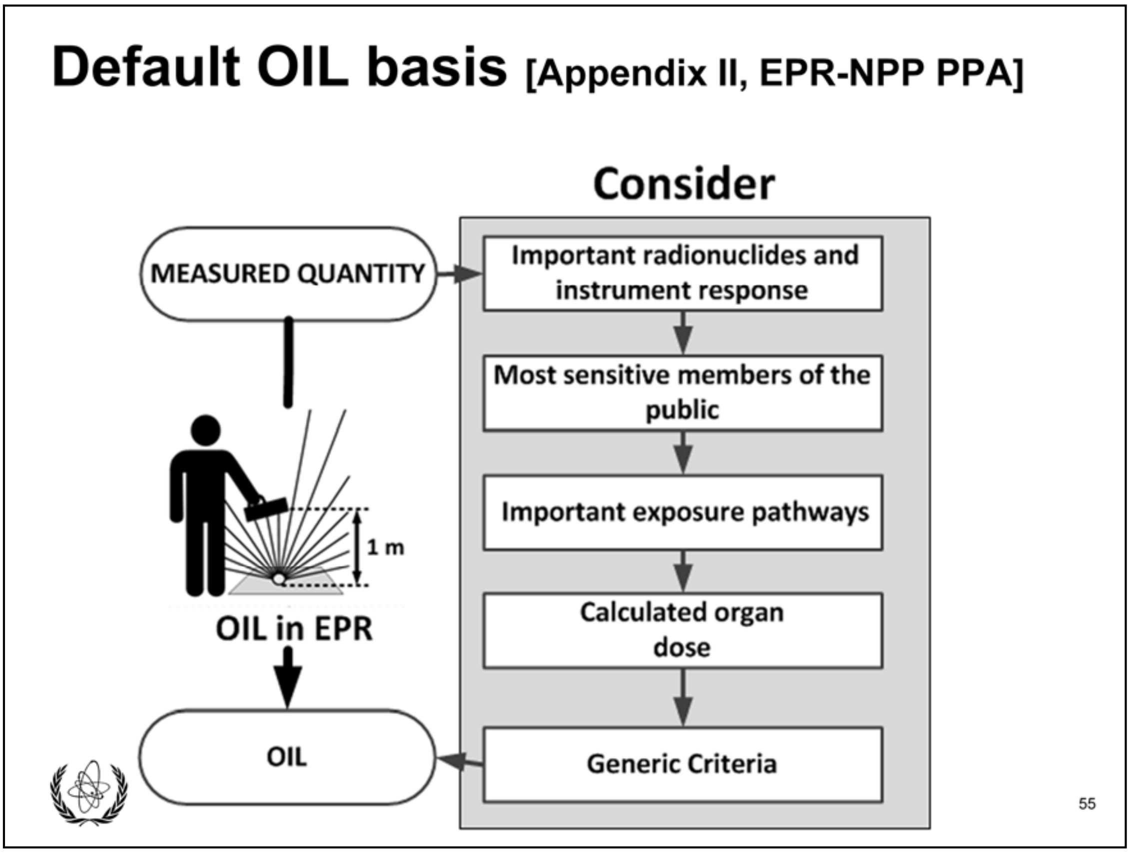
An example is shown here where people would be relocated from areas where the OIL2 of 25 μSv/h measured at 1 m above the ground is exceeded.



In Section 6 of EPR–NPP PUBLIC PROTECTIVE ACTIONS default OILs are provided for use following a release from a nuclear power plant core or spent fuel pool.

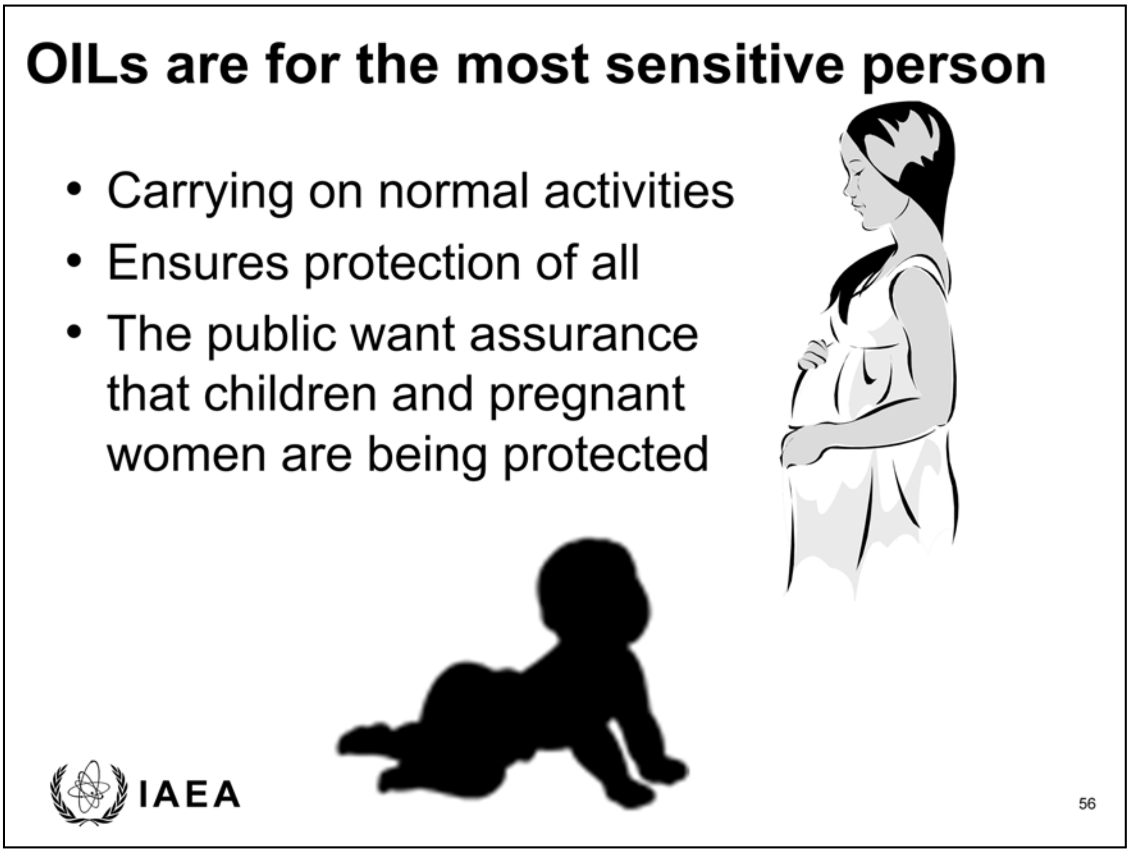
OILs are provided for:

- dose rate above the ground for determining if evacuation, relocation or food restrictions are warranted;
- dose rate from skin contamination to determine if decontamination or medical follow-up is warranted;
- dose rate from the thyroid to determine if medical follow-up is warranted;
- concentrations of cesium-137 and iodine-131 in food, water and milk to determine if restrictions are warranted.

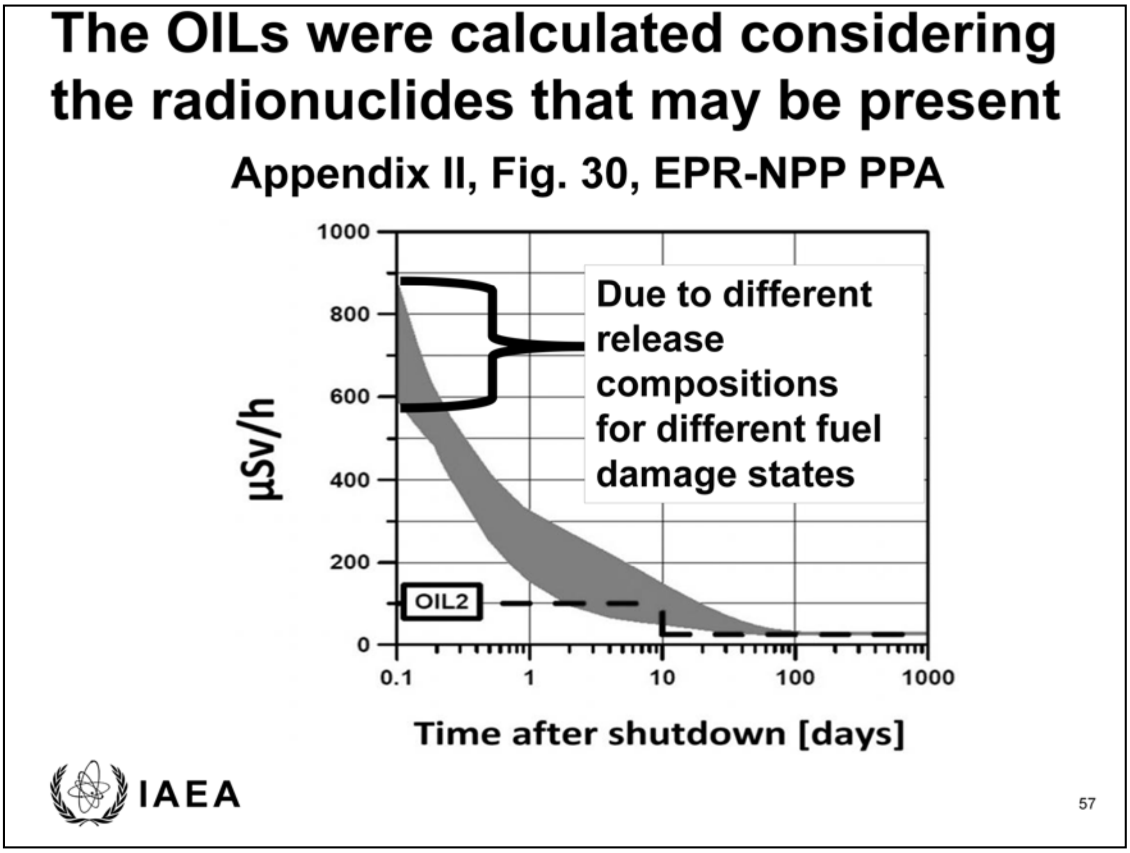


The basis for the OILs is discussed in EPR-NPP PUBLIC PROTECTIVE ACTIONS, Appendix II.

As shown in the figure, the default operation intervention levels were calculated considering: (a) all the radionuclides in a release from a nuclear power plant or spent fuel pool that are important (e.g. iodine and cesium), (b) the most sensitive members of the public (e.g. pregnant women and children), (c) important exposure pathways, (d) dose to organs (e.g. thyroid) and (e) the international generic criteria at which protective actions need to be taken.

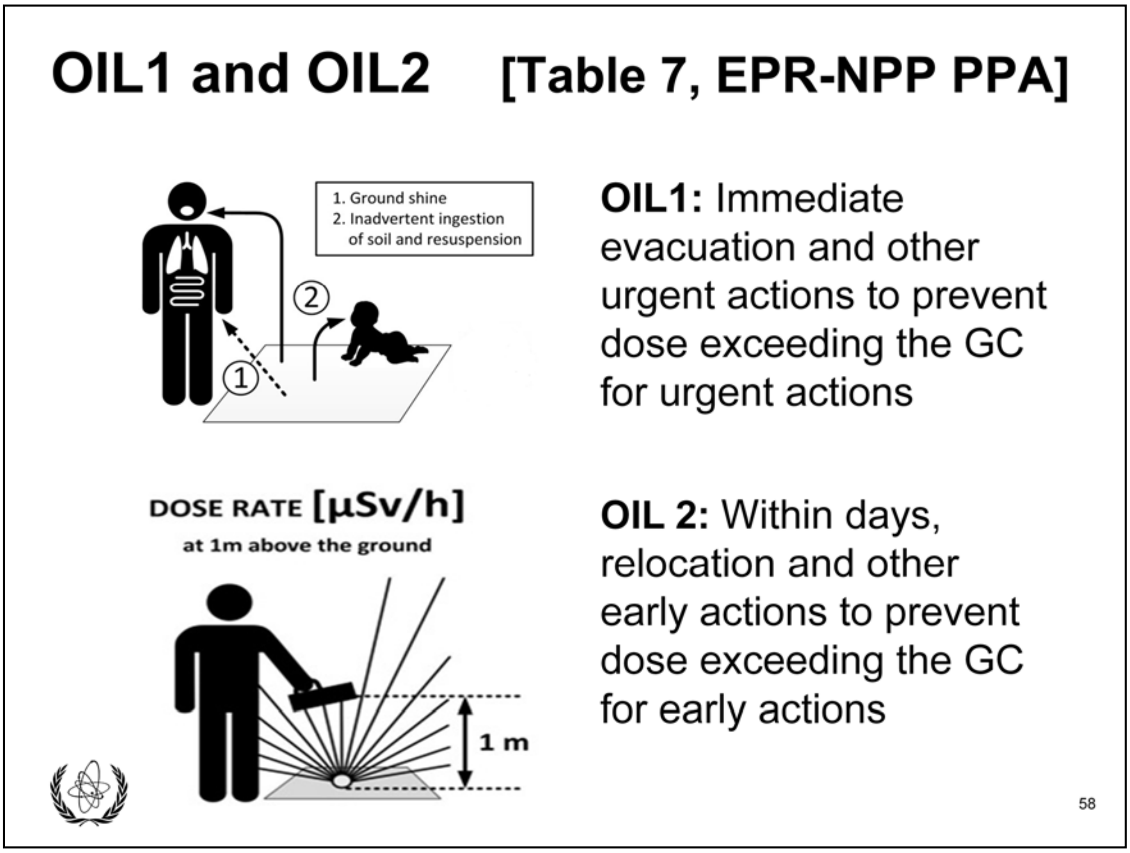


The OILs were calculated assuming the person that was most sensitive. In most cases this is children or pregnant women (fetus). This ensures that all members of the public will be protected. In addition, the public wants assurance that all everyone is being protected, in particular children and pregnant women.



Appendix II of EPR-NPP PUBLIC PROTECTIVE ACTIONS describes the basis for the OILs.

As an example, Fig. 30 in Appendix II shows that the default OIL2 value of 100 and 25 µSv/h (the dotted line) was selected after considering all the OIL2 values calculated (shaded area) considering: 1) the different release compositions projected for different fuel damage states (e.g. a gap release, fuel melt, melting through the reactor vessel); and 2) the effect of the change in the radionuclide composition with time after shutdown due to decay.



Turn to Table 7. This table of EPR-NPP PUBLIC PROTECTIVE ACTIONS provides default OILs for the dose rate from ground deposition. OIL1 and 2 are for the protection of somebody living on contaminated ground. When developing the OILs, it was assumed that the people were living normally on ground contaminated by a release and were being exposed to inhalation of resuspended material (dust), ground shine and inadvertent ingestion (for example, from eating dirt on hands, or from children playing on the ground).

OIL1 is based on generic criteria (GC) for taking urgent protective measures when the GC (100 mSv effective dose or equivalent to the fetus) are projected to be exceeded in 7 days. OIL 2 is based on generic criteria (GC) for taking early actions (100 mSv effective dose or equivalent to the fetus) when the GC are projected to be exceeded in one year.

The OILs are given in terms that would be reported by monitoring teams: µSv/h measured at 1 m above the ground.

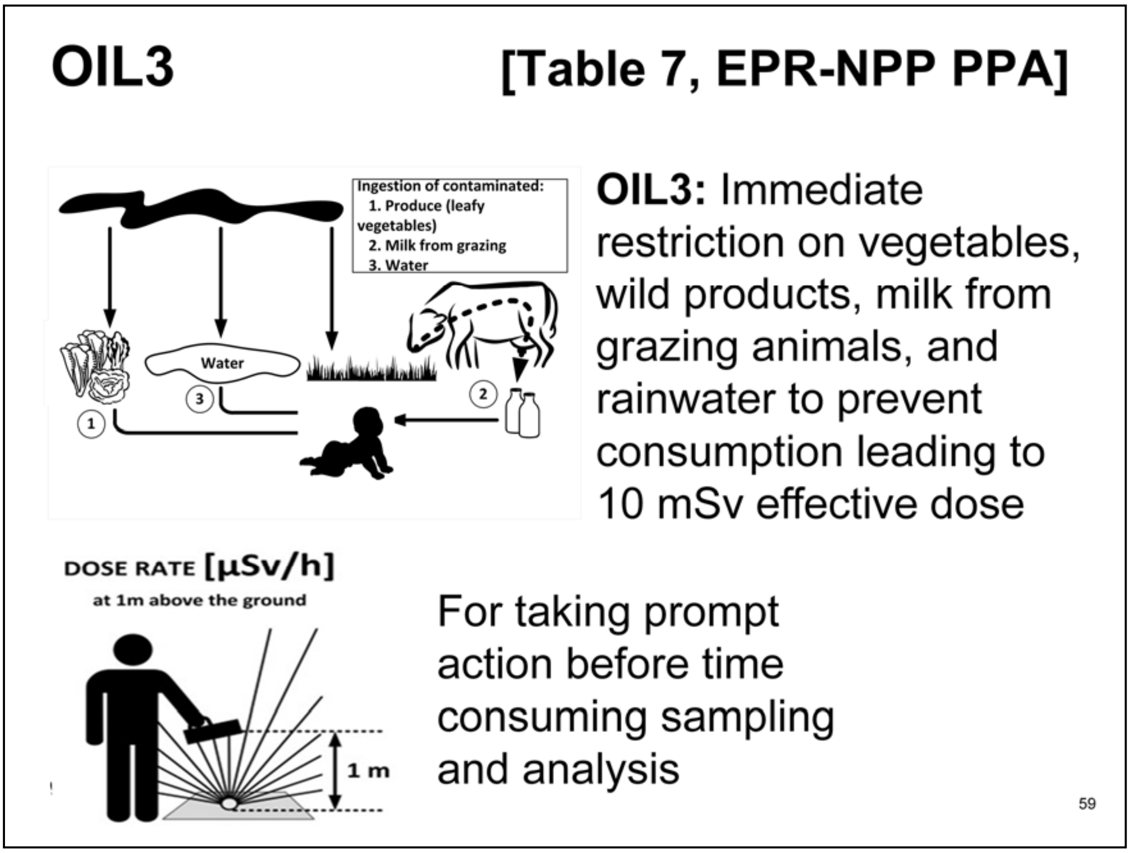
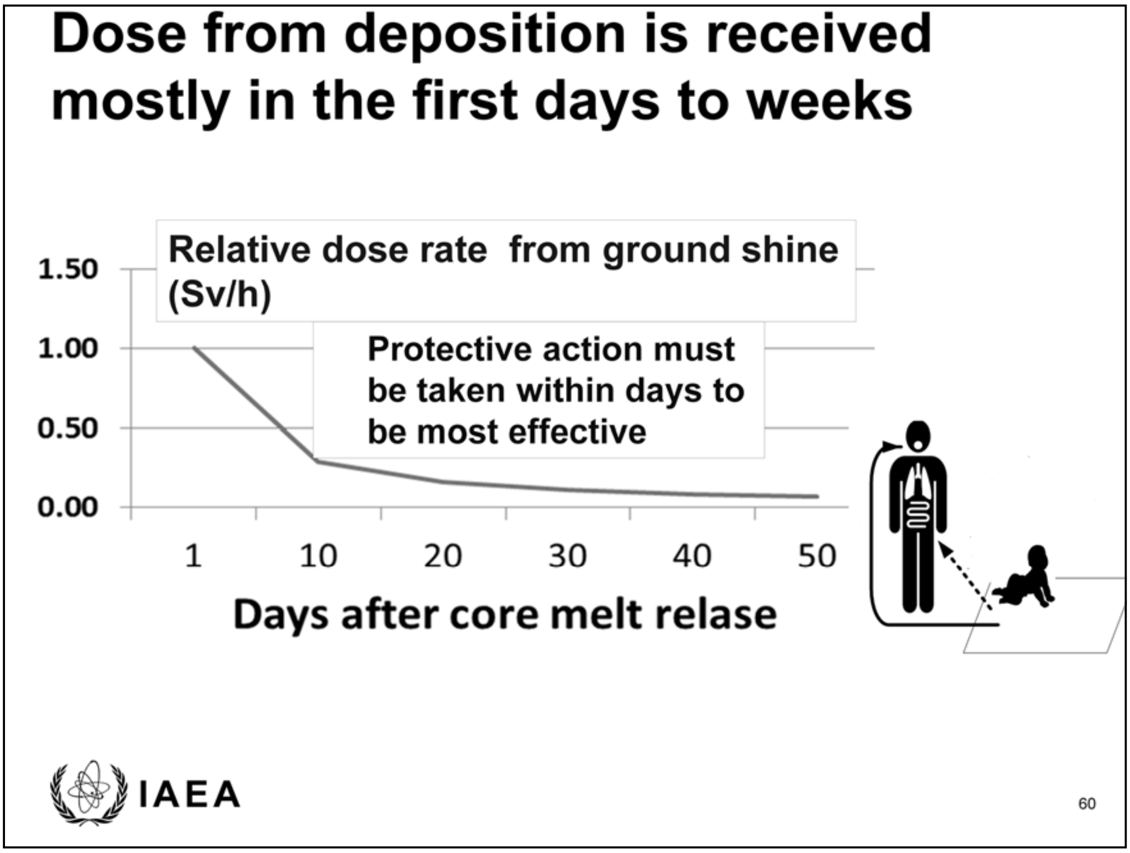


Table 7 of EPR-NPP PUBLIC PROTECTIVE ACTIONS provides default OIL (OIL3) values for the dose rate from ground deposition when immediate restrictions should be placed on: (a) distribution and consumption of non-essential produce, wild-grown products (e.g. mushrooms and game), milk from animals grazing in the area, rainwater and animal feed and (b) distribution of commodities until concentration levels have been assessed.

This OIL3 (based on dose rate) allows a prompt assessment to be made without waiting for time consuming sampling and analysis.

The OIL was calculated assuming that the most sensitive person eats the food for an entire year and was established to prevent 10 mSv effective dose, as discussed in Appendix II.



This shows the relative dose rate from deposition from a core melt accident for the first 50 days. It is clear that the dose rate falls rapidly within the first two weeks. Acting within the first few days is the most effective way of avoiding dose from deposition.

Completion time for monitoring of OIL1, OIL2 and OIL3 - to reduce dose from deposition [Table 6, EPR-NPP PPA]

- Decisions based on monitoring must be made quickly in order to be effective
- The longer the delay, the more dose people receive

Where OILs are exceeded	Goals: identified and protected within
OIL1 Evacuation	Hours to a day
OIL2 Relocation	Days to a week
OIL3 Food restrictions	Days to a week

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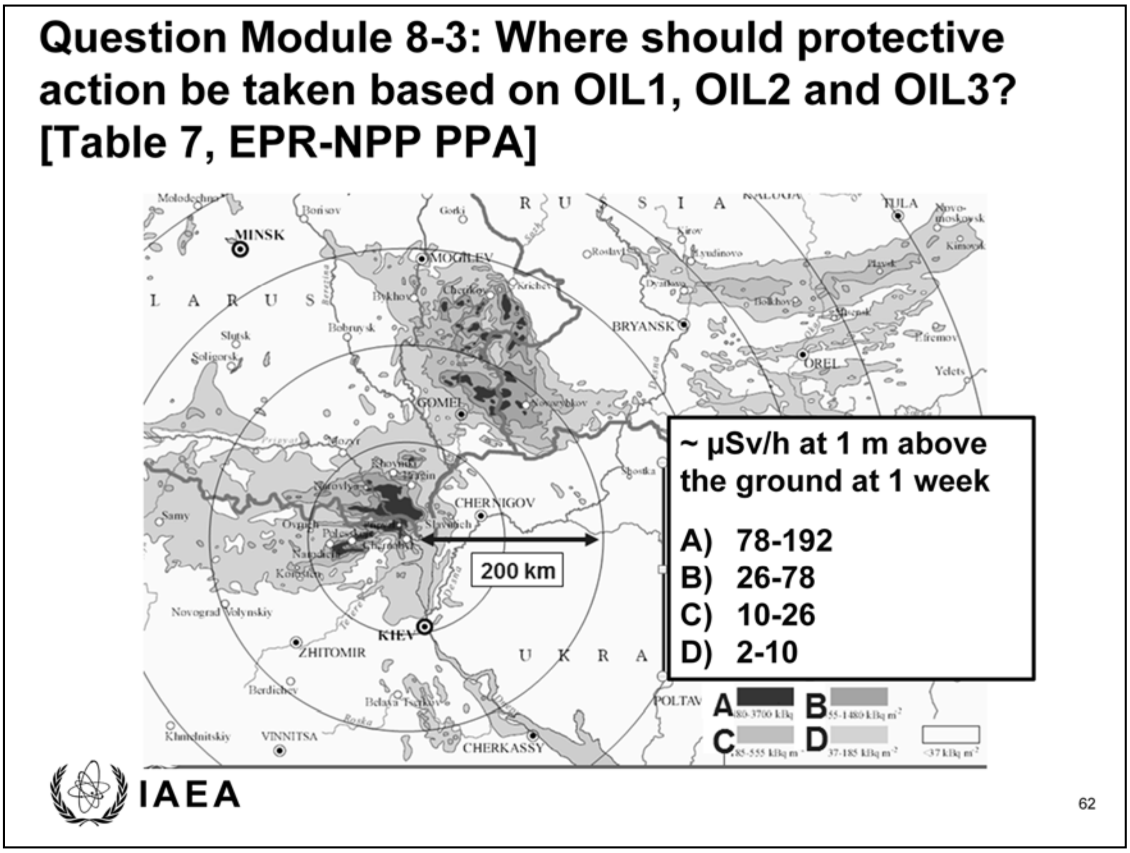
A delay of just a few days in acting following deposition can result in the population receiving most of the dose that could have been prevented by prompt monitoring.

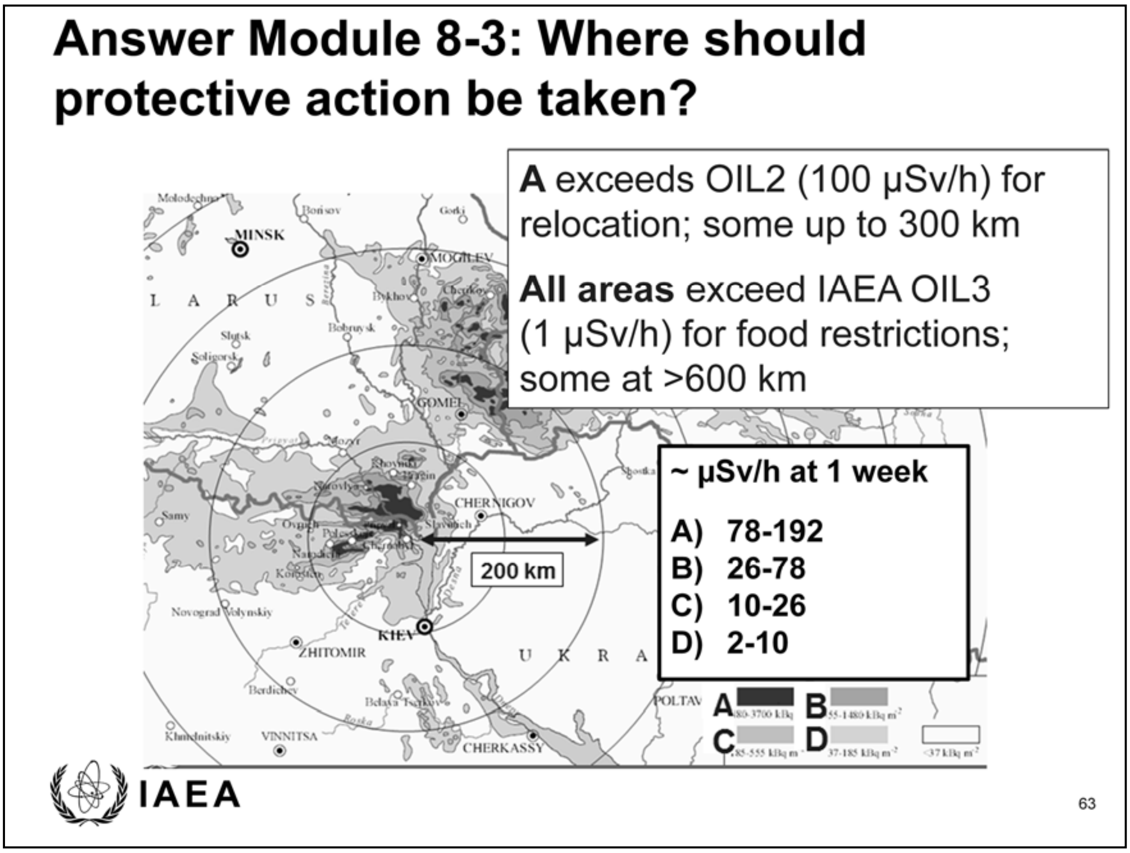
As shown in Table 6 of EPR-NPP PUBLIC PROTECTIVE ACTIONS, the goal of monitoring should be to identify areas where the OILs require:

- OIL1 – evacuation following a release within hours to a day
- OIL2 – relocation within days to a week
- OIL3 – restriction on foodstuffs within days to week.



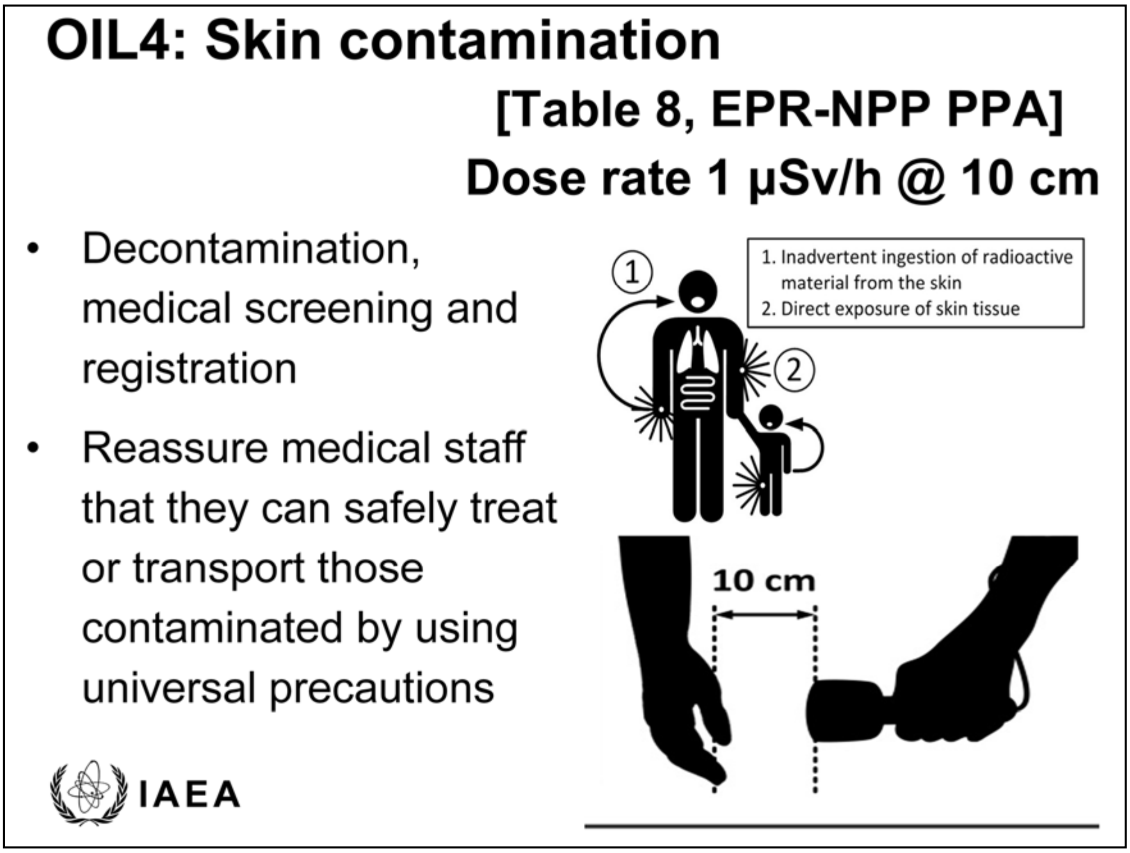
Ask the participants to decide where protective action is needed on the basis of OIL1, OIL2 and OIL3 in Table 7 of EPR-NPP PUBLIC PROTECTIVE ACTIONS. Tell them to use the OIL assuming <10 days after shutdown.

This shows the complex levels of ^{137}Cs contamination resulting from the Chernobyl accident and the table shows the relationship of the concentrations to the approximate dose rate (µSv/h) at 1 m above ground 1 week after the start of the emergency. The dose rate was calculated considering all of the radionuclides present.



The OIL2 values for <10 days after shutdown (100 µSv/h) should have been used. The red areas (A) exceed OIL2 for relocation (100 mSv/year) up to about 300 km from the plant.

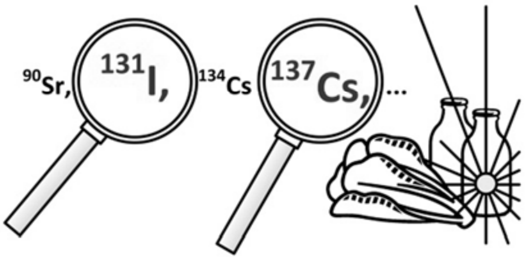
All the colored areas exceed the IAEA OIL3 for restrictions on vegetables, milk from grazing animals and rainwater. Some of these areas are more than 600 km from the plant. If these restrictions had been put in place quickly following the Chernobyl accident, most of the thyroid cancers would have been prevented.



Turn to Table 8. Table 8 of EPR-NPP PUBLIC PROTECTIVE ACTIONS provides a default OIL (OIL4) for used when monitoring the skin. If the OIL4 level, 1 μSv/h at 10 cm, is exceeded, this indicates that the person may have inhaled or inadvertently ingested enough contaminated material to result in severe effects to the thyroid. Therefore, if the OIL4 values are exceeded, the person should be decontaminated and registered for possible later medical follow-up.

Because people have refused to treat or transport potentially contaminated individuals in the past, one of the actions is to reassure those treating and/or transporting contaminated individuals they can do so safely if they use universal precautions against infection (gloves, mask, etc.).

OIL7: Food, milk and water concentrations [Table 9, EPR-NPP PPA]



Exceeded if either is exceeded	
I-131 (Bq/kg)	Cs-137 (Bq/kg)
1000	200

Considered: all the radionuclides present – 10 mSv in 1 year – most of what is consumed is contaminated

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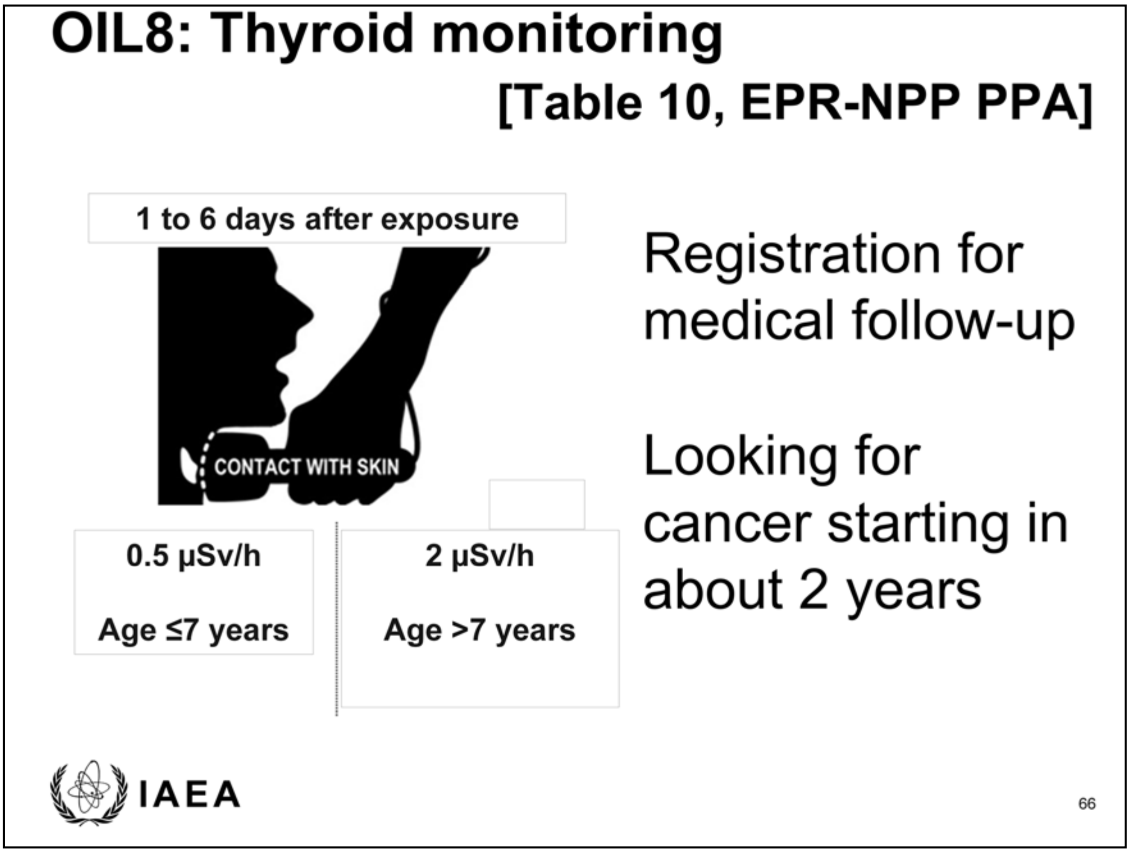
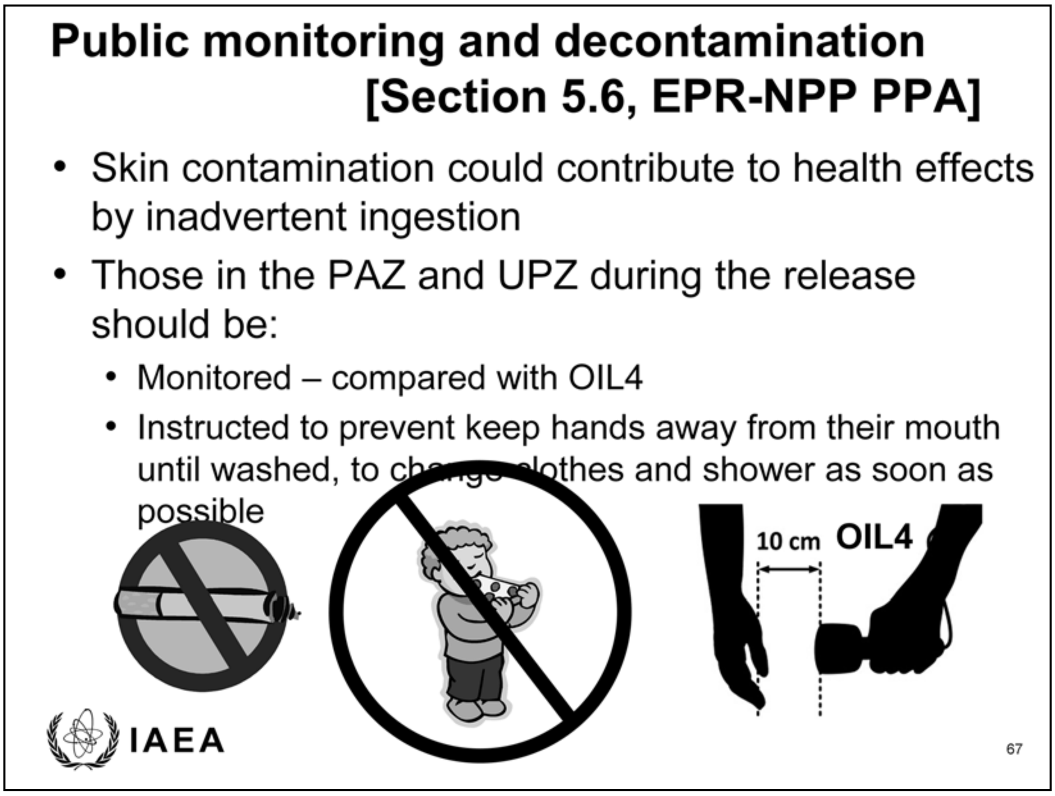
Turn to Table 9. Table 9 of EPR-NPP PUBLIC PROTECTIVE ACTIONS provides default operational intervention levels (OIL7) for food water and milk concentrations. The OIL values are for the two marker isotopes I-131 and Cs-137. The OIL is exceeded if either OIL for the I-131 or the Cs-137 is exceeded. It is important to understand that the OIL values were calculated taking all the radionuclides expected to be present (e.g. I-131, Cs-134, Ba-140, Sr-90, Ru-106…) into consideration, not just the marker isotopes.

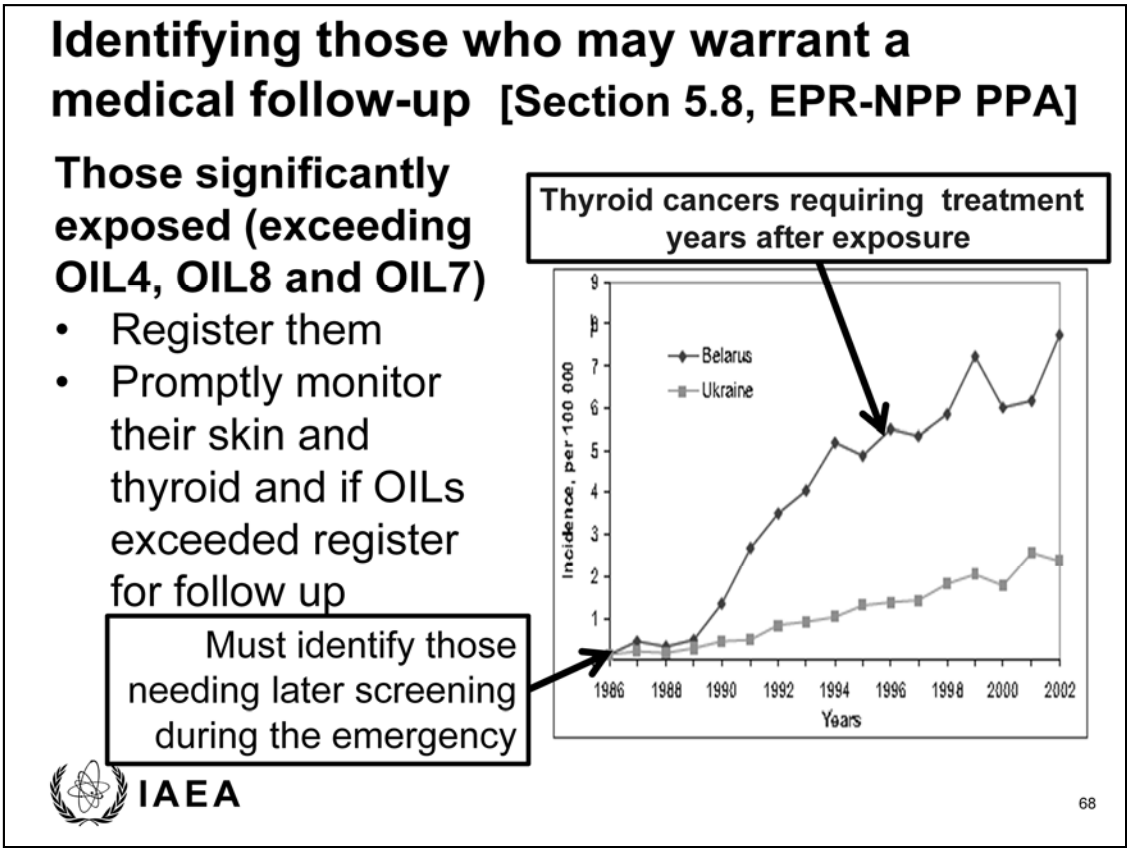
The OIL assumes that the most sensitive person consumes the food/water/milk for 1 year and that most of the item consumed is contaminated; the OIL is based on a generic criterion of 10 mSv effective dose.



Turn to Table 10. Table 10 of EPR-NPP PUBLIC PROTECTIVE ACTIONS provides default operational intervention levels (OIL8) for monitoring of the thyroid by a dose rate instrument. If exceeded, the person's dose to the thyroid could be between 100–200 mSv: they should be registered for medical follow-up and in about 2 years for medical examinations for thyroid cancer.



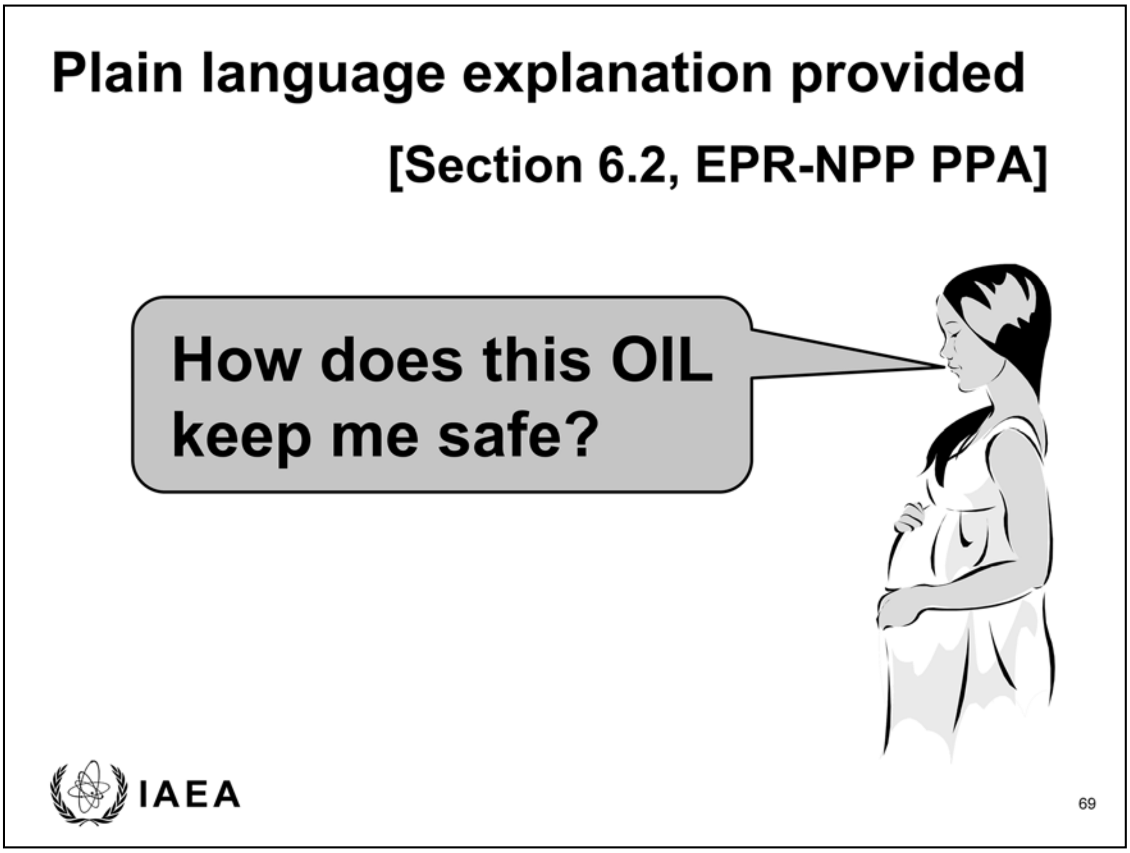
As discussed in Section 5.5 of EPR-NPP PUBLIC PROTECTIVE ACTIONS, skin contamination could result in a significant internal dose from inadvertent ingestion. In addition, high levels of skin contamination indicate that the person may have inhaled or ingested enough radioactive material to warrant a medical evaluation. OIL4 indicates when decontamination or medical evaluation is warranted. Anyone who might be contaminated (for example by being in the PAZ and UPZ during the release) should be instructed to keep their hands away from their mouths and to change their clothing.



The importance of identifying children who may have received high thyroid doses for medical monitoring was demonstrated following the Chernobyl accident. Cancers began to appear in those who were children at the time of the accident 2 years after the accident. These cancers respond favourably to early treatment, and to date, only a few of the children diagnosed in Belarus with thyroid cancer have died as a result of the cancer. The problem is identifying who should receive a medial follow-up years later when the cancers will begin to appear.

Therefore, as discussed in Section 5.8 of EPR-NPP PUBLIC PROTECTIVE ACTIONS, those who may have been exposed (to values exceeding OIL4, OIL8 or who may have consumed foodstuff exceeding OIL7) need to be registered immediately. This will allow to estimate and record their doses and determine who should later receive medical follow-up. Registering will also enable to provide a basis for informed counseling of pregnant women. In order to estimate their dose, all those within the PAZ and UPZ at the time of the accident need to register and provide information on their location during the emergency. They will also need to have their skin and thyroid monitored to determine if OIL4 (skin contamination) or OIL8 (thyroid contamination) values are exceeded. Finally, the dose to others, such as those who may have consumed contaminated food, water, or milk with values exceeding OIL7 should be estimated.

IAEA report The Chernobyl Forum: 2003–2005, IAEA, Second revised version



Experience has shown that decision makers take actions and the public follow their instructions best when they understand how the actions provide for their safety. Therefore, Section 6.2 provides a plain language explanation of how the OILs and associated actions provide for the safety of all members of the public.

Protective Actions for an Emergency at a Nuclear Power Plant

Module 8

Part II

Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

IAEA
International Atomic Energy Agency

Lecture:

L-08 Protective Actions for an Emergency at a Nuclear Power Plant – Part II

Purpose:

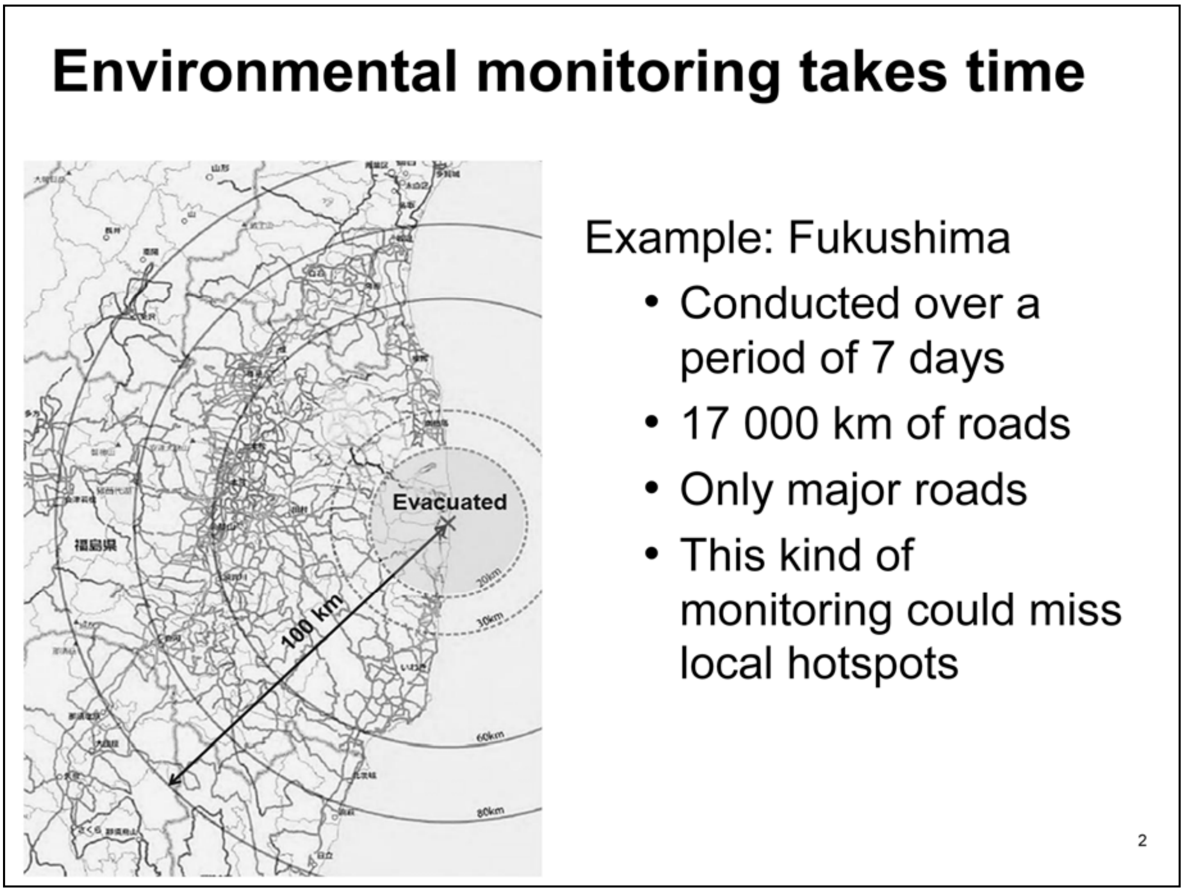
To explain the actions required to protect the public for a severe emergency at a nuclear power plant.

Learning objectives: On completion of this lecture participants will:

- Describe the risk to the public posed by a severe emergency at a nuclear power plant or spent fuel pool
- Decide on the protective actions and other response actions needed to protect the public based on:
  - Conditions at the plant
  - Environmental monitoring and sampling data

Author: Thomas MCKENNA **Revisions:** Phillip VILAR WELTER, Brian DODD, Eduardo LURASCHI

Duration: 2 hours



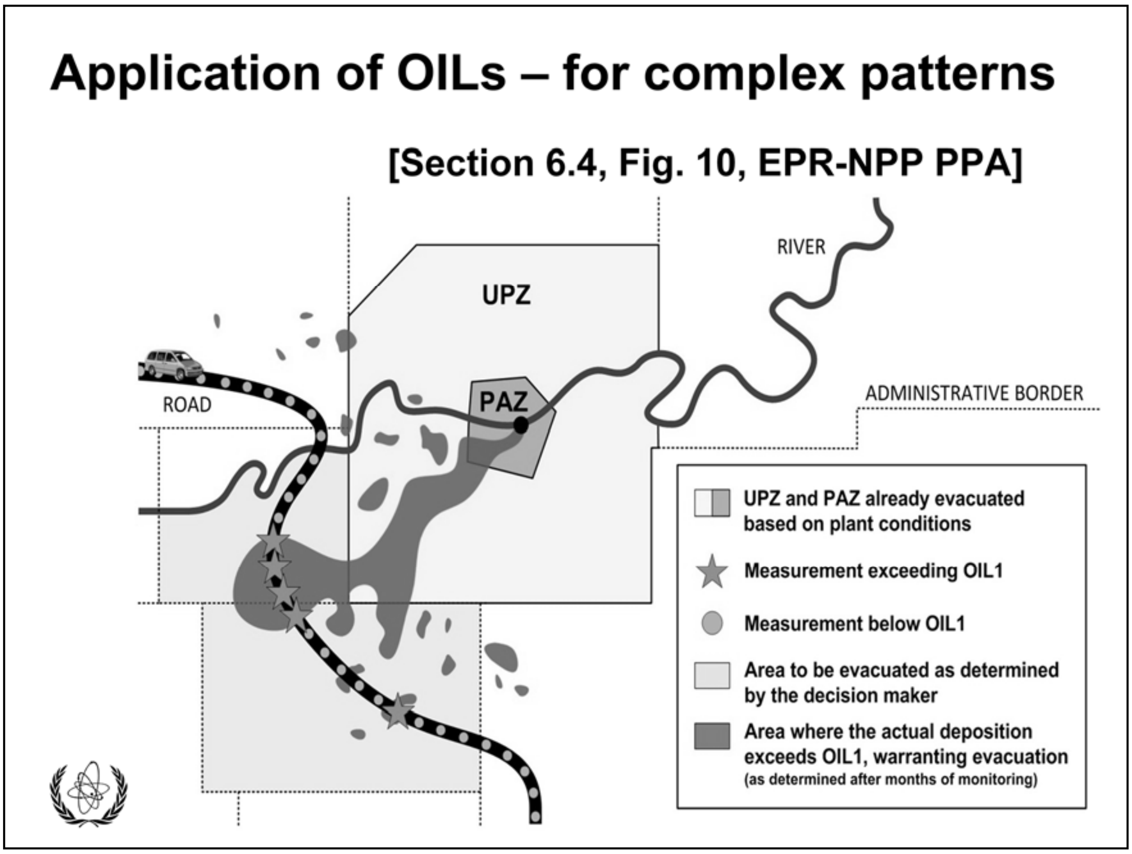
This slide shows a map of the vehicle-borne monitoring performed after the accident at the Fukushima Daiichi nuclear power plant. Monitoring was performed on national and prefectural roads within 100 km from the plant, and on municipal roads within 80 km of the plant. A total of about 17 000 km roads could be monitored. It took 7 days to do this survey. This period is too long for the implementation of effective urgent protective actions. In addition, the map does not show the detail of the distribution of radioactive material (hotspots), leaving most of the areas unmonitored.

This shows that early environmental monitoring can only be used to identify those general areas requiring protective actions after the release.

Sources:

INTERNATIONAL ATOMIC ENERGY AGENCY, Status of the Fukushima Daiichi Nuclear Power Plant and Related Environmental Conditions (2011) p. 35 (IEC).

NUCLEAR EMERGENCY RESPONSE HEADQUARTERS OF THE GOVERNMENT OF JAPAN, Additional report of the Japanese Government to the IAEA, The accident at TEPCO’s Fukushima Nuclear Power Stations (second Report) (Sept. 2011).



As discussed in Section 6.4 of the IAEA publication Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor, EPR-NPP PUBLIC PROTECTIVE ACTIONS (EPR-NPP PUBLIC PROTECTIVE ACTIONS), hotspots (areas where OILs are exceeded) warranting evacuation, relocation or food restriction might be small and the pattern of hotspots could be very complex[1]. This will make it impossible to identify all hotspots within days or even weeks requiring action following a release. This is further complicated by the fact that there may be an ongoing release.

Therefore, initial monitoring should be conducted to identify general areas (e.g. local governmental administrative districts) where hot spots occur that exceed the OIL for evacuation, relocation or food restrictions and the decision maker should recommend that all of those in the administrative area (light blue areas in Fig. 10 of EPR-NPP PUBLIC PROTECTIVE ACTIONS) where there were measurements that exceed an OIL should take the indicated actions (as was done at Fukushima).

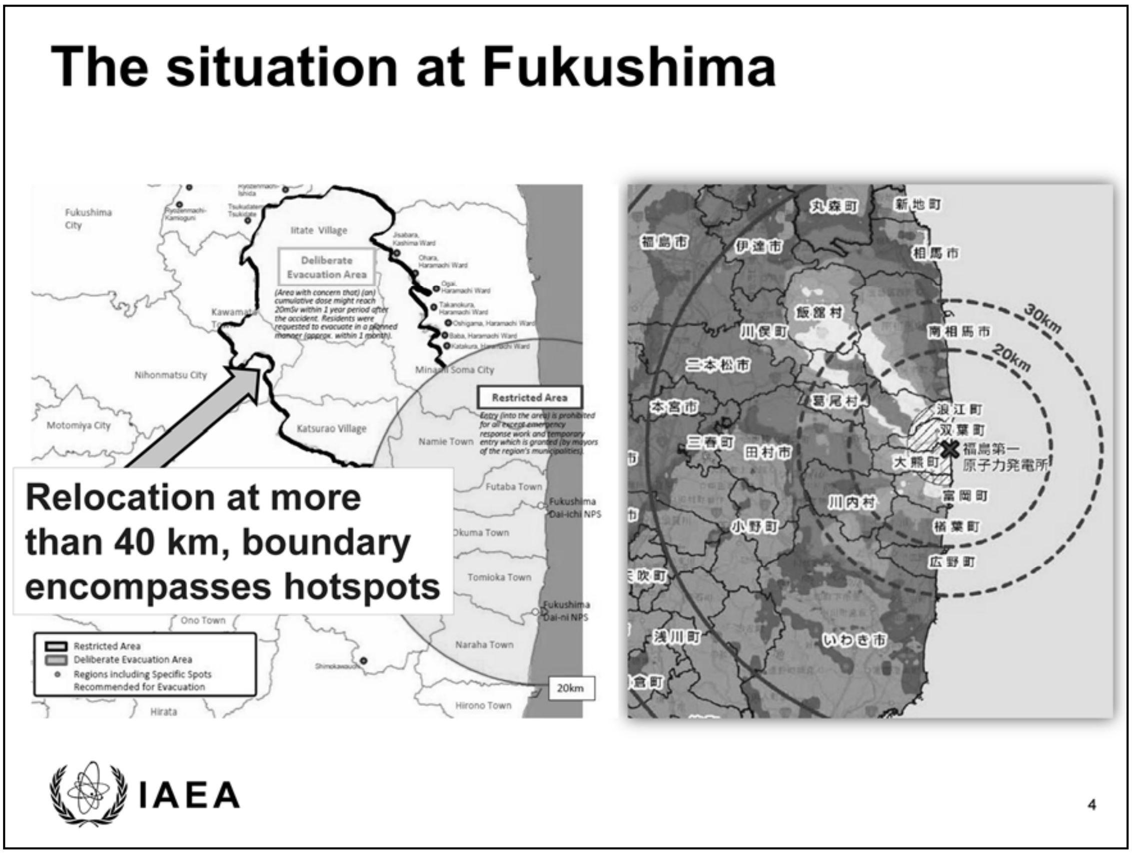
Abbreviations:

OIL – operational intervention level

PAZ – precautionary action zone

UPZ – urgent protective action planning zone

References to pages, tables and figures in square brackets in this presentation are to the IAEA publication Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor, EPR-NPP PUBLIC PROTECTIVE ACTIONS.



The figure on the right shows the deposition pattern following the Fukushima release and the figure on the left shows the area where evacuation and relocation have been implemented. It can be seen that relocations occurred more than 40 km from the plant (called the deliberate evacuation area) and the boundaries of this area were established such that they were easily understood by the population and local officials, but encompassed the area that could have hotspots requiring relocation.

Sources:

MINISTRY OF ECONOMY TRADE AND INDUSTRY OF THE GOVERNMENT OF JAPAN, Restricted Area, Deliberate Evacuation Area And Regions including Specific Spots Recommended for Evacuation (as of November 25, 2011), http://www.meti.go.jp/english/earthquake/nuclear/roadmap/pdf/evacuation_map_111125.pdf .

INTERNATIONAL ATOMIC ENERGY AGENCY, Status of the Fukushima Daiichi Nuclear Power Plant and Related Environmental Conditions (2011), p. 35 (IEC).

Displaying monitoring results

[Figs 11, 12, EPR-NPP PPA]

Display only the locations where actions need to be taken (OILs exceeded)

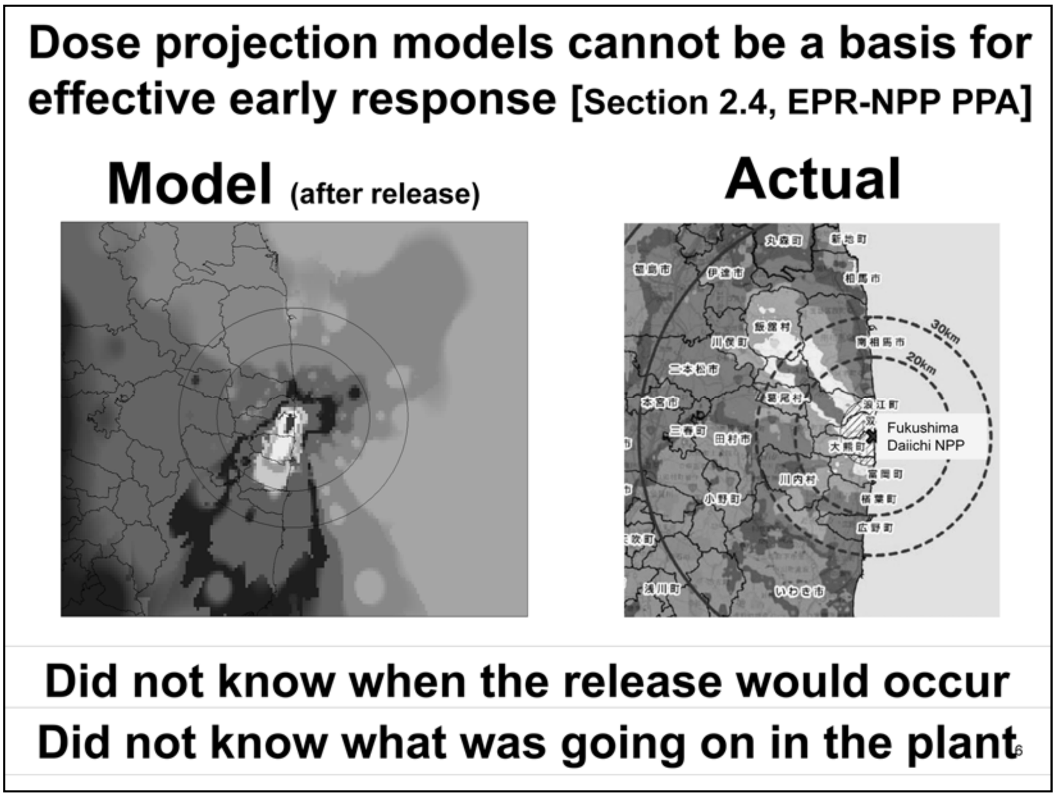
- **Displaying more can cause inappropriate actions**
- **Include message of caution on results (e.g. they are preliminary and may be revised)**

OIL1	≥ 1000 μSv/h
OIL2	≥ 25 μSv/h (for t > 10 days[a])
	≥ 100 μSv/h (for t ≤ 10 days[a])
OIL3	≥ 1 μSv/h
NONE	< 1 μSv/h

5

Turn to Fig 11. As discussed in Section 6.5, showing maps during emergencies with monitoring results that are below those requiring a response action (i.e. showing locations, that do not exceed an OIL) has led to confusion and anxiety amongst the public and in some cases resulted in the public taking actions that did more harm than good; such as unnecessary relocation and stigmatization towards those from the affected area.

It is recommended in Section 6.5 when displaying monitoring and sampling results to only display locations where OILs or other criteria requiring protective or other response action should be taken, as shown in Fig. 11. In addition as shown in Figs 12 and 13, the maps should include a message of caution concerning their use and the actions required.



As discussed in Section 2.4, experience and analysis have shown that dose projections cannot be used as a basis for effective protective action because the time, duration, and composition of a release of radioactive material will not be known. In addition, model protections would, in most cases be too late, to be the basis for taking effective protective actions during the most severe reactor or spent fuel emergency.

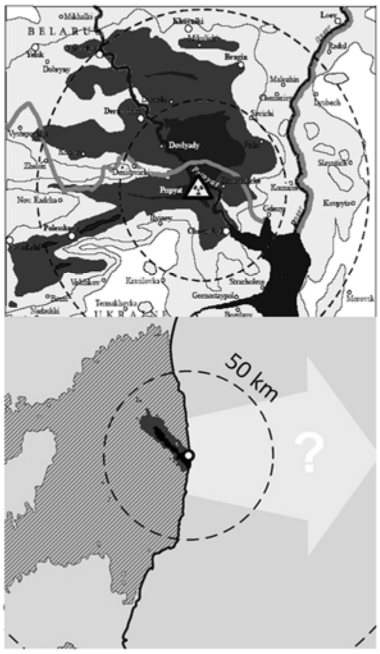
The Japanese experience is a good example of the difficulty of using models as a basis for taking protective actions in the event of severe reactor emergency. On the left you see the projection made by a dose model that was made 4 months after the accident in July/August 2011 and on the right is the actual deposition from the release measured by airborne monitoring. The actual deposition figure shows what appears to be a clear downwind direction; however, a large percentage of the release was out to sea, and thus not shown on the map of the deposition. Therefore, if this accident had occurred inland, major contamination would have occurred in all directions.

Sources:

TOSHIMITSU HOMMA, Radiation protection issues on preparedness and response for a severe nuclear accident : Experiences of the Fukushima Accident (2011), paper presented at the ICRP Symposium on the International System of Radiological Protection, 24-26 October 2011, Bethesda, MD, USA.

INTERNATIONAL ATOMIC ENERGY AGENCY, Status of the Fukushima Daiichi Nuclear Power Plant and related environmental conditions (May 6, 2011) p. 35 (IEC)

Take urgent protective action in all directions



- The timing, size and duration of the release is unknown
- Impossible to project area impacted
- Long-term or intermittent release could affect all directions

7

It will be impossible to project the area that would be impacted by a major release. The timing, size and duration of the release will be unknown and a long-term or intermittent releases could affect all directions, as the wind shifts with time.

Consequently, urgent protective actions that are critical for preventing severe health effects (urgent actions) should be taken in all directions around the plant.

The figures shows the deposition pattern resulting from several days of release from the Chernobyl emergency at the top and Fukushima on the bottom – clearly areas are affected in all directions.

Getting the Public to Comply with Recommended Protective Actions

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The public protects itself

It is important to realize that members of the public protect themselves (they take the actions)

Therefore clear communication is all important

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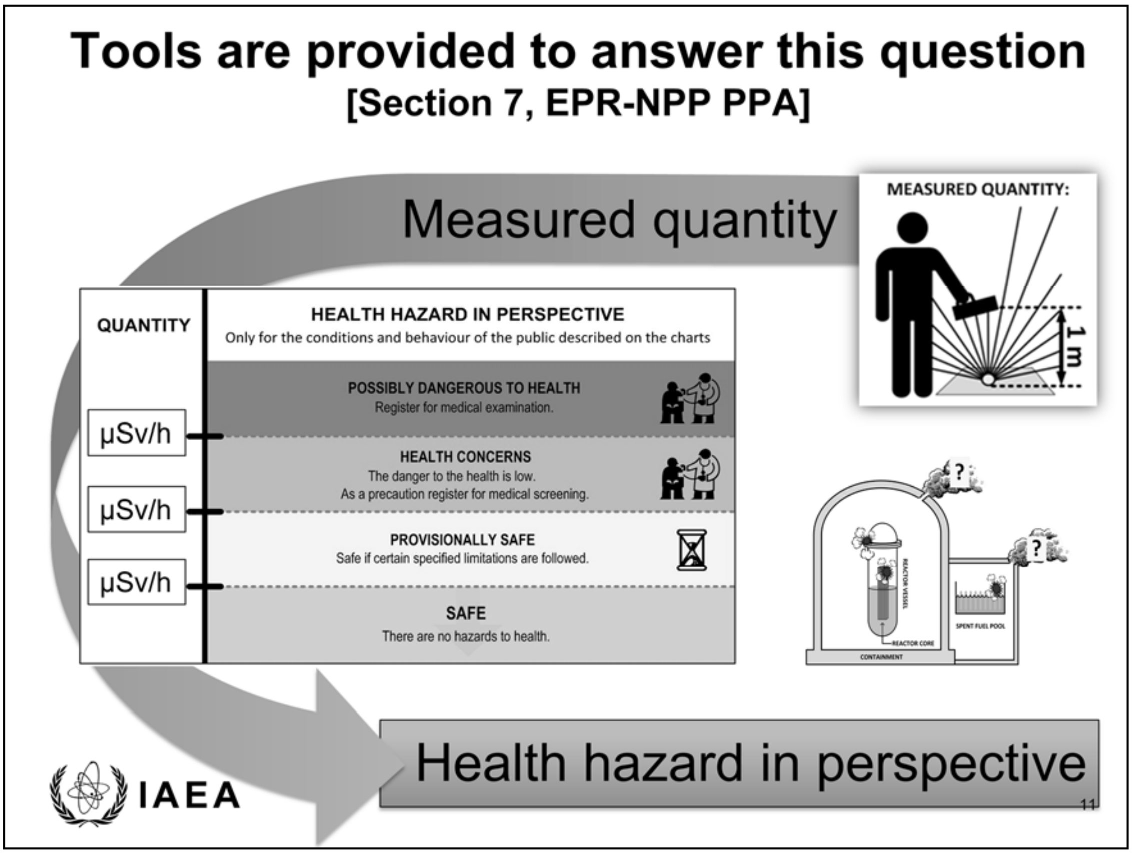
9

Public panic

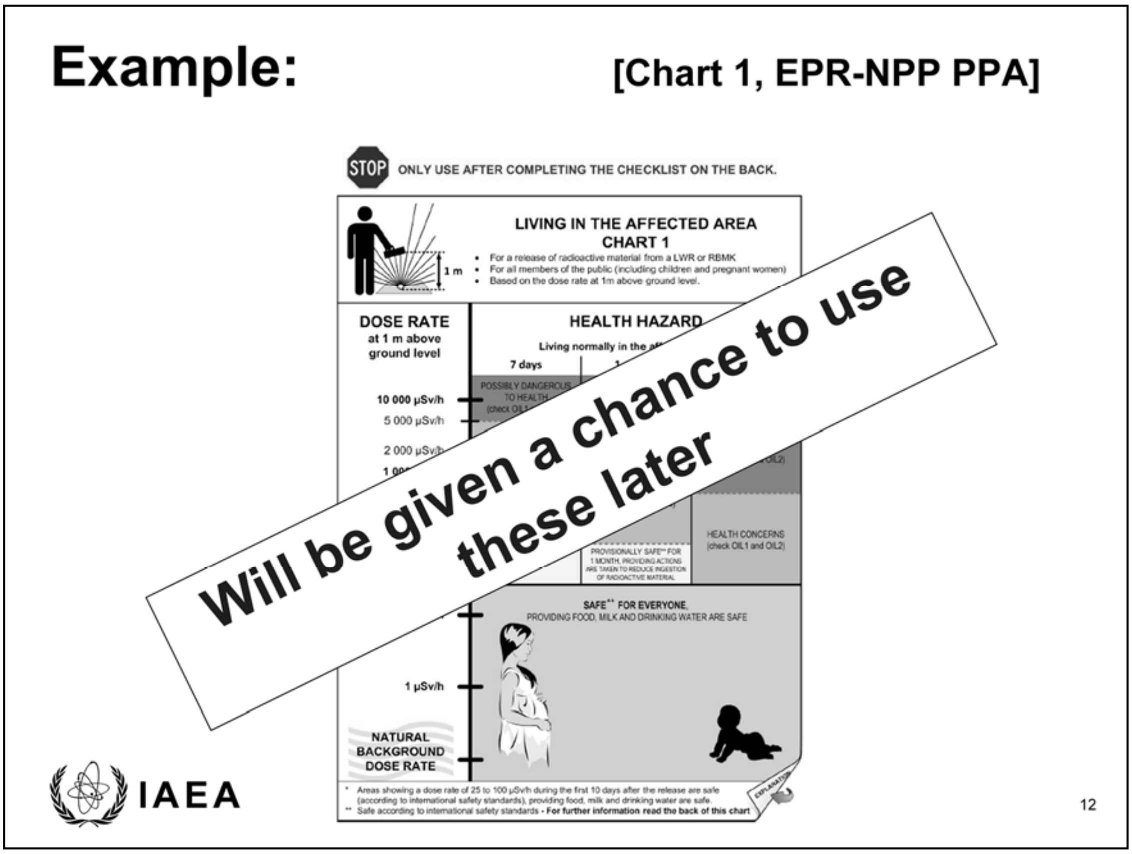
- People do not panic unless they receive:
  - conflicting information (often from official sources)
  - information they do not understand (Bq/km², cps, mSv...)
- They will take actions they feel best protect their family
- We do a terrible job in using the media to inform them

IAEA 10

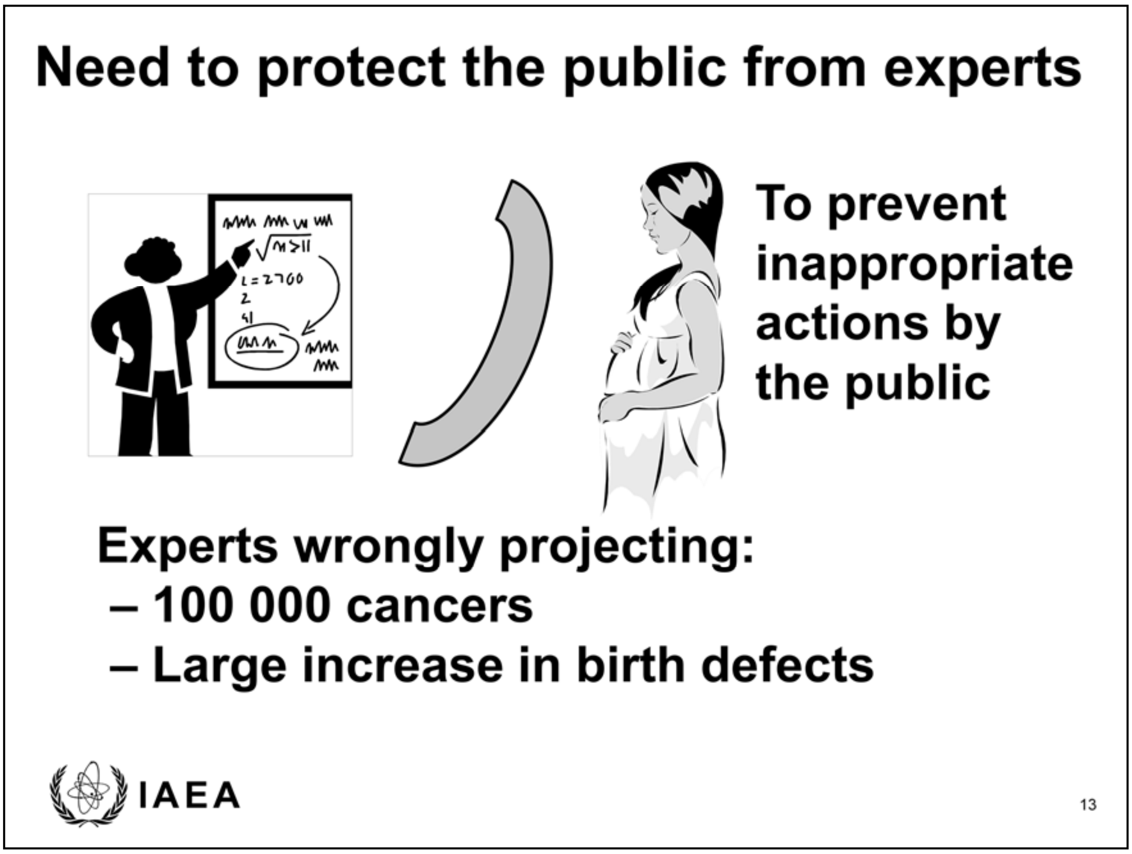
It has often been stated that the public panic during a nuclear or radiological emergency when they express concern or do not follow official recommendations. However, subsequent investigations of some emergencies have found that the public received confusing and inconsistent information concerning the risk of exposure and the appropriate action to be taken to reduce the risk. This information often emanated from apparently official sources, the media and other so-called experts. In many cases, the confusion was partly the result of local officials, national officials and the operator attempting, without prior coordination, to address the media from different locations (e.g. national capital, local regional capital, emergency location). Under these circumstances, the public did what they felt was appropriate to protect themselves, their loved ones and their interests. This often resulted in the public taking actions that did not appear to follow official recommendations or actions that were later found to be inappropriate and, in some cases, harmful, and which later resulted in severe adverse economic and psychological consequences.



Section 7 of EPR-NPP PUBLIC PROTECTIVE ACTIONS provides tools to answer this question. It allows the measured quantity to be directly related to the health hazard.



Turn to Chart 1. Chart 1 is an example of the charts that are provided to relate a measured quantity (in this case the dose rate above the ground) to the health hazard. You will be given an opportunity use these charts later.



Experts who during emergencies wrongly project excess cancer increases, birth defects and other health effects can cause the public and decision makers to take inappropriate actions.

Therefore it is important that you be prepared to respond to these projections and statements.

Public compliance with recommendations

…can be very low if:

- no information is given before the emergency
- conflicting information is given during the emergency

Note that typically about 10% of people never follow instructions anyway

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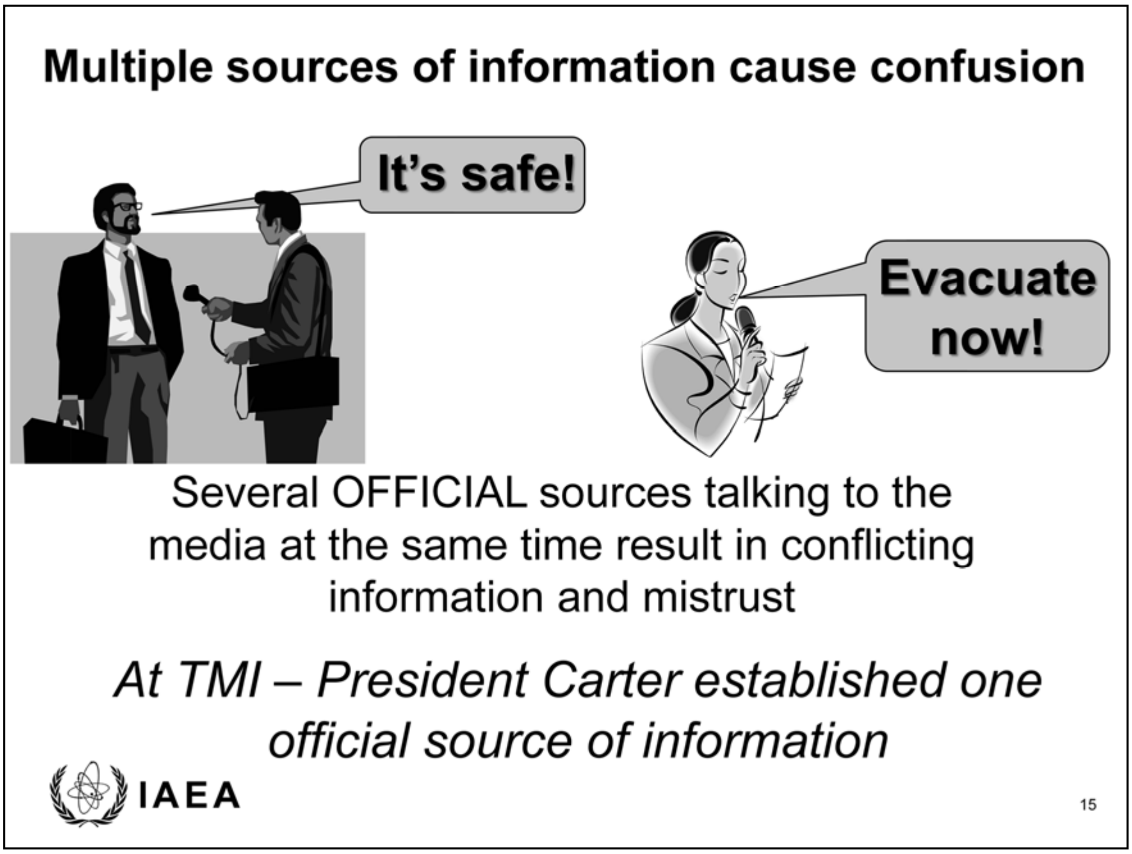
The compliance with imposed food restrictions was alarmingly low in some areas directly affected by Chernobyl and recommendations concerning evacuation during the Three Mile Island accident in the USA (TMI) were not followed. This was in part because of the lack of information early in the event and conflicting information later.

There will be better compliance with advice if trust is maintained by:

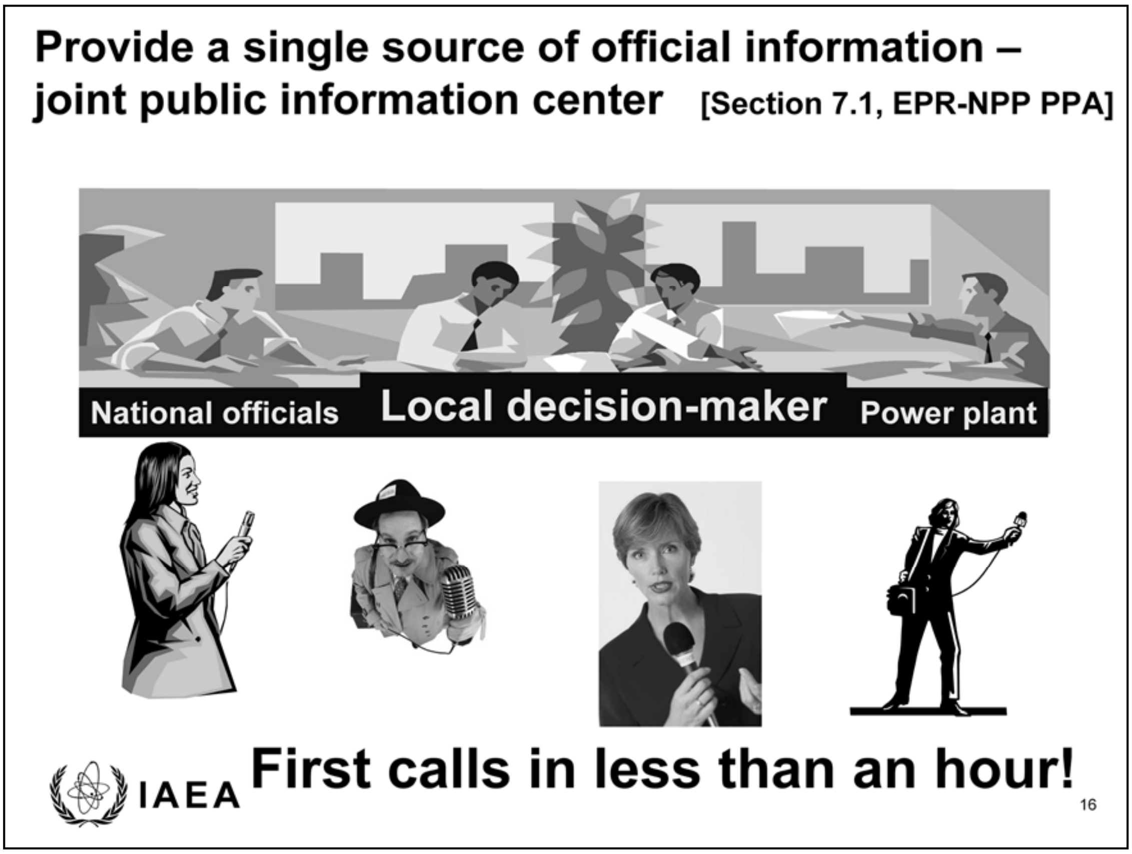
- ongoing information programmes that provide the public information about what they should do and expect before an emergency
- clear and simple advice during an emergency
- consistent advice and assessment (a single official information point).

It should be remembered that a small percentage of the population will never follow the recommendations – no matter how clearly given.



During the TMI and Goiânia emergencies [5], national authorities had several independent people and centres (local and national) simultaneously answering media questions. This resulted in considerable confusion, and release of conflicting information which resulted in public and media mistrust of the government response. During TMI, this was fixed when the President of the United States of America instructed that all information to the media must originate from a single location close to the facility.

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Lessons Learned from the Response to Radiation Emergencies (1945-2010), EPR-LESSONS LEARNED, IAEA, Vienna (2012).



Once the emergency becomes known there will be media attention at the site, and at the national and at local levels within an hour or less.

As recommended in Section 7.1, within an hour or two of a General Emergency being declared a consistent, understandable message needs to be communicated to the public. This requires the establishment of a joint public information centre at which a single official spokesperson briefs the public via the media.

Evacuation effectiveness

- Evacuations are common
- People do not panic
- Travel during evacuations is safer than normal travel
- Advanced arrangements can increase the speed of evacuations
- But effective and fast evacuations have been performed with no prior arrangement

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Some local officials have been reluctant to order an evacuation because they believed incorrectly that it would cause panic and numerous traffic fatalities. However, nearly fifty years of research on major evacuations (including those in response to serious radiation emergencies, release of a toxic chemical, the discovery of an unexploded World War II bomb, hurricanes) have shown that evacuations are common and can be undertaken without panic and increased risk of traffic fatalities [5]. However, experience also shows that evacuations can be performed promptly with no preparation.

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Lessons Learned from the Response to Radiation Emergencies (1945-2010), EPR-LESSONS LEARNED, IAEA, Vienna (2012).

People will evacuate even if not recommended if:

- They lose trust in what they are hearing
- There is conflicting information about the seriousness of the event
- Any segment of the population (e.g. pregnant women and children) is told to evacuate
- People stay together as families

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At TMI, two days after the core had melted, pregnant women and preschool aged children were advised to leave the area within a 5-mile radius [5]. Approximately ten times as many people evacuated as were specifically advised to do so [5]. Much of this was due to confusing and conflicting information about the seriousness of the accident, as well as to expectations that there would be further evacuations later. At TMI, the protective action was aimed at a subgroup of the population (i.e. pregnant women and pre-school children). Experience has shown that the public will keep all of their family together, so when a subgroup is told to evacuate: everyone will evacuate.

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Lessons Learned from the Response to Radiation Emergencies (1945-2010), EPR-LESSONS LEARNED, IAEA, Vienna (2012).

No plan in advance, evacuation took:

- *1.5 hours* for 3000 people within 2.6 km radius
- *Less than 1 hour* for 1500 people within 2.6 km radius
- *Less than 1 hour* for 2000 people within 5.1 km² area
- *1-2 hours* for 1500 people within 1.3 km² area
- *2 hours* for 5000 people in a 12.8 km² area

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Studies of numerous technical emergencies involving chemical spills fires and chemical plants etc. has shown that local officials could promptly evacuate the population nearby with literally no advance planning. Examples in the USA include:

1. Accident involving a truck transporting toxic pesticide, 1994
2. Leak at Gaylord Chemical Plant, 1995
3. Fire at a propane storage facility, 1998
4. Derailment of Union Pacific Railroad train containing hazardous cargo, 2000
5. Brandon ruptured pipeline leaking anhydrous ammonia, 2003.

Source: U.S. NUCLEAR REGULATORY COMMISSION, Office of Nuclear Security and Incident Response, Identification and Analysis of Factors Affecting Emergency Evacuations, Appendices, Sandia National Laboratories, NUREG/CR-6864, Vol. 2, SAND 2004-5901, Washington, DC (2005).

Other Considerations

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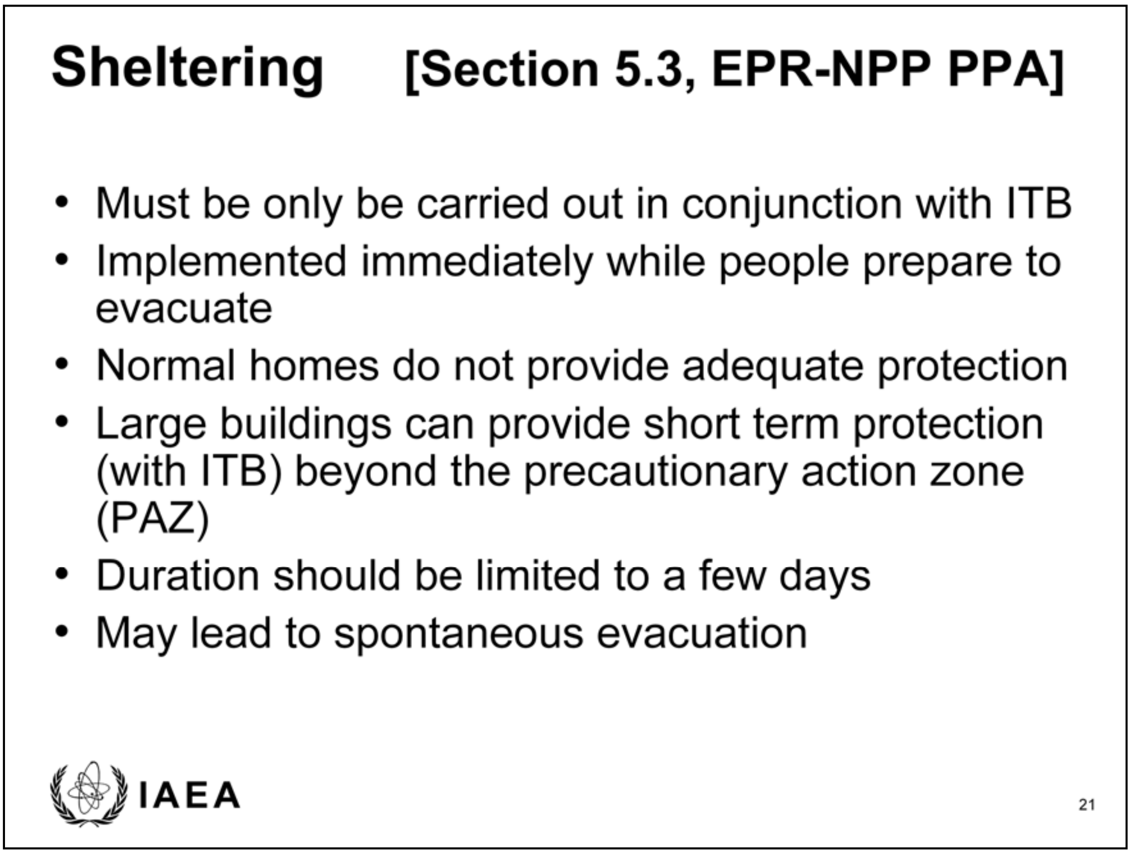

Section 5.3 of EPR-NPP PUBLIC PROTECTIVE ACTIONS discusses sheltering. Sheltering even in large buildings does not provide adequate protection from inhalation of iodine. Therefore, sheltering should always be supplemented by the taking of an iodine thyroid blocking (ITB) agent.

Sheltering is easy to implement, but in most cases cannot be carried out for long periods. In addition, sheltering can be used as a preparation for evacuation. The people in an area of potential risk can be instructed to "go inside" and listen to their radios for further instruction while preparations for evacuation are being made.

For a very severe reactor release, sheltering even in a large building may not be sufficient to prevent deterministic health effects close to the facility (in the PAZ). Sheltering in a large building may prevent severe deterministic effects in areas beyond the precautionary action zone (3–5 km PAZ). Sheltering is not a long term protective measure and typically this is assumed to be carried out only for a few days.

Experience shows that recommendations to shelter have led to spontaneous evacuations.

Once the emergency is announced to the public, be prepared for:

- Failure of normal communications, both landline and mobile due to overloading
- International interest:
  - requests for information
  - offers of assistance

Busy – no signal

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Overloading and sometimes the breakdown of public telephone systems (land lines and mobile systems) in the vicinity of an event (and in some cases on a broader scale) often happen shortly after the pubic becomes aware of an event perceived as significant. This prevented the regulatory body from maintaining communications with the site during the TMI emergency and hampered many other aspects of the official emergency response. This occurred following the attack on 11 September 2001 in the USA, earthquakes, the TMI emergency and in at least one case by people calling to try to get tickets for a rock concert.

Once the emergency becomes known, there will be offers of help and calls with advice. During the first few days, the TMI control room received 4000 phone calls with advice. This greatly interfered with the response.

Belarus is within 5 km of Chernobyl and was heavily impacted by the release from that plant. However, due to slow notification, evacuations within Belarus did not start until four days after the start of evacuations in the Ukraine.

Arrangements must be in place for immediately notifying officials responsible for the areas where urgent protective actions should be taken (PAZ, UPZ and ICPD) in bordering states. These arrangements should be routinely tested during exercises.

This requires that arrangements be established in advance. In addition, under the Convention on Early Notification of a Nuclear Accident, States Party commit that, in the event of a nuclear accident that may have transboundary radiological consequences, they will notify countries that may be affected and the IAEA.

Abbreviation:

ICPD – ingestion and commodities planning distance

Actions for those potentially exposed

[Section 2.3, EPR-NPP PPA]

- Register
- Immediately treat those with injuries – using universal precautions
- Immediate examination for symptoms of high exposure (vomiting)
- Outside UPZ – monitor skin and thyroid
- Decontaminate or instruct on how to do later

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Section 2.3 of EPR-NPP PUBLIC PROTECTIVE ACTIONS discusses actions needed to be taken for those potentially exposed.

Refusal to treat those who may be contaminated

- Need to advise that use of universal precautions against infectious agents (gloves, surgical mask…) is sufficient when treating contaminated patients

Effectiveness proven during Po-210 emergency in the UK

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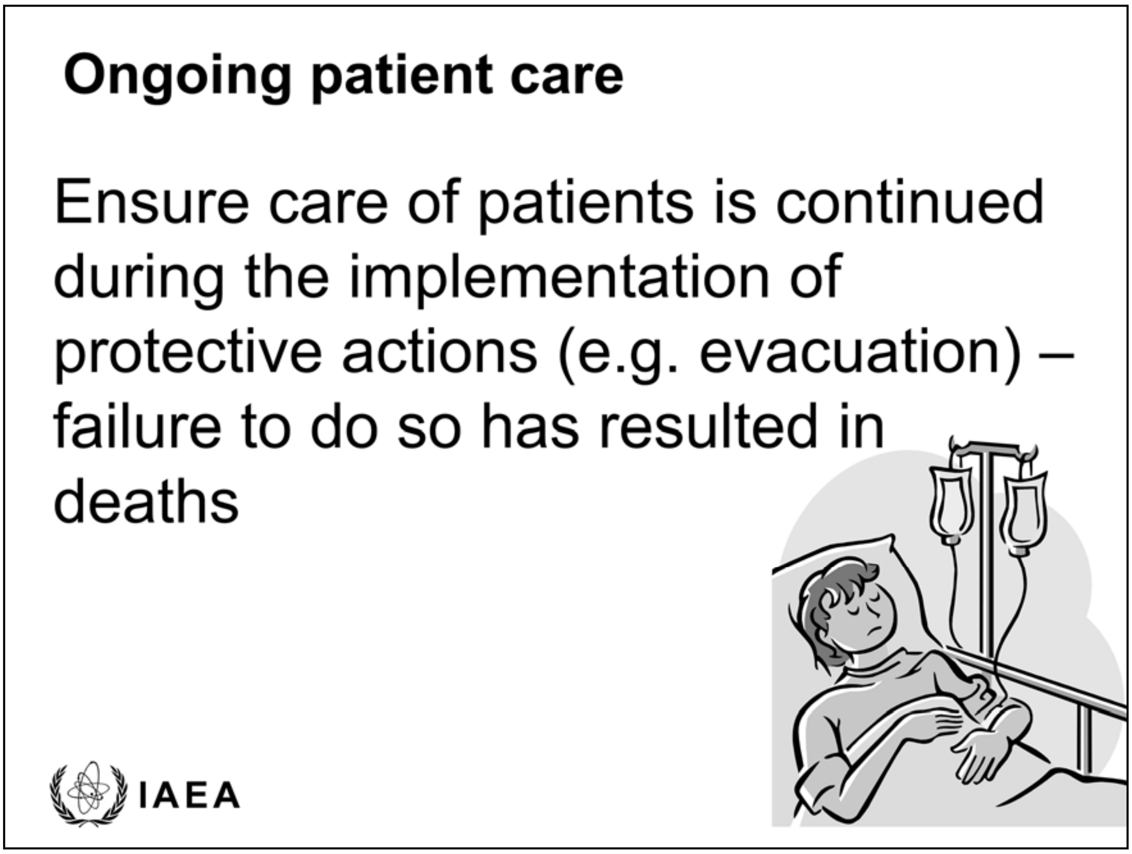
In several past emergencies potentially contaminated people have been stigmatized and shunned, and medical staff have refused to treat them. However, as discussed in Sections 2.3 and 5.6 of EPR-NPP PUBLIC PROTECTIVE ACTIONS, those transporting and/or treating contaminated individuals can do so safely if they use universal precautions against infectious agents (gloves, mask, etc.).

Use of universal precautions proved very effective in protecting the medical staff treating the person contaminated with polonium-210 in the UK, even though they did not know that the person was contaminated.

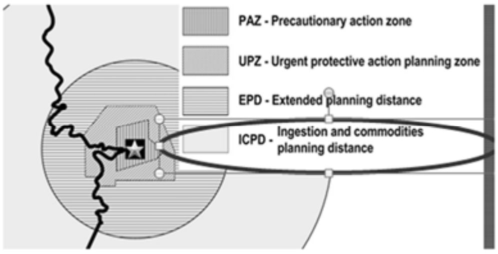


When implementing protective actions such as sheltering or evacuation, provision of care to those patients requiring continuous care needs to be ensured. Failure to have arrangements in place for ensuring continued treatment of critically ill patients for their evacuation (both during transportation and on arrival at the receiving facility) led to deaths during the evacuations conducted owing to the Fukushima accident.

"More than 50 patients have been reported as dying either during or soon after evacuation, probably owing to hypothermia, dehydration and deterioration of underlying medical problems."

Source: TANIGAWA, W., HOSOI, Y., HIROHASHI, N., IWASAKI Y., KAMIYA, K., Loss of life after evacuation: lessons learned from the Fukushima accident, The Lancet, **379**(9819), 2012, pp. 889-891.

To reduce economic consequence within ICPD [Section 5.9, EPR-NPP PPA]



- Reassured that commodities do not exceed internationally criteria for trade
- Certification system can be effective
- Restrict the distribution of commodities within the ICPD until certification

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Section 5.9 of EPR-NPP PUBLIC PROTECTIVE ACTIONS discusses protection of trade and commercial interest. Emergencies have caused adverse economic consequences. National and international customers need to be reassured that exports from the affected region are being carefully controlled to ensure that they are not contaminated (i.e. do not exceed international criteria for trade). Experience has shown that establishing a testing and certification system can mitigate the economic impact of a radiological emergency on international trade. Therefore, provisions need to be in place to restrict the distribution of commodities within the ICPD until certification can be used to verify that products from the affected area are safe and do not exceed internationally agreed criteria for trade.

Decision Making

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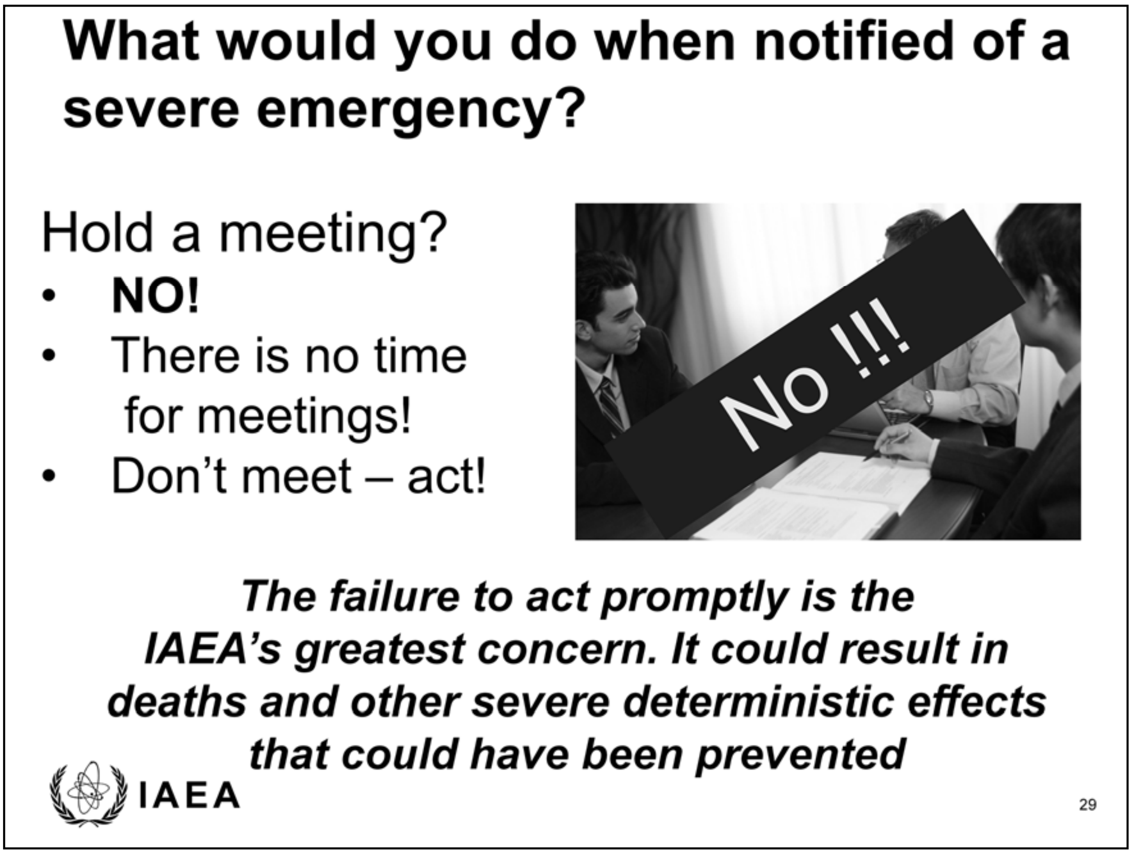

When asked in various IAEA workshops what will be the first thing that off-site officials do in the event of a severe emergency? The answer given in many cases is that they would hold a meeting.

However, we have seen that there is no time in the event of a severe emergency to hold a meeting.

In the past - response of decision makers was not effective

- Overwhelmed –did not understand their roles and too many things to do
- Did not participate in training but sent subordinates
- Did not follow or know existing plans
- Developed ad hoc plans which caused great confusion as others were following the pre-established plans

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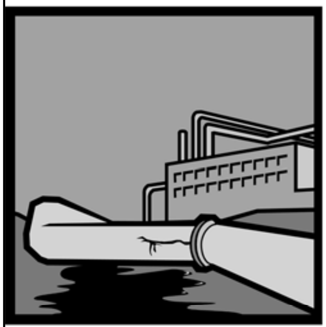
Many managers directing initial response were ineffective because they had not been trained under realistic emergency conditions and the response system was not designed for severe emergencies (e.g. TMI, Chernobyl).

These managers were overwhelmed and confused by the stressful environment, performed their subordinates' tasks rather than their own managerial roles, had to move to new locations at crucial times, lacked telephone access because of jammed lines, and failed to develop an understanding of the true nature and severity of the emergencies.

During the response to emergencies senior officials/managers caused confusion by developing ad hoc plans because they were unaware of the plans and procedures that their organizations had established. Quite often, senior managers and decision makers failed to recognize the need for their participation in training and for identifying their roles in emergency situations. They had their subordinates attend the training even though during a real the response they were the ones responsible.

Source: Lessons Learned from the Response to Radiation Emergencies (1945-2010) EPR-Lessons Learned IAEA 2012

Question Module 8-4: How long did the decision to evacuate take in these cases?



- Leak at a chemical plant
- Derailed train with hazardous cargo
- Ruptured pipeline leaking anhydrous ammonia
- Fire at a propane storage facility
- Accident involving a truck transporting toxic pesticide

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Ask the participants: How long did the decision to evacuate take for the following situations?

Answer Module 8-4: How long to decide? *FAST*

The decision to evacuate took:

- ***15 and 30 minutes*** – leak at a chemical plant
- ***2 minutes*** – derailed train with hazardous cargo
- ***30 minutes*** – ruptured pipeline leaking anhydrous ammonia
- ***10 minutes*** – fire at a propane storage facility
- ***40 minutes*** – accident involving a truck transporting toxic pesticide

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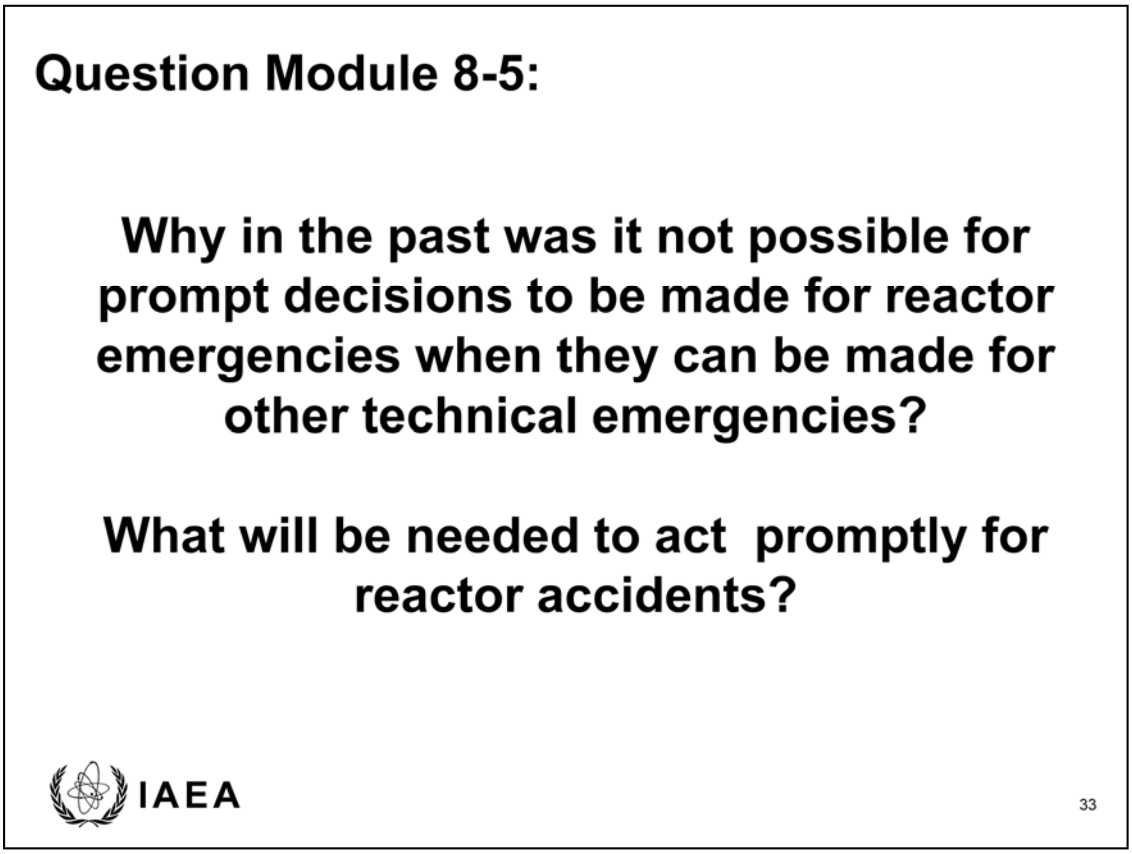
Numerous technical emergencies involving chemical plants hazardous cargoes facilities with hazardous materials occur routinely and local officials have been able to promptly make decisions to evacuate the public. This shows that decisions were made within 30 minutes to evacuate the public living around all of these emergencies. And this was without any prior planning. Prompt decisions can and must be made also for severe reactor emergencies if we want to be able to protect the public.

Source: U.S. NUCLEAR REGULATORY COMMISSION, Office of Nuclear Security and Incident Response, Identification and Analysis of Factors Affecting Emergency Evacuations, Appendices, Sandia National Laboratories, NUREG/CR-6864, Vol. 2, SAND 2004-5901, Washington, DC (2005).



Ask the participants to provide the reasons why they think decisions cannot be made for a reactor emergency promptly but can be for other types of emergencies.

Answer Module 8-5:

Why in the past was it not possible for prompt decisions to be made for reactor emergencies when they can be made for other technical emergencies?

What will be needed to act promptly for reactor accidents?

Open discussion

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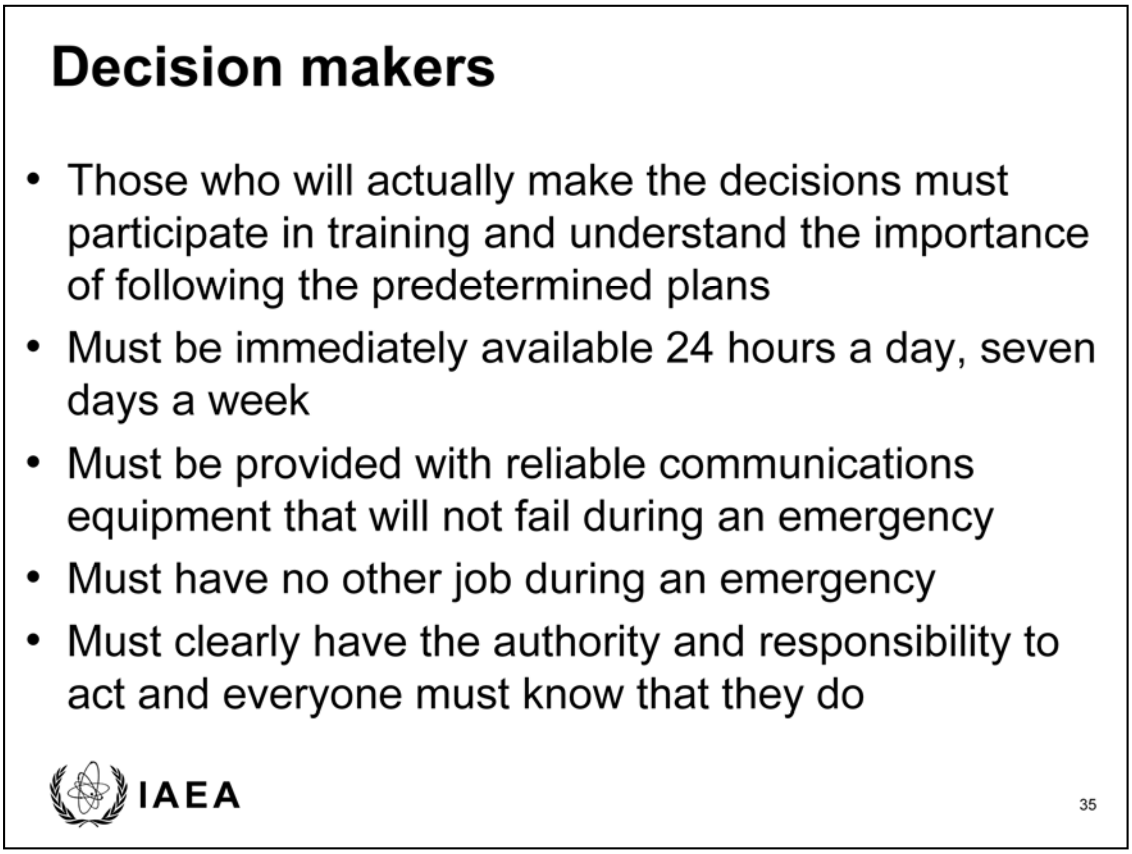
Ask the participants to provide the reasons why they think decisions cannot be made for a reactor emergency promptly, but can be for other types of emergencies.



Past emergencies have shown that part of the reason decision makers do not act promptly is that they had not participated in training, did not understand the procedures, were not available when the emergency occurred, could not communicate, had some other distracting job during the emergency, and it was not clear to them or others that they had the responsibility and authority to act.

The protective action strategy

Concept of operations

[Section 2, EPR-NPP PPA]

The concept of operations pulls this all together by listing the steps that need to be taken in a severe emergency

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Let us now quickly summarize by walking through the steps

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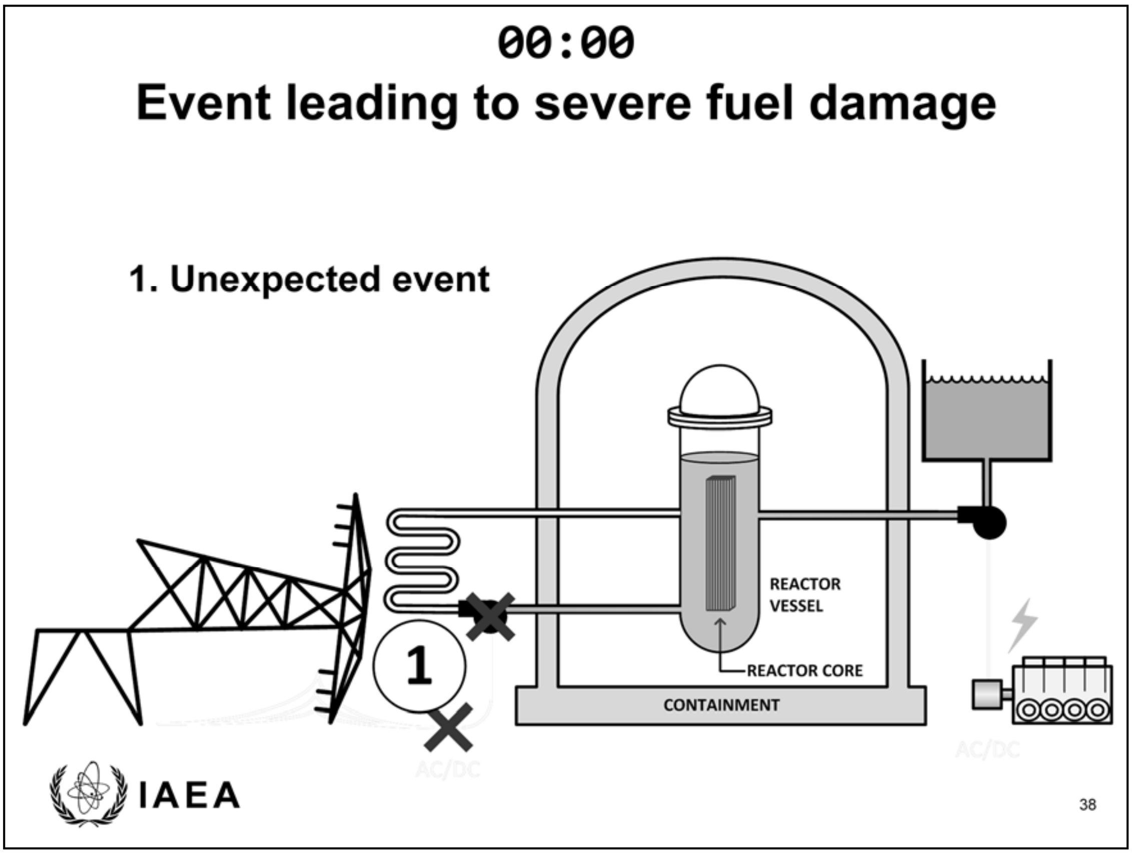
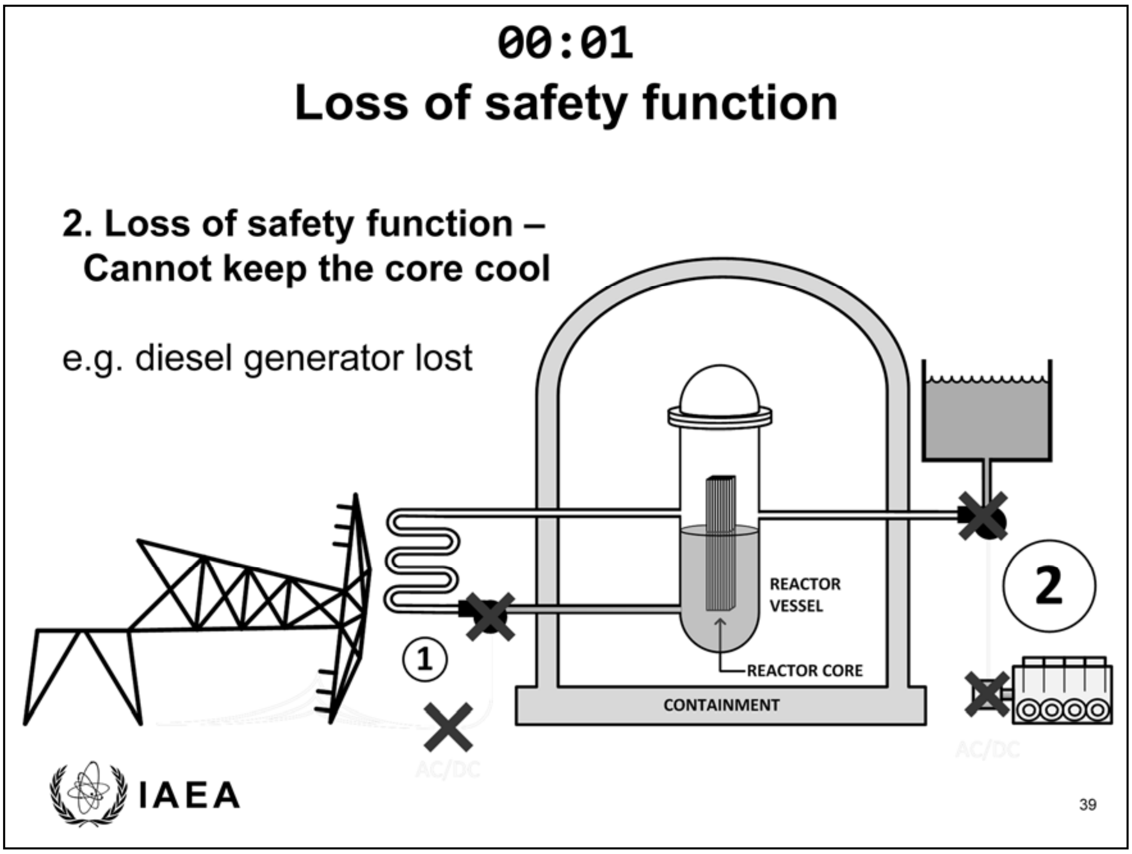
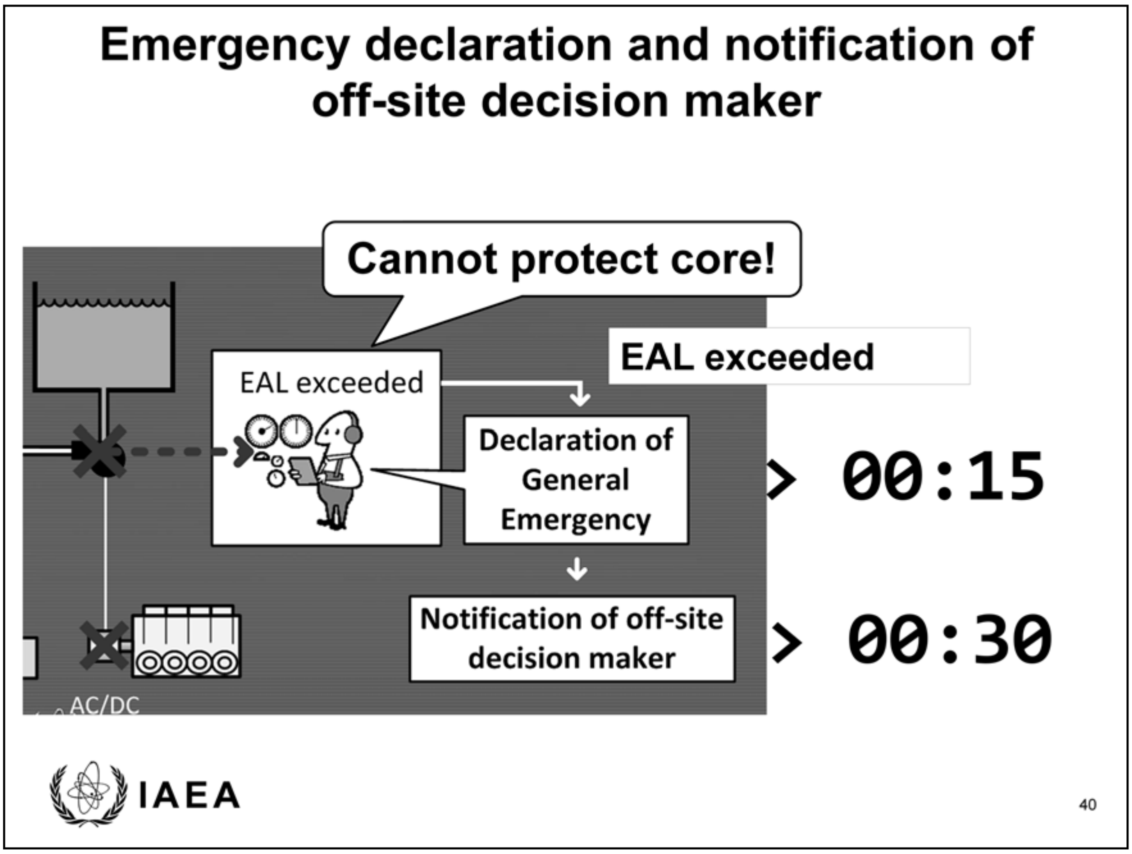
Have the participants turn to Fig. 1 and follow them through the example on the next slides.



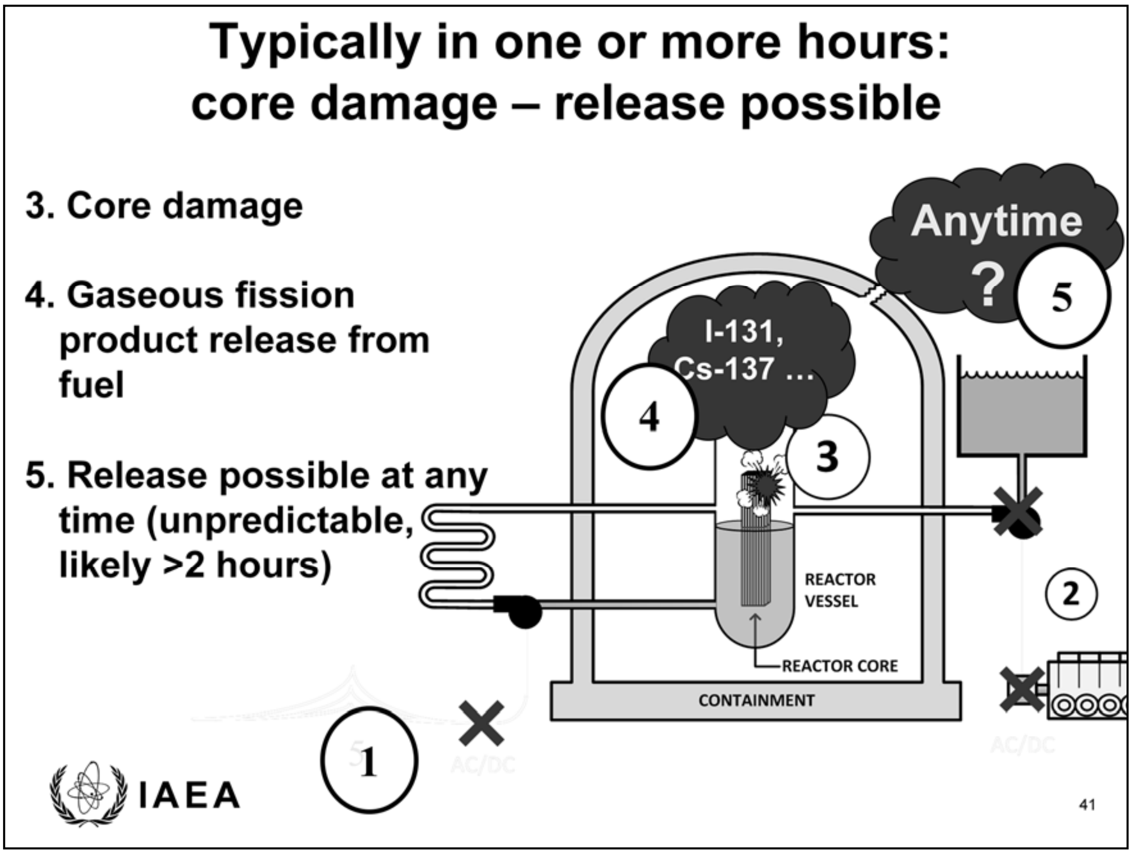
Some event occurs that could lead to core damage if the safety systems do not work as designed, for example in this case the loss of off-site power. However, if the emergency systems work as planned, there should not be a problem. So in this case there should not be any problem because the diesel generator should start up and provide the power needed to drive the pumps used to providing cooling water to the fuel in the reactor core.



In this case, the diesel generator attempted to switch on to provide power to the pumps keeping the core cooled, but for some reason failed. This means that cooling will not be provided to the core.



In our example the failure the DC generator means that the plant can no longer keep the core covered with water and cooled. This would result in an emergency action level (EAL) calling for the declaration of a **General Emergency** to be exceeded. As soon as the operators in the control room see the EAL is exceeded they will declare a General Emergency and within less than 30 minutes of the loss of diesel generator function will have notified off-site officials that a General Emergency has occurred and recommend that these off-site officials take action to protect the public immediately.



Within an hour or less of the loss of safety functions needed to protect the fuel in the core, in this case the diesel generator, the core of reactor will become uncovered and rapidly heat up (at a rate of 2°C/second). Once uncovered, within a short time the volatile radioactive material in the core (e.g. I and Cs) will be cooked out of the fuel and released in a gaseous form, most likely into the containment (but possibly directly to the atmosphere). This radioactive material, since it is in a gaseous form, could be directly released to the atmosphere if the containment does not function properly. Most likely a release will not occur less than 2 hours following the start of the emergency, but could occur at any time. The actual release, timing and size of the release would be unpredictable.

>00:45

Decision maker instructs public to act

Within minutes of being notified of a General Emergency, the off-site officials notify the public to start taking protective actions and activate the on-site response

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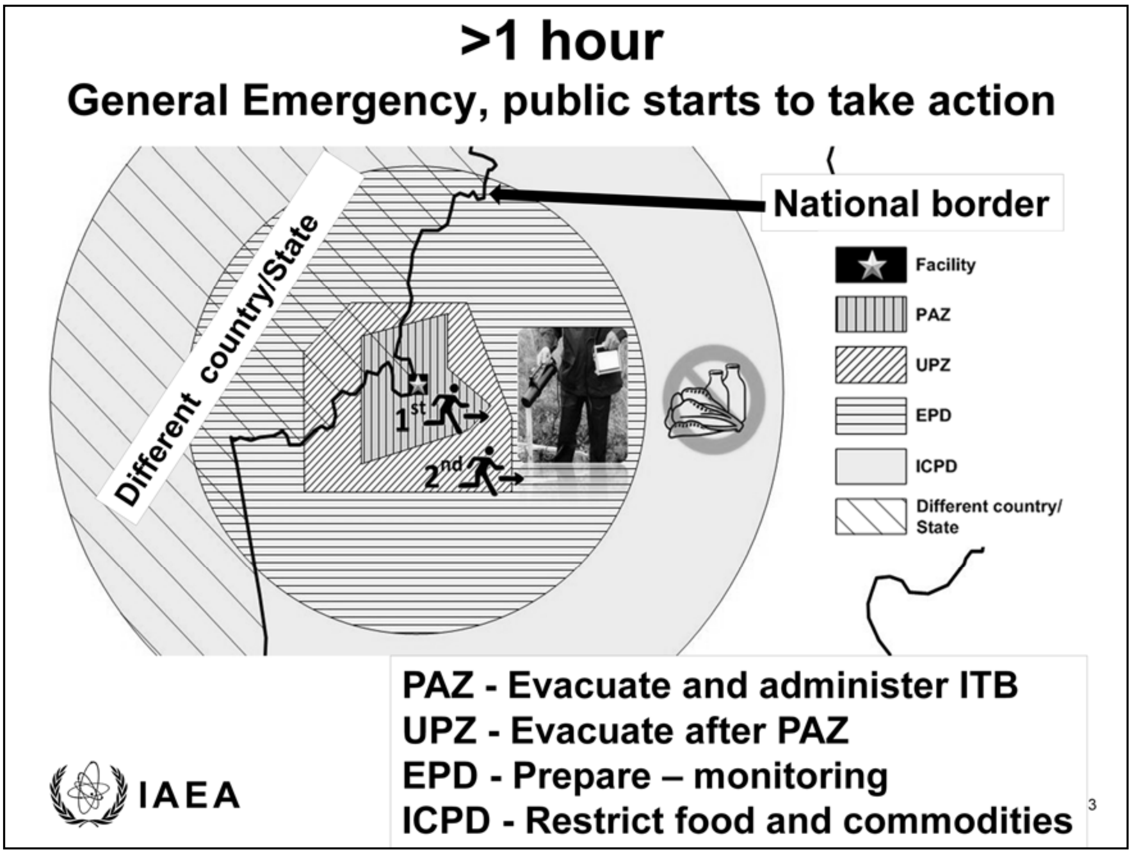


Within less than 1 hour of the detection of the emergency event (in this case the loss of the diesel generator) and with the benefit of prior instruction as part of an emergency preparedness programme, the public promptly take the recommended protective actions. These are described in further detail in the following slide.

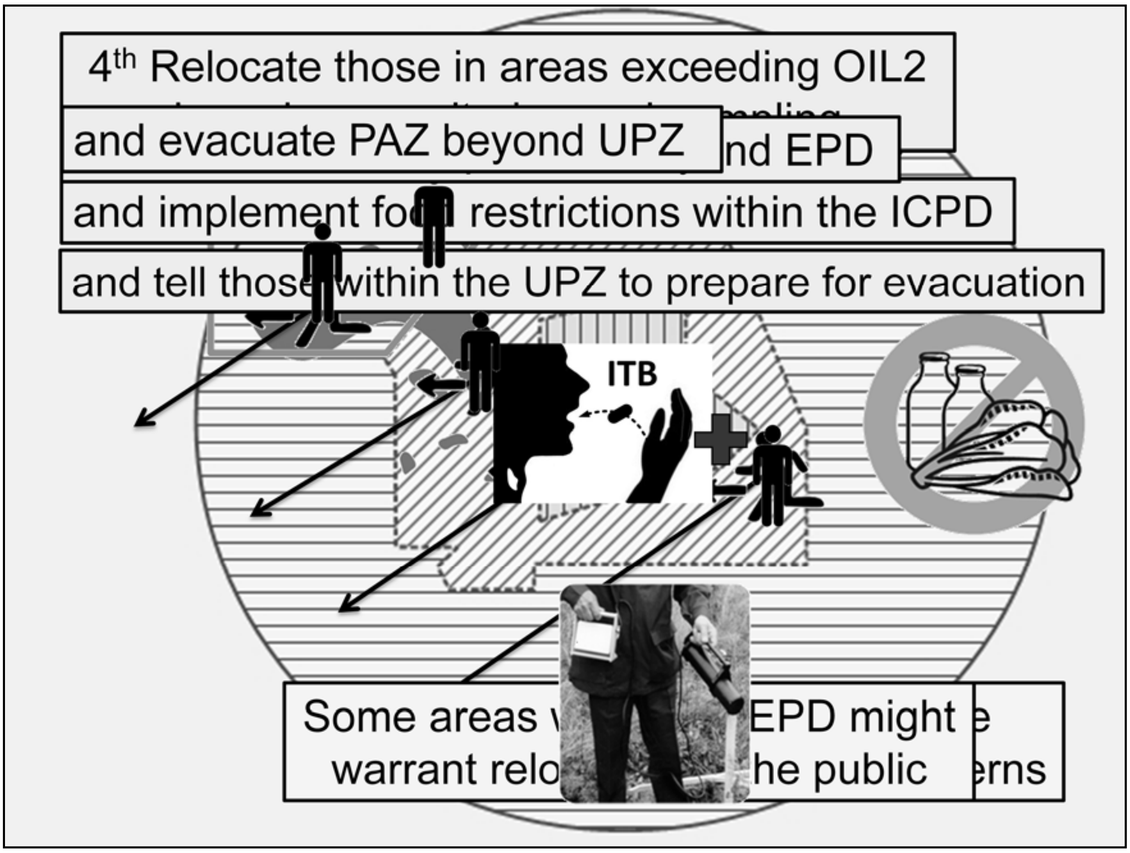
Abbreviations:

PAZ – precautionary action zone

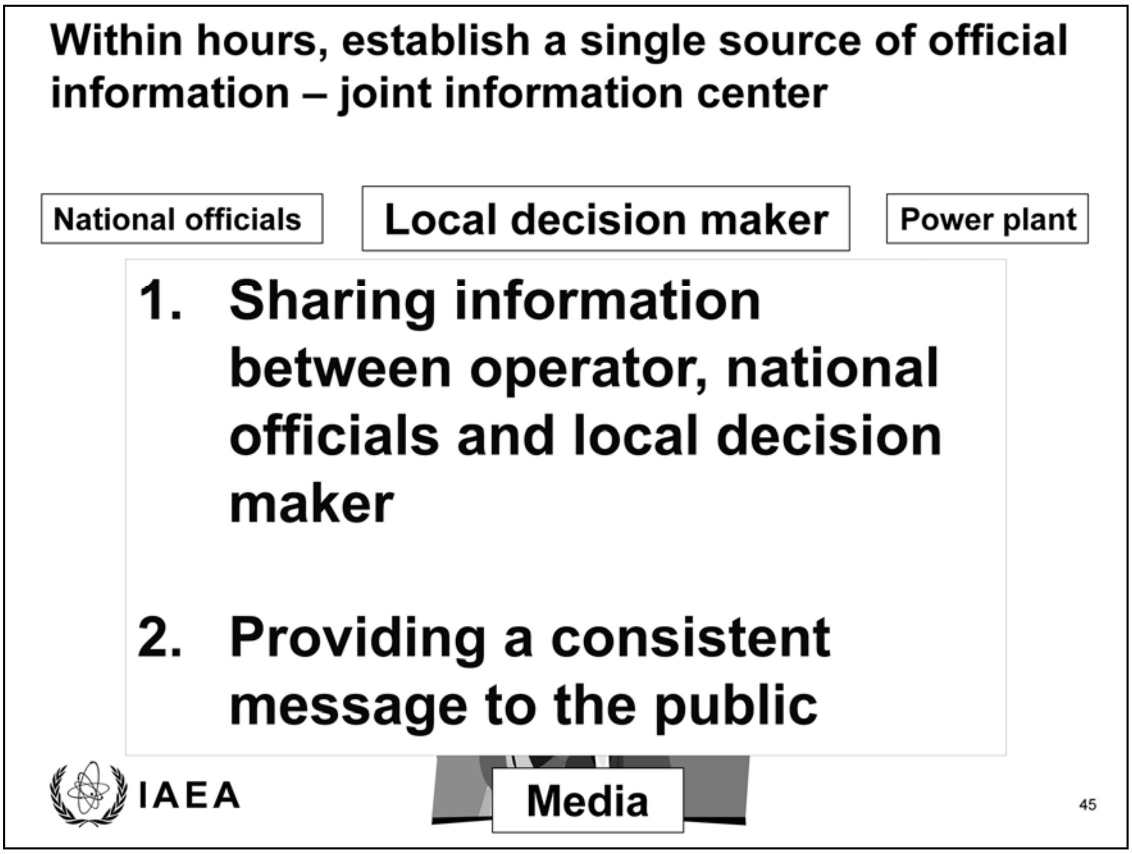
UPZ – urgent protective action planning zone

EPD – extended planning distance

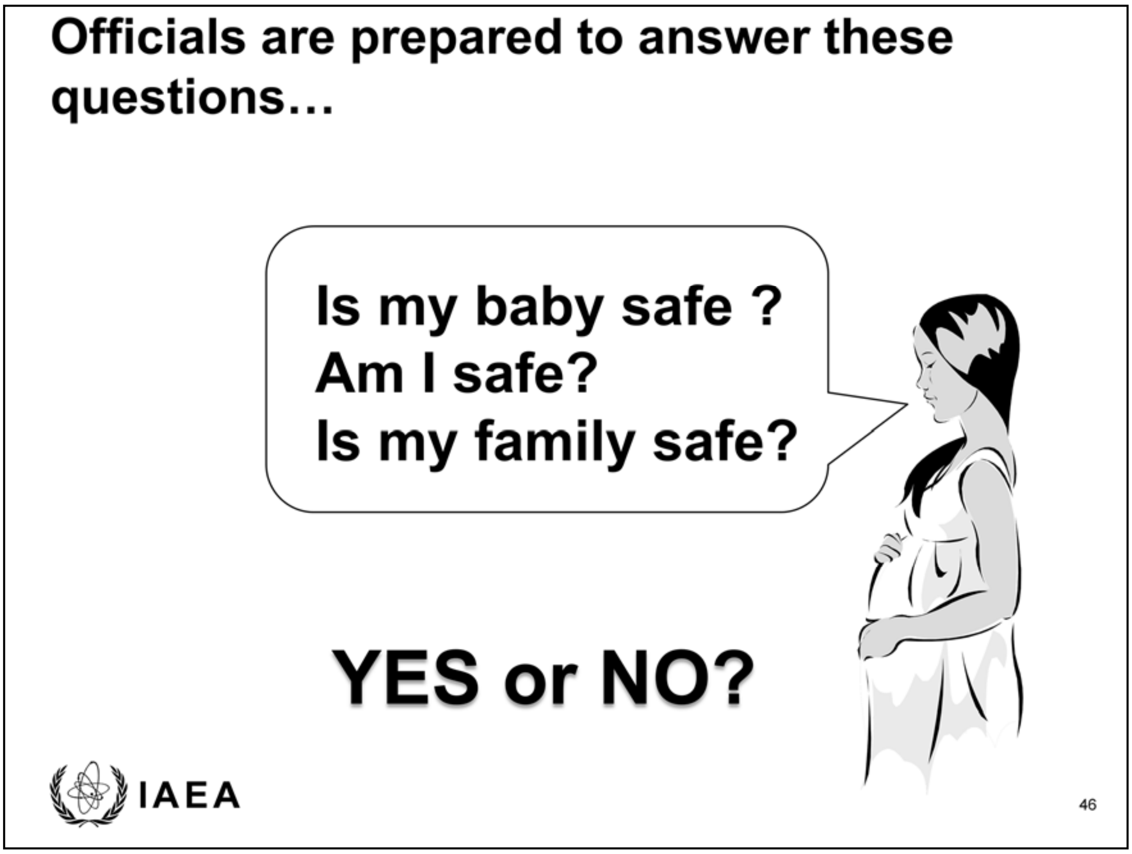
ICPD – ingestion and commodities planning distance



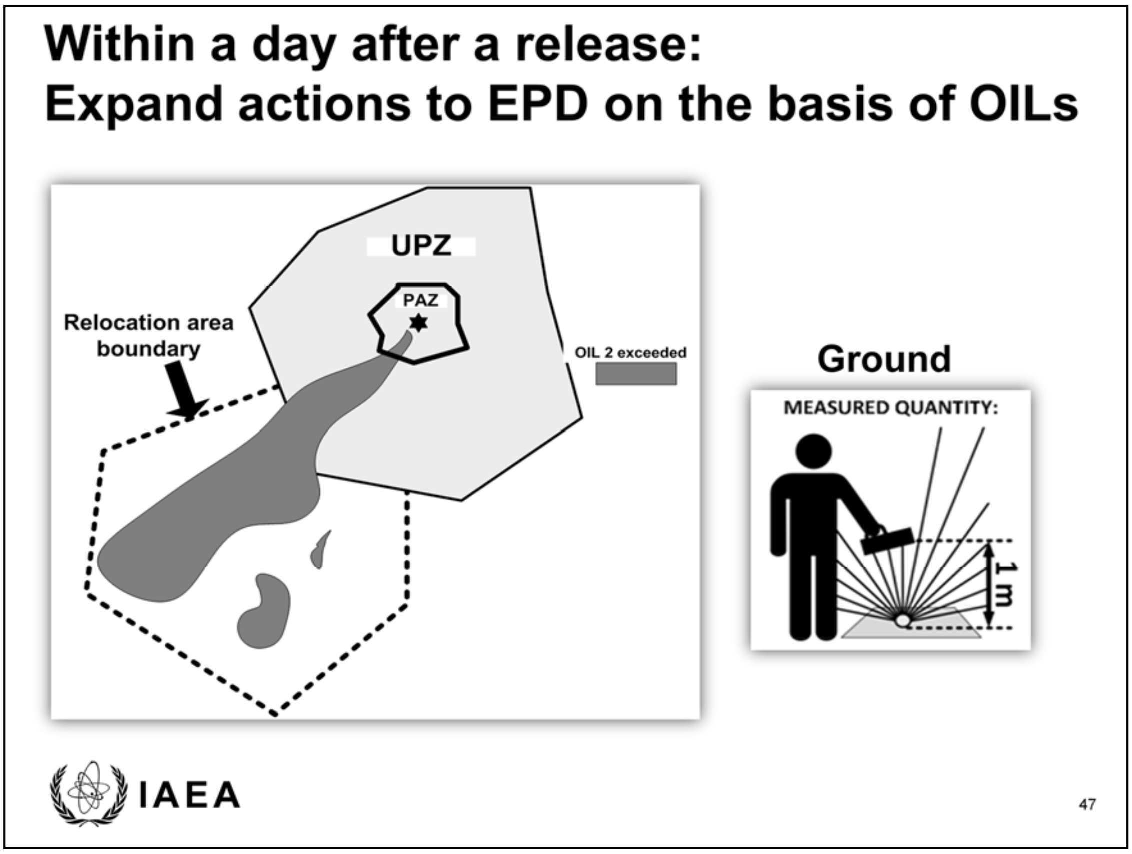
Protective actions that need to be implemented following a severe emergency at a nuclear power plant or spent fuel pool.



Within hours, a joint information centre is established that acts as the single and only source of information for the media. Representatives of national and local governments, as well as the facility should be present to support the local decision maker in providing a single coherent message that is understandable to the public.



Officials are prepared to answer these questions with yes or no



After a release, monitor to identify where OILs are exceeded, and therefore where additional protective actions should be taken within:

Hours to one day: evacuation where OIL1 is exceeded;

Days :

- relocate where OIL2 is exceeded;
- restrict produce where OIL3 is exceeded.

One week: sample and analyse food, water and milk to confirm the adequacy of controls using OIL7.

In addition – within hours:

- Monitor the public actions and media to identify inappropriate responses
- Register, screen, monitor and decontaminate evacuees
- Implement provisions to protect trade and commodities
- Alert hospitals to prepare

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Within hours of detection of the condition in the plant leading to core damage:

Monitor the public actions and media to identify inappropriate responses and address new concerns.

Register, monitor, decontaminate and screen evacuees to determine if they should receive immediate treatment or be registered for later medical follow-up.

Implement controls to reassure interested parties (e.g. other countries) that controls are in place to ensure all exports and trade are not contaminated and meet international standards.

Alert local hospitals to prepare to treat contaminated and exposed individuals.

Summary

Event leading to core damage occurs	00:00
Classified General Emergency by NPP	00:15
Off-site decision maker notified	00:30
Public notified to act	00:45
Public starts to act, food and commodities restricted	01:00
Media briefing Centres for monitoring evacuees	Hours
Monitoring of EPD – actions based on OILs	Days

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Questions Module 8-6, 8-7 and 8-8:

6. Name examples of urgent protective actions.

7. Why do operational criteria need to be developed in advance?

8. What are emergency action levels (EALs)?

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Answer Module 8-6:

6. Urgent protective actions:

- Evacuation or providing substantial shelter
- Decontamination of evacuees
- Taking iodine thyroid blocking (ITB) agents
- Reduction of inadvertent ingestion
- Stopping consumption/distribution of all local produce, milk from animals grazing in the area and rainwater
- Registration of those in the area
- Identification of those needing medical examination or counselling

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Answer Module 8-7:

7. Why do operational criteria need to be developed in advance?

   - No time to develop during a emergency
   - Needed for immediate decisions
   - Difficult to develop and justify criteria during the emergency
   - Criteria developed during emergencies are not trusted by the public

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Answer Module 8-8:

8. What are emergency action levels (EALs)?

- Predetermined observable threshold
- Triggers for taking response actions (declaration of emergency class)
- Observable / known to control room that indicates:
  - a threat to the core or spent fuel pool
  - actual or projected core or spent fuel pool damage

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Questions Module 8-9, 8-10, 8-11:

9. You are the local decision maker and the plant just called and reported that they cannot keep the core covered with water. What should you do?

10. When should protective actions be implemented?

11. When should you start monitoring and for what purpose?

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Answer Module 8-9:

9. You are the local decision maker and the plant just called and reported that they cannot keep the core covered with water. What should you do?

Implement the action for a General Emergency
– most important: evacuate and provide ITB for the public that is located near the NPP

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Answer Module 8-10:

10. When should the protective actions be implemented near the plant?

Before or shortly after a release, as failure to act could result in deaths and other severe deterministic health effects off-site that could have been prevented

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Answer Module 8-11:

11. When should you start monitoring and for what purpose?

Monitoring has to be performed promptly after a release to implement protective actions where OILs are exceeded.

- Where evacuation is needed: within hours
- Where relocation is needed: within days

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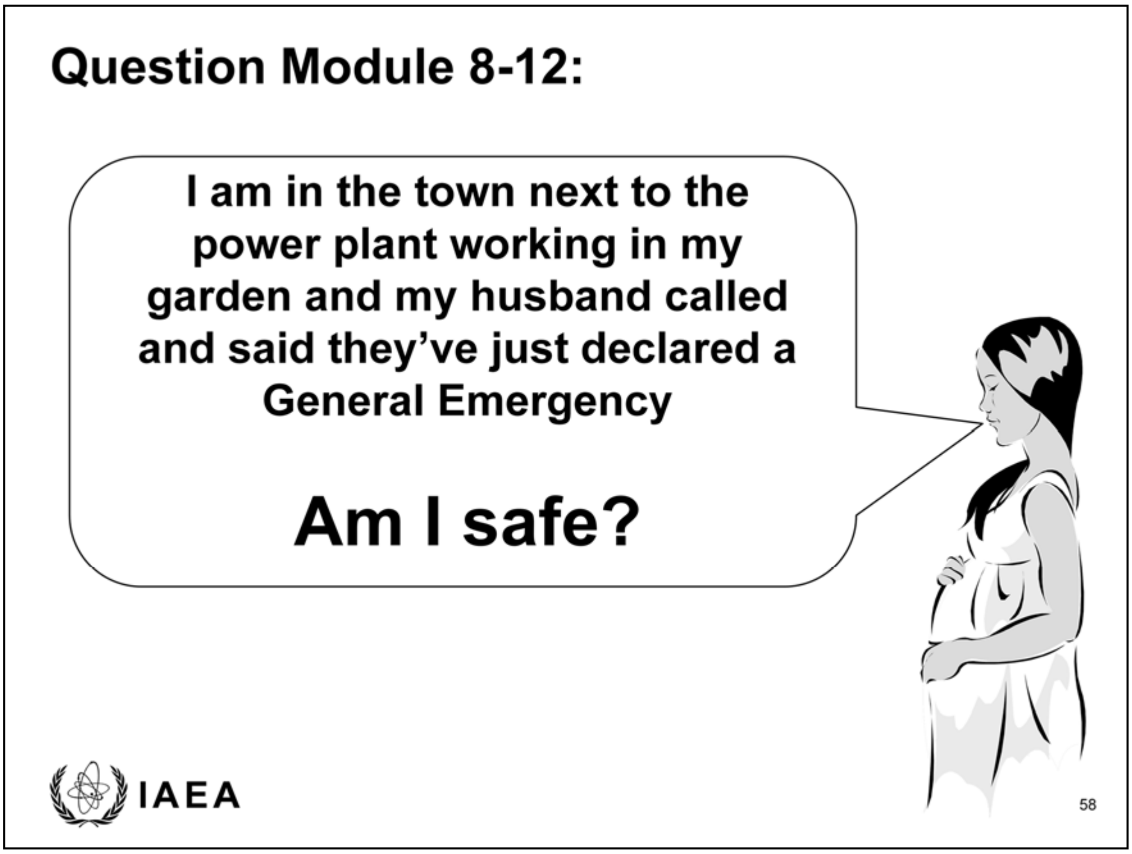
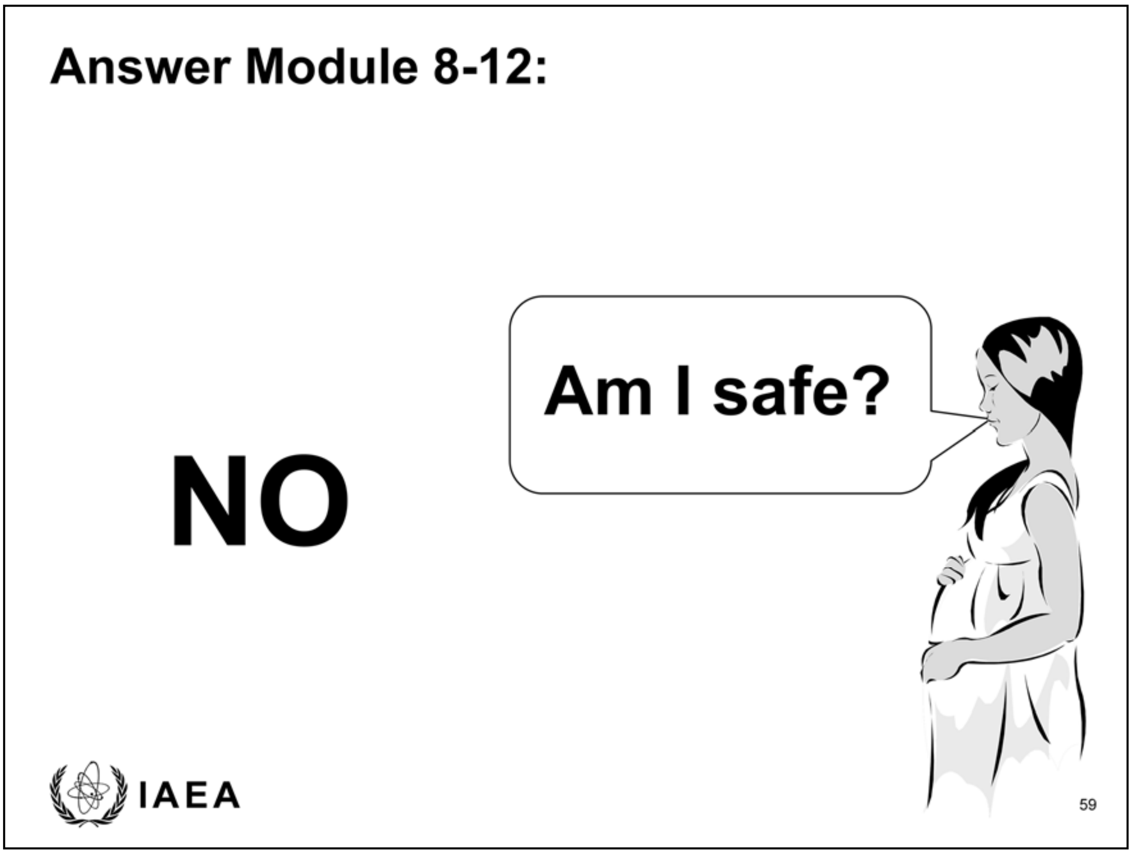


Be prepared to answer this question with yes or no: **Are we safe?**



Be prepared to answer this question with yes or no: **Are we safe?**

Question Module 8-13: Two weeks after the accident at the NPP, 50 km away

While working in the garden – this guy said the dose rate is 75 μSv/hr in my garden.

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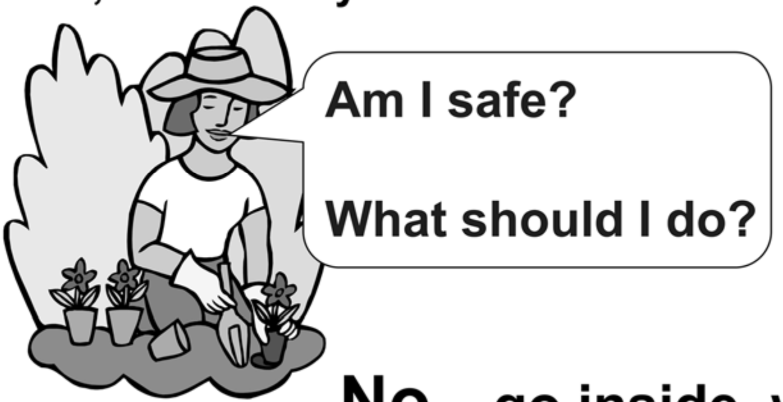
Answer 8-13: Two weeks after the accident at the NPP, 50 km away



No – go inside, wash and stay out of the garden

[Table 7 (OIL2) and Chart 1, EPR-NPP PPA]

You are safe only if you are preventing inadvertent ingestion

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Public and Media Response to an Emergency at a Nuclear Power Plant

Module 9

Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

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Lecture: L-09 Public and Media Response to an Emergency at a Nuclear Power Plant
Purpose: To provide an overview of public concerns raised in the media following a severe nuclear power plant emergency and to demonstrate the importance of answering the principle concern of the public: "Am I safe?"
Learning objectives: On completing this module participants will:

- List important public concerns raised in the media;
- Explain how they may be addressed;
- Prevent the public taking inappropriate actions that do more harm than good;
- Describe the importance of:
  - answering the principle concern of the public: "Am I safe?"
  - communicating that the most sensitive members of the public (pregnant women and children) have been considered
  - explaining what are appropriate and inappropriate actions to take
  - placing in perspective criteria used as a basis for decision making
  - mitigating the economic impact of the emergency
  - preventing stigma towards persons from the affected area.

Duration: 1.5 hours

Note: This presentation is mainly based on research conducted shortly after the accident at the TEPCO Fukushima Daiichi nuclear power station March 2011.
It presents the public concerns as indicated by published news articles. A full list of the concerns that decision makers should be prepared to answer can be found in 'Appendix V - Typical questions and concerns of the public in a nuclear or radiological emergency', on pp. 123-124 of the IAEA publication: *Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor*, (EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013).

Learning objectives

- On completing this module, participants will be able to:
  - List important public concerns raised in the media;
  - Explain how they may be addressed;
  - Prevent the public taking inappropriate actions that do more harm than good;
  - Describe the importance of:
    - answering the principal concern of the public: “Am I safe?”
    - communicating that the most sensitive members of the public (pregnant women and children) have been considered
    - explaining what are appropriate and inappropriate actions to take
    - putting in perspective criteria used as a basis for decision making
    - mitigating the economic impact of the emergency
    - preventing stigma towards those from the affected area

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Learning objectives – on completing this module, participants will be able to:

List important public concerns raised in the media;

Explain how they may be addressed;

Prevent the public taking inappropriate actions that do more harm than good;

Describe the importance of:

- answering the principle concern of the public: “Am I safe?”
- communicating that the most sensitive members of the public (pregnant women and children) have been considered
- explaining what are appropriate and inappropriate actions to take
- placing in perspective criteria used as a basis for decision making
- mitigating the economic impact of the emergency
- preventing stigma towards persons from the affected area.

Overview of Module 9

- Background information – why it is important to address public concerns
- Examples of public concerns raised in the media during the Fukushima emergency
- Activities on addressing public concerns
- Conclusions

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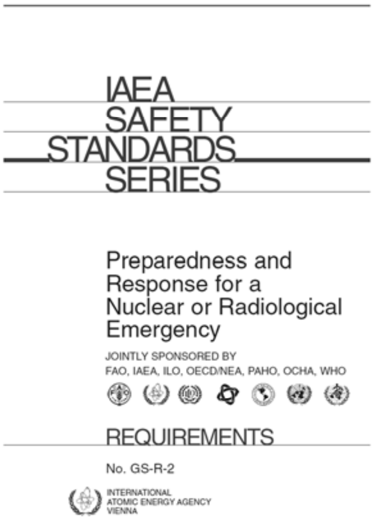
It is important to note here that the examples provided in this module are typical questions and concerns of the public that were collected from published news articles. The questions and concerns may not be scientifically accurate or well informed.

Why is it important to address public concerns?



- International Guidance establishes requirements for:
- responding to public concern
- responding to requests for information from the public and media
- responding to incorrect information and rumours

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The IAEA Safety Standards Series publication No. GS-R-2, Preparedness and Response for a Nuclear or Radiological Emergency, establishes the requirements that must be met to ensure the protection of people and the environment. The requirements established relevant to this module are:

1. Keeping the public informed, and 2. mitigating the non-radiological consequences of the emergency and the response. (Non-radiological consequences refers to the detrimental social, psychological, economic effects the emergency and the response may have).

Specifically, arrangements shall be made for:
– responding to public concern
– responding to requests for information from the public and media
– responding to incorrect information and rumours.

Para. 4.96. of this publication states: "Arrangements shall be made for responding to public concern in an actual or potential nuclear or radiological emergency. Preparations shall include arrangements for promptly explaining any health risks and what are appropriate and inappropriate personal actions for reducing risks. These arrangements shall include monitoring for and responding to any related health effects and preventing inappropriate actions…identifying the reasons for such actions (such as misinformation from the media or rumours)…"
In addition, para. 4.83. of this publication states "Arrangements shall be made for: providing useful, timely, truthful, consistent and appropriate information to the public in the event of a nuclear or radiological emergency; responding to incorrect information and rumours; and responding to requests for information from the public and from the news and information media."

Why is it important to address public concerns?

- If there is any doubt over safety, the public may take inappropriate actions that do more harm than good
- Believe they are protecting themselves and their families

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It is important to address public concerns during an emergency at a nuclear power plant in order to prevent the public taking inappropriate actions that do more harm than good, which are taken in the belief that they are protecting themselves and their families.

International guidance establishes requirements for addressing public concerns because in past emergencies members of the public, those responsible for protecting the public (i.e. decision makers) and others (e.g. medical staff) have taken inappropriate and damaging actions that were not justified based on the radiological health hazard.

In some cases these actions have resulted in injuries, an increased risk to health and deaths.

Examples of inappropriate and damaging actions taken:

- Unsafe evacuations
- Demanding unwarranted medical examinations
- Refusing to treat patients
- Inappropriate forms of ITB (e.g. antiseptic solution)
- Unnecessary restrictions on trade

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•Unsafe evacuations (leading to avoidable deaths of hospital and nursing home patients)
•Demanding unwarranted medical examinations that interfere with the treatment of those who are most at risk (e.g. the radiological accidents in Goiânia and Istanbul)
•Refusing to treat patients that were possibly contaminated
•Inappropriate forms of ITB (e.g. antiseptic solution)
•Economic damage from unnecessary restrictions on trade

Abbreviation:

ITB – iodine thyroid blocking

Examples of inappropriate and damaging actions taken:

- Shadow evacuations
- Pregnant women unnecessarily worrying about their fetus
- Unduly worrying about the possibility of radiation induced cancers
- Rejecting products from the affected area
- Closing schools

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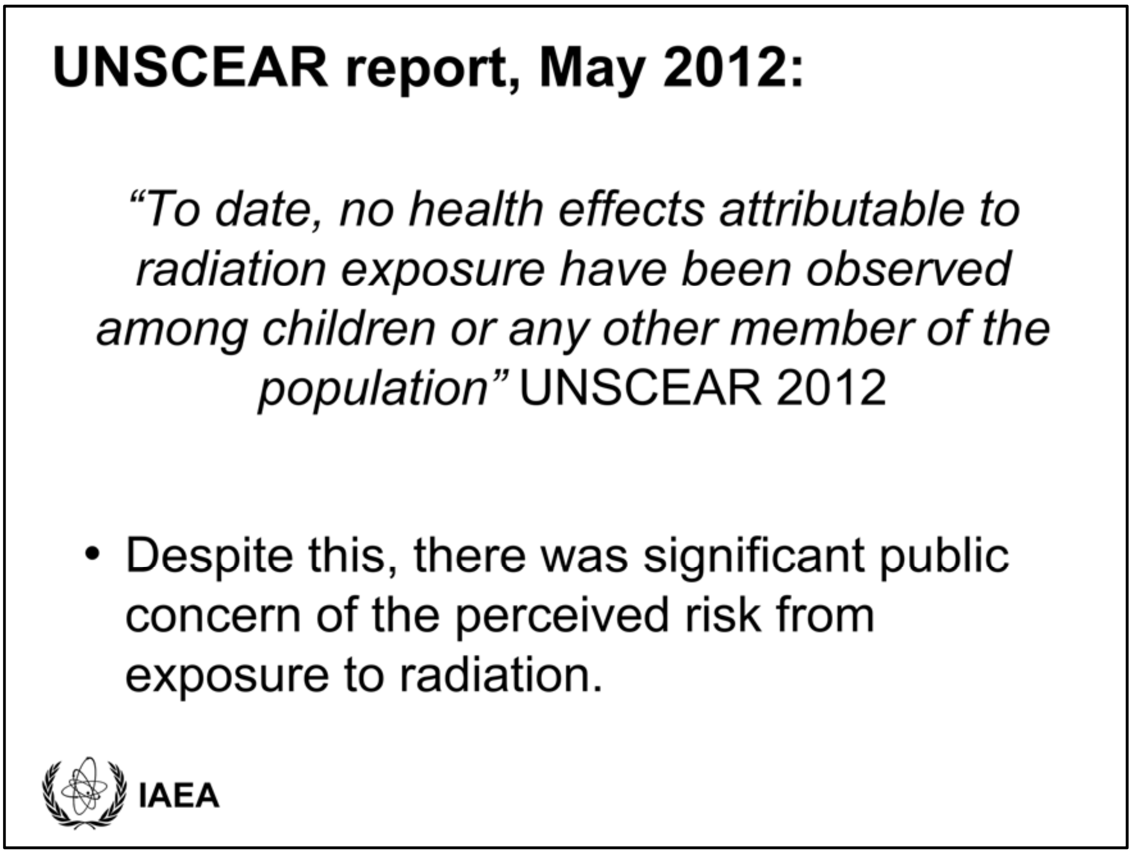
- Shadow evacuations. These are evacuations that were not recommended which obstructed the evacuation of those at risk.
- Pregnant women worrying unnecessarily about the possible radiation induced health effects to their fetus.
- Unduly worrying about the possibility of radiation induced cancers.
- Rejecting products from the affected area.
- Disrupting the education of students by closing schools unnecessarily.

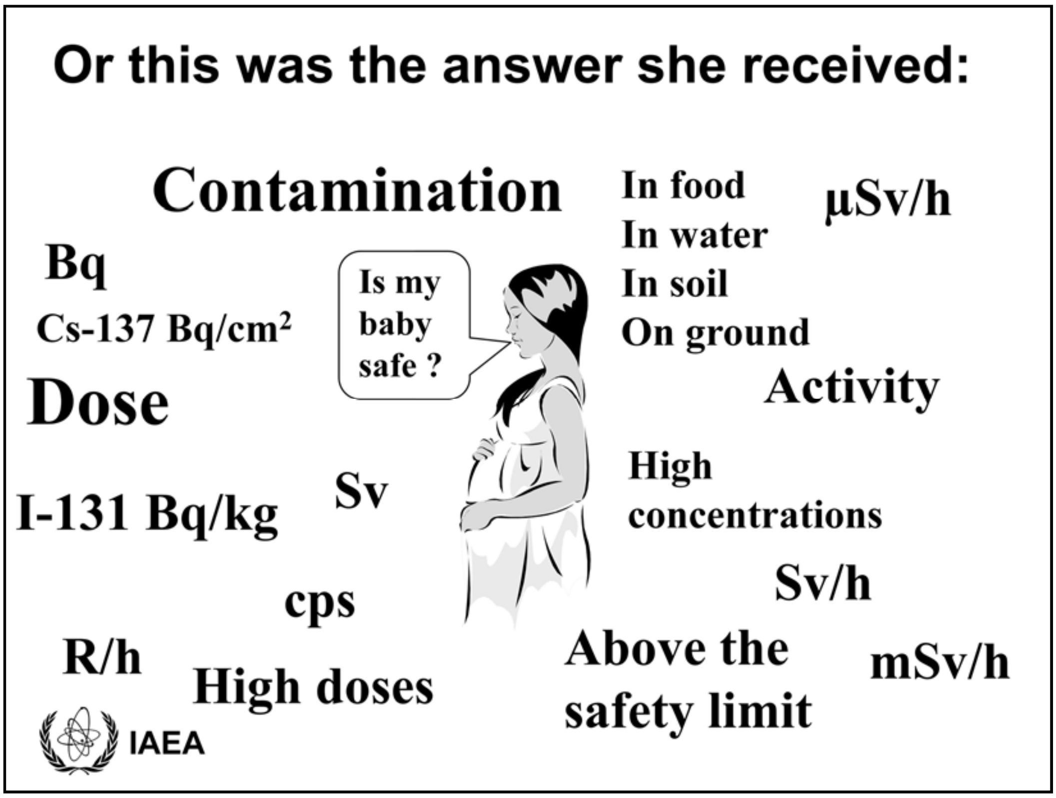


Ref. United Nations Scientific Committee on the Effects of Atomic Radiation, Report of United Nations Scientific Committee on the Effects of Atomic Radiation, Fifty-Ninth session, General Assembly Sixty-Seventh session, Supplement No. 46, New York: UN; 2012.

Despite this, there was significant public concern over the perceived risk from exposure to radiation.

The principle concern of the public during the emergency was “Am I Safe?”
The public want to know:
– What are the health risks?
– What are appropriate and inappropriate actions for reducing risks?

However, the public’s principle concern was typically not answered during the emergency.



Many measured and calculated quantities reported in an emergency.
Unfamiliar terminology and numerous different units (e.g. contamination, gray, sievert(s), becquerels).

The numbers and terminology are meaningless to the public and fail to answer their principle concern.

This is owing to the lack of perspective in terms of the health hazard. Contributing to undue worry and concern being felt among the public. Confusion and fear: members of the public take inappropriate actions that do more harm than good in the belief that they are protecting themselves and their families.

Examples of Public Concerns Raised in the Media

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The next two slides are examples of pregnant women worrying about the possible radiation-induced health effects to their fetus – as identified in news articles after the accident at Fukushima.

"Each time she goes to the hospital for a checkup, she is filled with anxiety that the ultrasound might reveal a deformity, so she counts and recounts the fingers and toes."
This quote is taken from an interview with an expectant mother (who became pregnant just before the accident).
She explained that her worry has become so all-consuming that she had considered abortion and suicide.

Source:
http://www.guardian.co.uk/world/2011/sep/09/fukushima-japan-nuclear-disaster-aftermath (article in The Guardian dated 9 September 2011)

Pregnant women concerned for their fetus

"My baby was born two weeks before the nuclear accident and I don't feed her with my milk as I'm afraid I was exposed to too much radiation."

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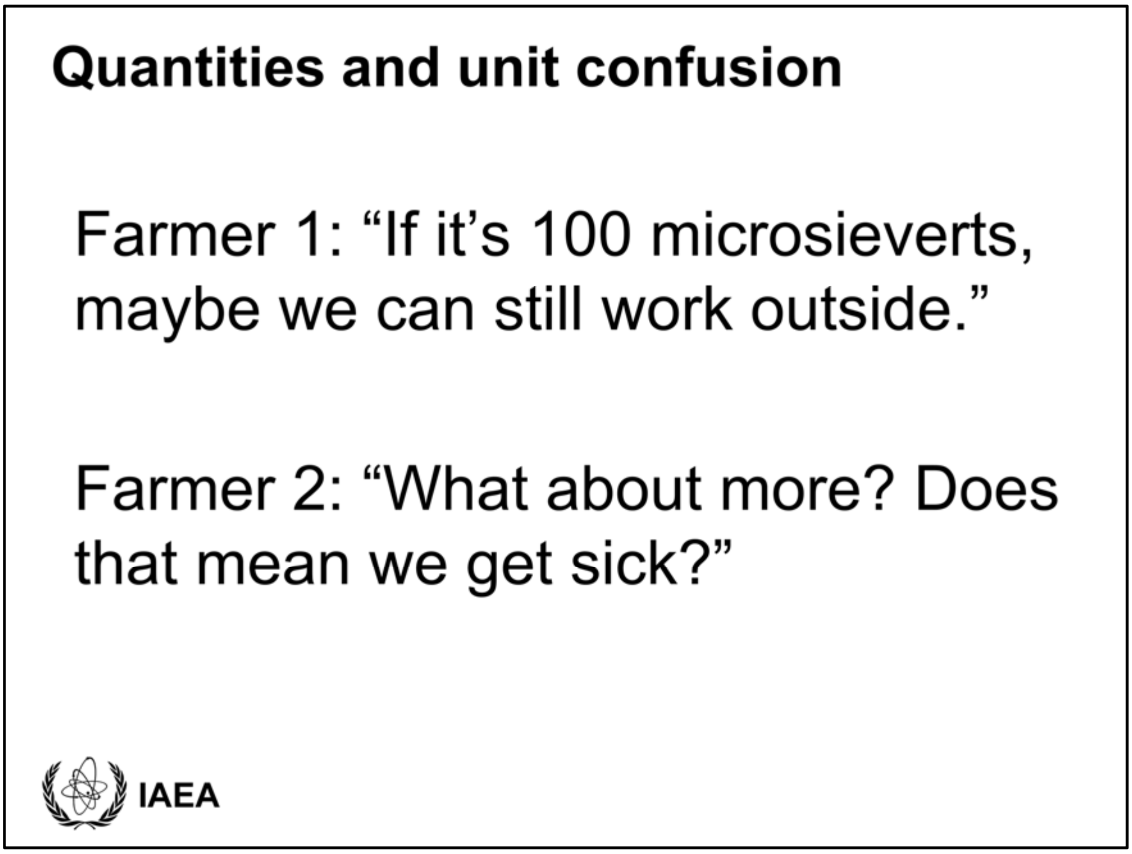
Mother: "My baby was born two weeks before the nuclear accident and I don't feed her with my milk as I'm afraid I was exposed to too much radiation."

Source:
http://www.reuters.com/article/2011/06/26/us-japan-fukushima-rally-idUSTRE75P0MB20110626
(article on Reuters web site dated 26 June 2011)



This is an exchange between two farmers from Iitate, Japan.
Farmer 1: “If it’s 100 microsieverts, maybe we can still work outside.”
Farmer 2: “What about more? Does that mean we get sick?”

This is an impossible question to answer because the farmers are confused and talking dose instead of dose rate…but is a good example of the problem.

Source:
http://www.nytimes.com/2011/04/06/world/asia/06village.html?src=twrhp
(article in the New York Times dated 6 April 2011)

Quantities and unit confusion

"As for plutonium-239 and -240, the largest combined amount found was 15 becquerels per square meter...If someone lives for 50 years in an area contaminated with 4 becquerels of plutonium-238, his total dose would be 0.027 millisieverts... The area with 15 becquerels would provide a cumulative dose of 0.12 millisievert... A cumulative dose of 100 millisieverts increases one's cancer risk by 0.5 percent, scientists say."

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Example of units and measurements being reported in the media.
This quote is taken from a news article that is recounting a government report on sampling and analysis test results:

"As for plutonium-239 and -240, the largest combined amount found was 15 becquerels per square meter...If someone lives for 50 years in an area contaminated with 4 becquerels of plutonium-238, his total dose would be 0.027 millisieverts... The area with 15 becquerels would provide a cumulative dose of 0.12 millisievert... A cumulative dose of 100 millisieverts increases one's cancer risk by 0.5 percent, scientists say."

Source:
http://www.japantimes.co.jp/text/nn20111004a3.html (article in Japan Times dated 2011-10-04 [accessed October 2011])

Quantities and unit confusion (cont.)

Housewife: "I couldn't keep up with the complex terminology. I couldn't understand what they were saying, so I'm not convinced (over safety)."

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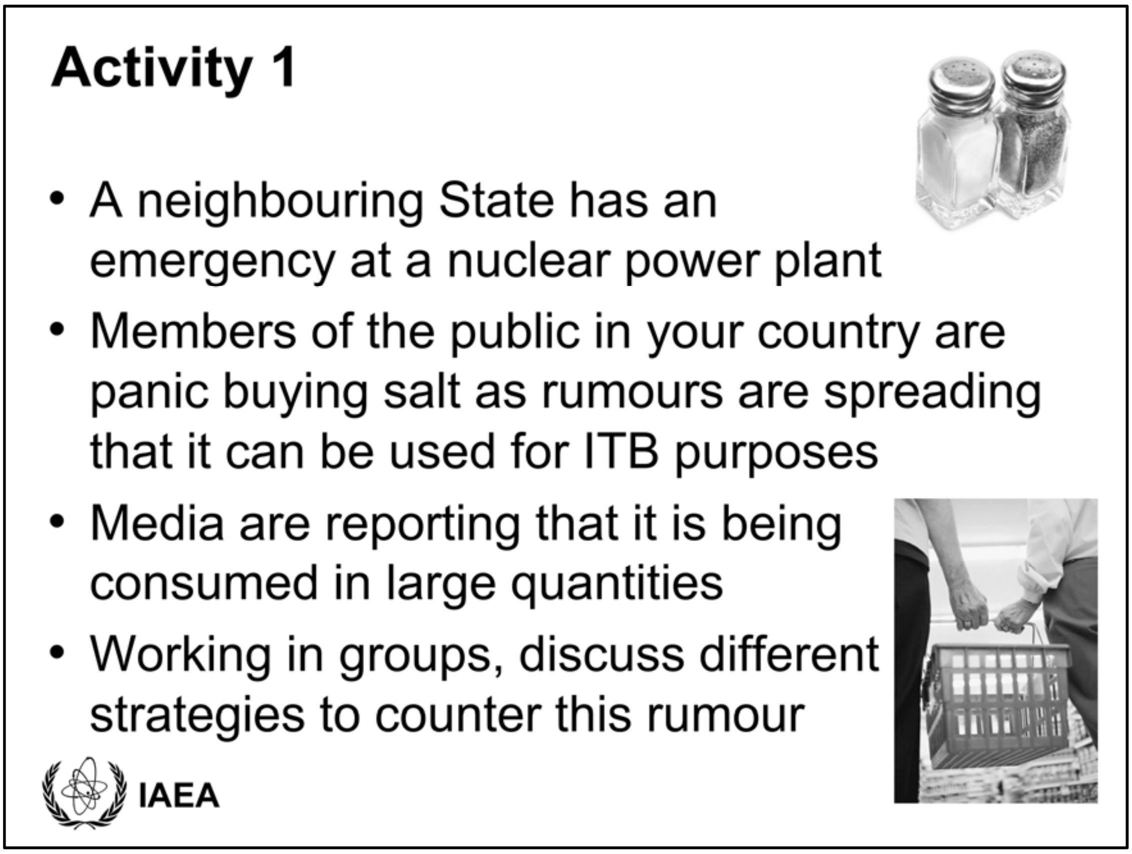
Example of housewife response to highly technical information:
"I couldn't keep up with the complex terminology. I couldn't understand what they were saying, so I'm not convinced (over safety)."

Source:
http://www.reuters.com/article/2011/06/26/us-japan-fukushima-rally-idUSTRE75P0MB20110626
(article in Reuters dated 26 June 2011)



– Worried shoppers emptied stores of salt in China in the first few days after the accident in Japan, following rumours that it could be used for ITB purposes.

– Text messages and emails also circulated that iodine antiseptic solution can be used as a protective measure, by applying it to the neck, as it will protect against exposure to radiation.

Source:
http://www.chinadaily.com.cn/cndy/2011-03/18/content_12189705.htm (article in the China Daily dated 18 March 2011)
http://news.nationalpost.com/2011/03/15/health-authorities-advise-iodine-pills-of-limited-use-as-panic-buying-sets-in/ (article in the National Post dated 15 March 2011)

Public and media focus: Most sensitive

- "It's impossible to know how the radiation would affect Riko in the next five to ten years or longer. She may want to have children in the future, and as parents we have to do everything we can to limit her risk of radiation exposure."

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The media have a tendency to focus on the safety of the most sensitive members of society (pregnant women and young children).

"It's impossible to know how the radiation would affect Riko in the next five to 10 years or longer. She may want to have children in the future, and as parents we have to do everything we can to limit her risk of radiation exposure."

Source:
http://articles.latimes.com/2011/may/29/world/la-fg-japan-radiation-children-20110529 (article in the Los Angeles Times dated 29 May 2011)

Communicate that the most sensitive individuals were considered

- Protective action recommendations should *emphasize* that the most sensitive members of the public have been considered (i.e. both children **and** pregnant women) when communicated to the public

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Why should it be communicated?

- The public and media want to know that both pregnant women and children were considered in protective action recommendations.

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Example – Fukushima accident

- On 21 March instructions issued on the consumption of tap water:
  – refrain from giving infants formula milk dissolved in tap water

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On 21 March instructions were issued by the Ministry of Health, Labour and Welfare on the consumption of tap water:

– refrain from giving infants formula milk dissolved in tap water.

What about me?

- Father: “Tap water is OK for me, but all they said was that babies shouldn’t drink it. They haven’t said anything about what pregnant women should do.”

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It was reported in the media that there was confusion about the advice to refrain from giving infants formula milk dissolved by tap water.

Some experts stating it should also apply to pregnant women, since fetuses were also vulnerable.

Source:
http://www.nytimes.com/2011/03/24/world/asia/24japan.html?_r=2&hp (article in the New York Times dated 24 March 2011)

In summary:

- Clearly state that all members of the public most sensitive to radiation (i.e. children **and** pregnant women), have been considered in protective action recommendations

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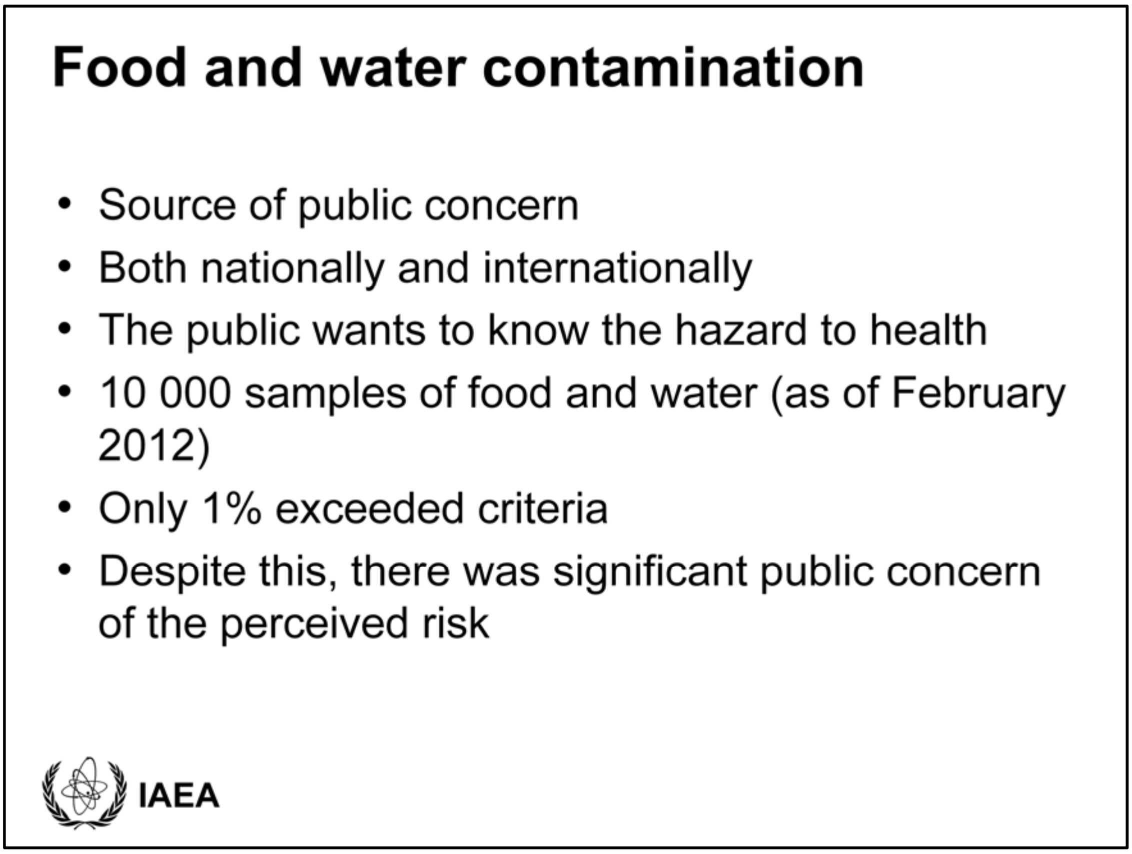

- Source of public concern
- Both nationally and internationally
- The public wants to know the hazard to health
- 10 000 samples of food and water (as of February 2012)
- Only 1% exceeded criteria
- Despite this, there was significant public concern of the perceived risk

Food and water contamination

"We are exhausted. We have to look at every food item we eat, we only use bottled water for cooking, and on top of that every day we confront this nagging dilemma whether it's really safe for our children to stay or not."

Food contamination was a major public concern after the Fukushima accident.

"We are exhausted. We have to look at every food item we eat, we only use bottled water for cooking, and on top of that every day we confront this nagging dilemma whether it's really safe for our children to stay or not."

This was a quote from the mother of a 4-year-old daughter, taken from a news article published on the Reuters web site on 26 June 2011.

Source:
http://www.reuters.com/article/2011/06/26/us-japan-fukushima-rally-idUSTRE75P0MB20110626

Food and water contamination

- Fisherman: “Fish from Chiba and Ibaraki are all caught from the same areas of the sea, yet only ours aren't selling well because they are labelled 'Fukushima.' It's absurd.”

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Fisherman: “Fish from Chiba and Ibaraki are all caught from the same areas of the sea, yet only ours aren't selling well because they are labelled 'Fukushima.' It's absurd.”

Source:
After Fukushima Fish Sales from Major Ports in Northeastern Japan Down as Much as 85-99% from a Year Ago (article in Kyodo News dated 7 October 2011)

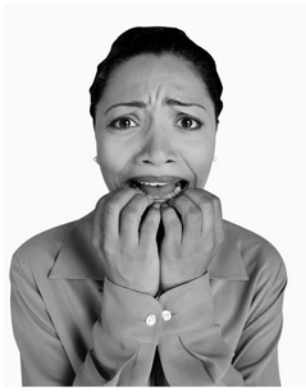
Indian government official: "Initially we didn't consider seriously about banning food imports from Japan as the volume was so low. But then we thought, why take risk, when something can be prevented.“

India imposed a three-month suspension on food imports from Japan.

Source:
http://online.wsj.com/article/SB10001424052748703806304576244633790290812.html (Article in Wall Street Journal Europe dated 5 April 2011)

International trade

- "The question is how to reduce anxiety, not present science," says Katsunori Nemoto of Keidanren, Japan's business lobby. [The Economist]



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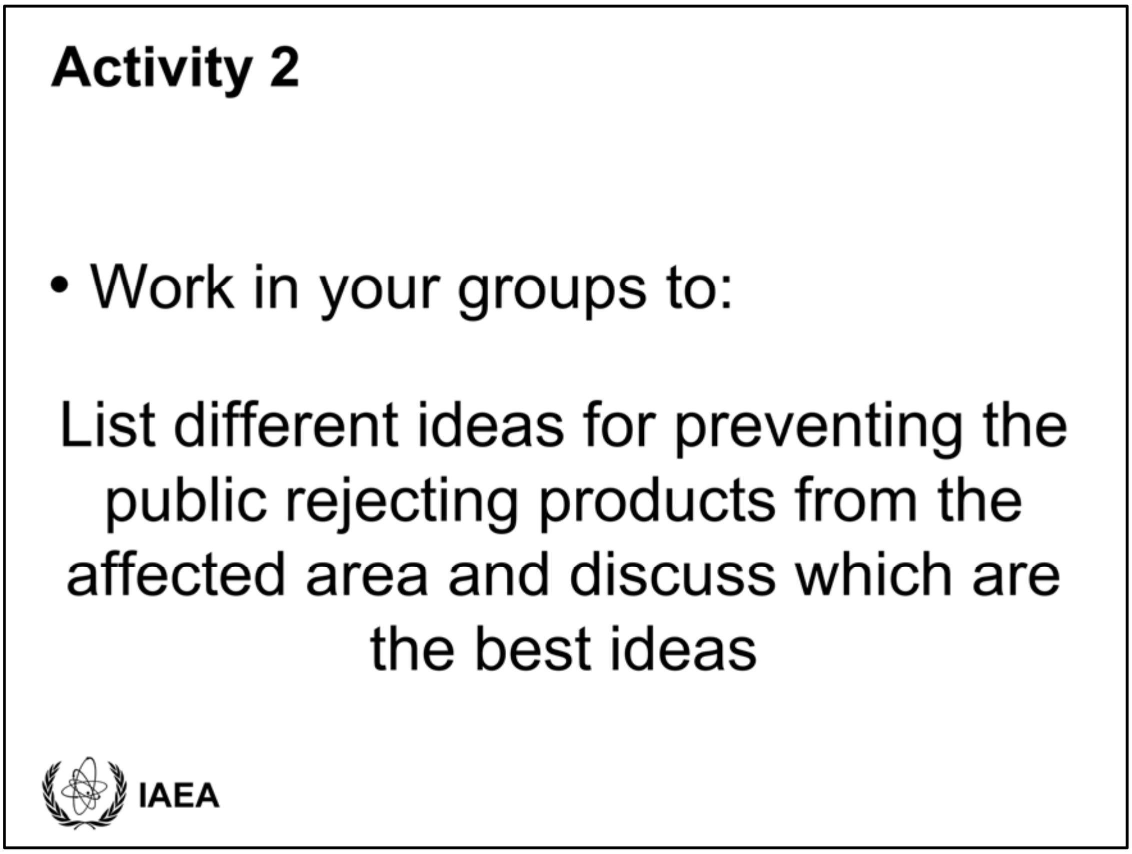
"The question is how to reduce anxiety, not present science," says Katsunori Nemoto of Keidanren, Japan's business lobby.

Source:
http://www.economist.com/node/18530743?story_id=18530743 (article in The Economist dated 7 April 2011)



Ask participants to list different ideas for preventing the public rejecting products from the affected area and discuss in their groups which are the best ideas.

Customs authorities in importing States required Japanese companies to submit certificates proving that their products are not contaminated with radiation.

For example, by the end of March 2011 the European Union had restricted food and animal feed from Japan and required confirmation of monitoring/analysis or certificate of origin.

Source:
http://www.economist.com/node/18530743?story_id=18530743 (article in The Economist dated 2011-04-07)

http://www.food.gov.uk/business-industry/imports/banned_restricted/japan#.UKS7deQ0V8E (Safeguard measures for imports of feed and food from Japan, UK Food Standards Agency, updated 2012-07-09)

Dose – confusion among the public on dose and safety limits

- Before the accident criteria = 1 mSv safety limit for public exposure
- During emergency = criteria is now 20 mSv
- Why was anything above 1 mSv unacceptable before and now 20 mSv is OK?

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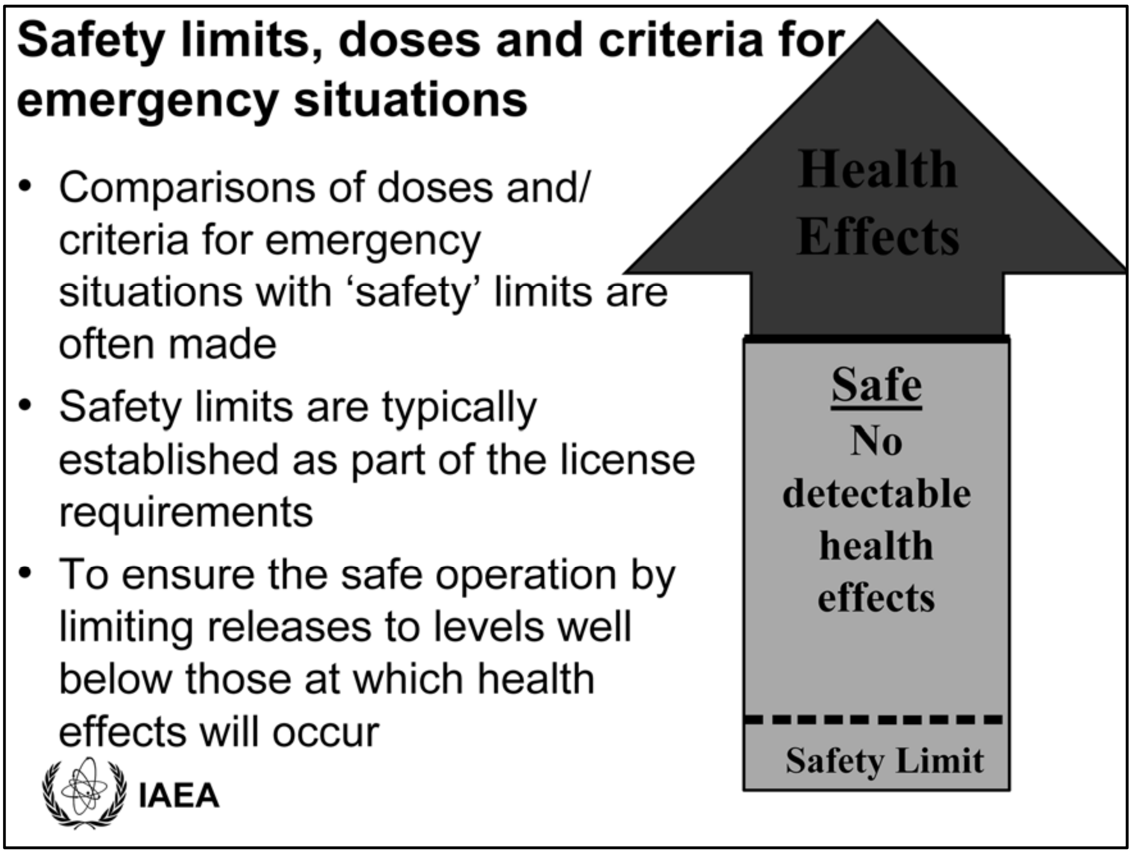
The next few slides demonstrate the need for putting into perspective the criteria being used as a basis for decision making.



During an emergency, comparisons of doses and/ criteria for emergency situations with 'safety' limits are often made.

Safety limits are typically established as part of the license requirements for the facility (e.g. nuclear power plant) or activity (e.g. mobile source used for radiography) to ensure the safe operation by limiting releases to levels well below those at which health effects will occur.

Dose limits – put the criteria into perspective for the public

- Criterion of 20 mSv used for:
– relocation
– re-opening of schools

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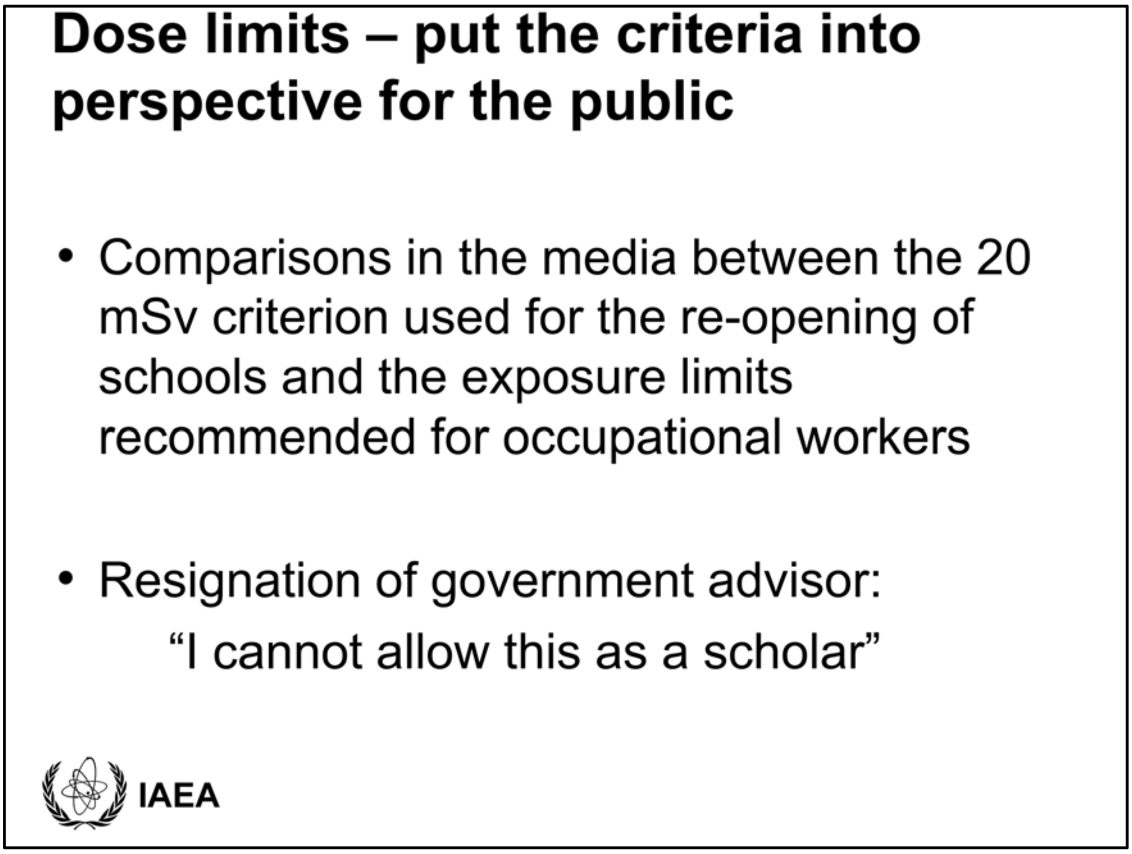
There was an overlap in the timing of discussions and decisions being made on the criteria to be used for relocation and the re-opening of schools.

On 10 April 2011 (one month after the start of the emergency at Fukushima) the criterion of 20 mSv was recommended by the Nuclear Safety Commission (Japanese technical advisory body) for identifying areas to be designated for 'deliberate evacuation'. ('Deliberate evacuation' is called relocation under IAEA guidance).

The criterion of 20 mSv was adopted for relocation 12 days after the advice was given on 22 April. This was in order to allow discussion with stakeholders.

At about the same time, on 19 April, the government established the same criteria of 20 mSv for the re-opening of schools.



However, there were concerns raised in the media and among the public. Some media reports made comparisons of the 20 mSv criterion used for the re-opening of schools with exposure limits recommended for occupational workers.

A government advisor resigned, declaring: "I cannot allow this as a scholar".

What does this mean?

- Heightened emotions and mistrust felt by the public towards scientists and politicians caused difficulties in establishing criteria during the emergency
- Confusion surrounding dose limits resulted in the public feeling that they were not being adequately protected

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What does this mean?

- To prevent this problem, the criteria need to be put into perspective in relation to the health hazard (including for the most sensitive individuals)

QUANTITY *	RADIOLOGICAL HEALTH HAZARD IN PERSPECTIVE
	POSSIBLY DANGEROUS TO HEALTH
Value	
	HEALTH CONCERNS The danger to health is low.
Value	
	PROVISIONALLY SAFE Safe if certain specified limitations are followed.
Value	
	SAFE** There are no hazards to health.

* Or another indicator such as the emergency class

** Safe according to international safety standards

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This will be discussed further in Module 10.

Evacuation and relocation – typical questions asked by the public

- Where is the evacuation zone?
- When must I leave?
- Where am I going?
- For how long?
- My family members are not here – how do I contact them?
- Will I be allowed to return?
- How secure are my possessions?
- What is the best option for me?
- What help is available?
- How will I afford it?
- What about:
  - my job?
  - my children's education?
  - care for the elderly?

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Some of the questions asked by the public following the evacuation order in Japan.

Evacuation and relocation

- Parent: “I want to move out soon so I don't have any remorse about my child's health.”
- The inability to afford the cost of relocating resulted in parents blaming them-selves for not protecting their children effectively

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Families will be particularly concerned over the safety of their children.
Will consider leaving even if the area they reside in is not designated for evacuation or relocation. (As already stated in previous slides, the public and media want to know that the most sensitive members of the public are being protected.)

Mother wants to relocate from contaminated area:
– she is unable to afford the cost
– she blames herself for possibly hurting her children

Sources:
http://news.smh.com.au/breaking-news-world/japan-names-more-fukushima-evacuations-20110630-1gtc4.html (article in Sydney Morning Herald dated 30 June 2011)
http://www.nytimes.com/2011/04/06/world/asia/06village.html?src=twrhp
(article in New York Times dated 5 April 2011)

Evacuation and relocation

- “My husband didn’t agree to the move and tells us to come back home,” explains a housewife from Fukushima City who now lives in Tokyo with her two children, aged 9 and 7.
- “I have to pay my bills in Tokyo and travel to Fukushima to see my husband three or four times a month. It’s very expensive and stressful but I didn’t see a choice.”

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This quote is from an interview with a mother who had chosen independently to relocate due to concerns of her children’s safety.

“My husband didn’t agree to the move and tells us to come back home,” a housewife from Fukushima City who now lives in Tokyo with her two children, aged 9 and 7.
“I have to pay my bills in Tokyo and travel to Fukushima to see my husband three or four times a month. It’s very expensive and stressful but I didn’t see a choice.”

They were living in an area that had not been designated for relocation. Spontaneous evacuations cause families to become separated as the father remains in the area for work.

There have been indications of divorce rates increasing.

[Ref. Yuki Tanaka, A Lesson from the Fukushima Nuclear Accident, Asia Pacific Journal, dated 21 May 2012, http://www.japanfocus.org/events/view/149]

[Ref. Quote on slide taken from: David McNeill, 'The Fukushima Nuclear Crisis and the Fight for Compensation,' The Asia-Pacific Journal, Vol 10, issue 10, No 6, 5 March 2012, http://www.japanfocus.org/-David-McNeill/3707]

Stigma – Discrimination

- Student: “I was annoyed at the way people discriminated against cars with Fukushima license plate numbers.”

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It was reported in several published news articles that evacuees from the affected area received verbal abuse and other forms of harassment.

Student: “I was annoyed at the way people discriminated against cars with Fukushima license numbers.”
Other forms of discrimination reported in the media include:
– A company in Fukushima asked employees to use license plates from another Prefecture.
– An employee driving a car with Fukushima plates was turned away from gas stations.

Stigma – bullying of school children

- Teacher: "Are you going to keep it secret that you come from Fukushima Prefecture?"

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Teacher: "Are you going to keep it secret that you come from Fukushima Prefecture?"
The mother replied no, there was no need to do so.
Her son then took a seat in front of the teacher's desk.
None of the other children sat next to him.

Children:
- Moved schools several times
- Suffered from feelings of isolation – children from another region refused to mingle with a child from an affected area.

Sources:
http://www.yomiuri.co.jp/dy/national/T110421006295.htm
http://www.asahi.com/english/TKY201109070229.html
http://www.asahi.com/english/TKY201108170241.html

Activity 3

- Work in your groups to:

List different ideas for preventing stigma towards individuals from the affected area and discuss which are the best ideas

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One year later and the issues continue to be a problem:

- "Some bloggers say we create toxic food and call us murderers because we continue to grow vegetables in Fukushima," said Mr Fujita.
- "As soon as you say that you are from Fukushima, people have this 'don't touch' attitude," he said.
- "The evacuation has doubled the number of deaths among the elderly," he said. "I believe it's due to the stress of moving, which is also a huge concern for children and pregnant women."

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This slide presents concerns of the public raised in the media – in articles that were published one year after the emergency.

Source: http://www.bbc.co.uk/news/world-asia-16977120 (BBC article online dated 8 March 2012)

Two years later:

- "I came back just to run away from the stress," he says. With no job, and no prospects, "I can't see the future".
- The children carry dosimeters provided by the health survey to collect radiation data and to calm public concerns. But their mother Yuka wonders whether they will one day develop cancer.

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This slide presents concerns of the public raised in the media – in articles that were published two years after the emergency.

An evacuee, Ookubo couldn't stand the temporary housing, where he had started drinking and suffered from stomach aches. After renting a room in Kawamata, he began squatting in his parents' abandoned home. "I came back just to run away from the stress," he says. With no job, and no prospects, "I can't see the future," he says.

The children carry dosimeters provided by the health survey to collect radiation data and to calm public concerns. But their mother Yuka wonders whether they will one day develop cancer.

Source:
http://www.nature.com/news/fukushima-fallout-of-fear-1.12194 (article in Nature dated 16 January 2013)

Conclusions

- Arrangements need to be in place to address public concern, which is principally: “Am I safe?”
- Include an explanation that the most sensitive members of the public (pregnant women and children) were considered
- Communicate what are appropriate (and if necessary) inappropriate actions to take
- Arrangements need to be in place for detecting rumours and correcting misinformation

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- Include an explanation that the most sensitive members of the public (pregnant women and children) were considered
- Communicate what are appropriate (and if necessary) inappropriate actions to take
- Arrangements need to be in place for detecting rumours and correcting misinformation

Conclusions – continued

- Contamination of food was a significant source of public concern from the perceived risk
- Mitigate the economic impact by providing for testing and certification
- Put into perspective the criteria that are being used as a basis for decision making
- Prepare to mitigate the impact of stigma towards the affected population

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- Contamination of food was a significant source of public concern from the perceived risk
- Mitigate the economic impact by providing for testing and certification
- Put into perspective the criteria that are being used as a basis for decision making
- Prepare to mitigate the impact of stigma towards the affected population

Important issues and questions – 1

- Is my family safe now?
- What can I do to ensure my family is safe now?
- What is contamination and is it dangerous?
- Should I buy and wear a dosimeter?
- What quantity of radiation exposure is safe? When will I get sick from radiation?
- Why has the annual safety limit been changed from 1 mSv/year to 100 mSv/year?
- Can children play outside?
- Should I take measures to decontaminate my home (such as remove all topsoil from my garden)?
- What does radiation levels 20 times above normal mean?

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Based on experience with previous nuclear emergencies, a set of frequently asked questions from members of the public is provided on the next two slides. You should prepare answers to as many of these as possible in advance. Taken from Appendix V of the publication *Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor*, EPR-NPP PUBLIC PROTECTIVE ACTIONS, IAEA, Vienna (2013).

Important issues and questions – 2

- What could be the consequences for my health?
- What dose may I have received and what does it mean to my health?
- Do my internal radiation levels need to be checked? What do the measurements and test results mean?
- I was monitored and contamination was found. Am I OK?
- What happens when I am exposed to radiation? What are the possible health effects?
- I am pregnant. What are the dangers for my baby? Will my baby have birth defects? Should I have an abortion?
- Can I breast feed my baby?
- Can ________ protect against radiation exposure?
- Should I take potassium iodide (KI) pills?
- Should I use other forms of iodine to protect against radiation exposure?

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Based on experience with previous nuclear emergencies, a set of frequently asked questions from members of the public is provided on the next two slides. You should prepare answers to as many of these as possible in advance.

Important issues and questions – 3

- Can I drink the milk or tap water? Should I use bottled water?
- Can I eat the food? Where was the food I am buying grown?
- Should I use a Geiger counter to test radiation levels of the local produce I buy?
- Why are some supermarkets restricting acceptable contamination levels of local produce further than the government set limit?

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Important issues and questions – 4

- How long will evacuation be in place and when will I be allowed to return home?
- There is conflicting advice for the evacuation area. Which advice should I follow?
- Why is it safe to be outside the evacuation areas in an emergency?
- What are hotspots?
- I am old and have lived here all of my life. Being exposed or contaminated does not concern me, I do not want to evacuate.
- I do not want to be on unemployment benefits if evacuated. Where can I find a job?
- I need to evacuate but the removal company is refusing to enter the affected area. How should I transport my belongings?
- What should I do about my animals (farm animals, pets)?

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Important issues and questions – 5

- My child is being bullied at school because we are from the affected area. What should I do?
- My car is not allowed into the gas station because the number plate is from the affected area. What should I do?
- Supermarkets will not sell and consumers will not buy my produce because it is from the affected area. What should I do?

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Placing Measured Operational Quantities and Calculated Doses in Perspective

Module 10

Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

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International Atomic Energy Agency

Lecture: L-10 Placing Measured Operational Quantities and Calculated Doses in Perspective
Purpose: This module provides participants with the opportunity to use the tools the IAEA has created for placing the health hazard into perspective for measured operational quantities and calculated doses.
Objectives: Upon completion of this lecture the participants will know the system created by the IAEA and how to use the tools.
Duration: 2 hours

Learning objectives

- Upon completion of this module participants will:
  - Know the common errors made when communicating with the public during a reactor core or spent fuel pool emergency
  - Know the IAEA radiological health hazard system
  - Be able to define a ‘safe exposure situation’
  - Use the IAEA radiological health hazard charts provided in EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013 to place a measured operational quantity into perspective
  - Use the IAEA tools to ensure that dose calculations have been performed correctly

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‘Do Not’ and ‘Do’ when communicating with the public

Do Not:	Do:
• Project excess cancer deaths	• Answer the public’s principal concern: “Am I safe?”
• Make irrelevant comparisons with other exposure situations (e.g. dose received from an X ray or a transatlantic flight)	• Calculate all relevant doses and consider all relevant exposure pathways
• Use terms such as ‘high dose rates’ or ‘highly contaminated’, ‘Bq/m^2’ and ‘100 times above normal levels’	• Place in perspective the radiological health hazard

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In the left column of this table under ‘do not’ is a list of the common errors that have previously been made when trying to place in perspective the health hazards from radioactive material released from a reactor core or spent fuel pool. The right column of the table lists what should be done when placing in perspective the health hazards from radioactive material released from a reactor core or spent fuel pool.

‘Do Not’ and ‘Do’ when communicating with the public

Do Not:	Do:
• Compare doses with ‘safety’ limits and imply that health effects are possible if the limits are exceeded	• State that all members of the public, to include children and pregnant women (and the fetus), have been considered in protective action recommendations
• Cause undue concern with the use of the terms ‘hotspot’ and ‘contaminated’	• Provide plain language explanations

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‘Hotspot’ and ‘contaminated’ – definitions provided in Section 6.3

- A source of considerable confusion and public concern
- In many cases, very low levels of radiation were shown on maps that would not cause any health effects and would therefore not warrant any response actions
- However, this was not clearly explained to the public and decision makers

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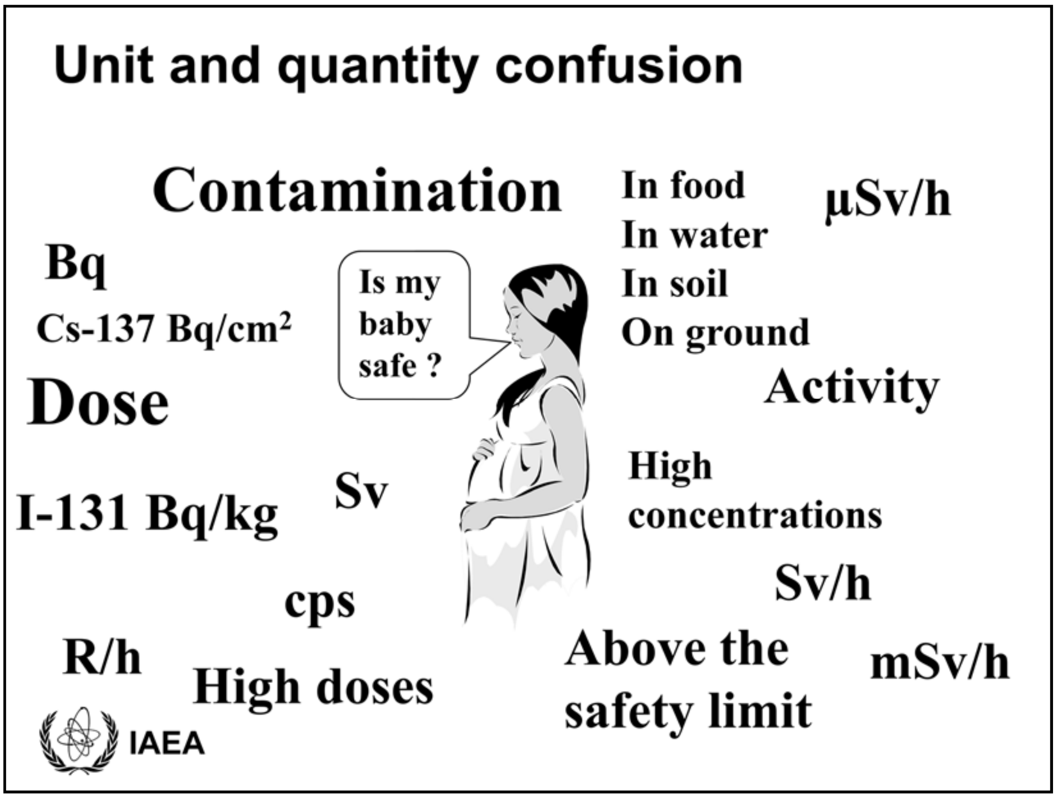
Definitions of the terms ‘hotspot’ and ‘contaminated’ are provided in Section 6.3 of EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013.

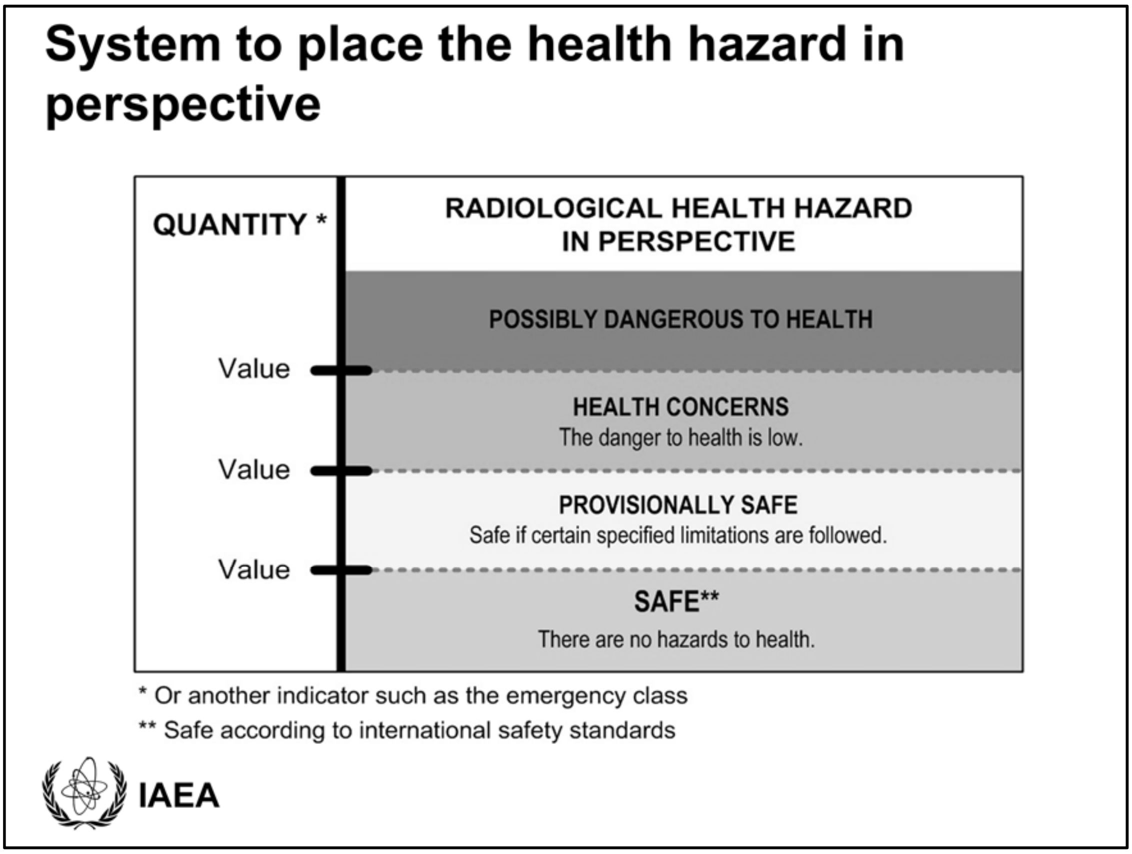
These two terms are a source of considerable confusion and public concern.
In many cases, very low levels of radiation have been shown on maps that would not cause any health effects and would therefore not warrant any response actions.
However, this was not clearly explained to the public and decision makers.



Note to lecturer – this slide has animation and will start immediately when the slide is displayed.

Many measured and calculated quantities are reported in an emergency. They are:

1. Often used incorrectly
   – e.g. use of effective dose to assess health effects, not considering the members of the public most sensitive to radiation or all exposure pathways
2. Not placed in perspective in terms of the possible health hazard.



A system has been created in order to place the health hazard in perspective in a simple and understandable format for a measured quantity or calculated dose. This system embraces the various measured quantities such as dose rate (e.g. expressed in sieverts per hour, Sv/h), food concentrations (e.g. expressed in becquerels per kilogram, Bq/kg) or calculated doses (e.g. expressed in sieverts, Sv) that are reported and often used to describe the situation to the public and decision makers during an emergency involving a reactor core or spent fuel pool.

This system defines what is safe and also indicates where there are possible health concerns and when the situation is dangerous to health.

International standards (Generic Criteria)

Generic criteria are established at levels for:

- Acute doses for which protective actions and other response actions are expected to be taken under any circumstances to avoid or minimize severe deterministic effects;
- Protective actions and other response actions in emergency exposure situations to reasonably reduce the risk of stochastic effects.

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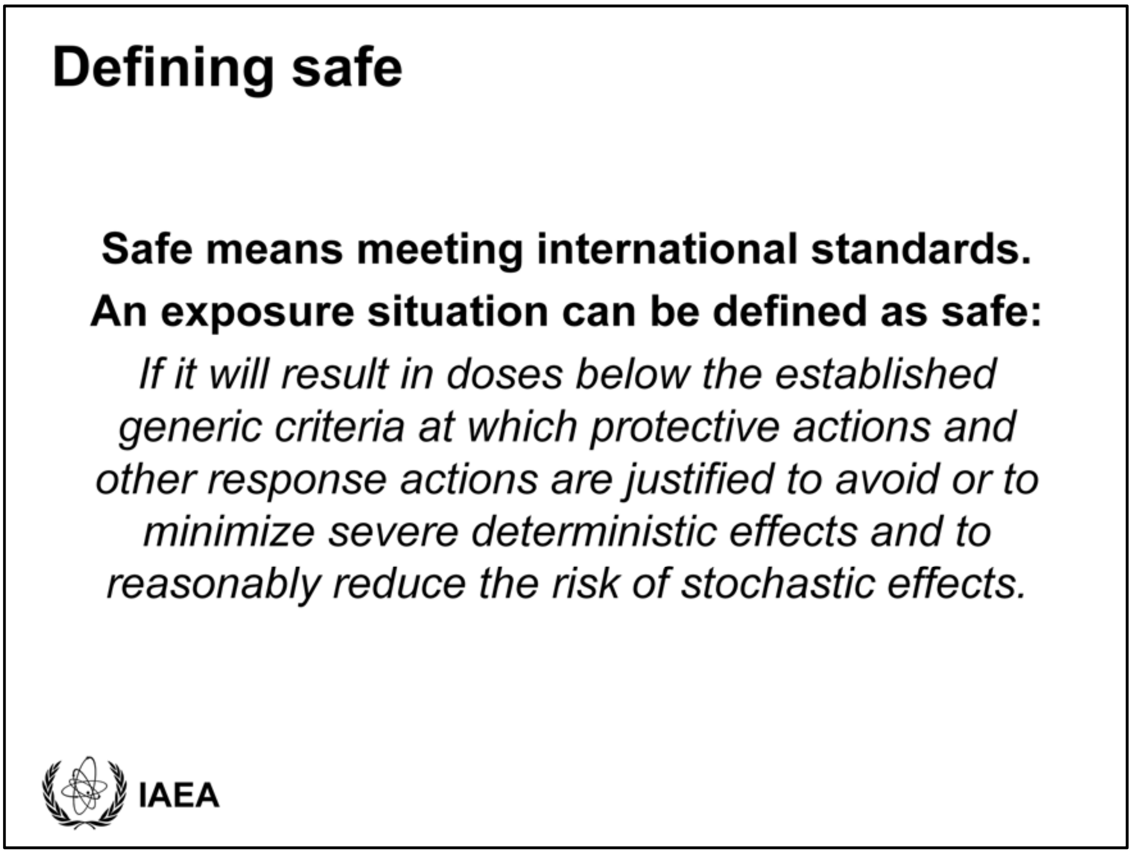
International guidance has established generic criteria (GC) at levels for:
– Acute doses for which protective actions and other response actions are expected to be taken under any circumstances to avoid or minimize severe deterministic effects;
– Protective actions and other response actions in emergency exposure situations to reasonably reduce the risk of stochastic effects.

(Ref. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS OFFICE FOR THE CO-ORDINATION OF HUMANITARIAN AFFAIRS, WORLD HEALTH ORGANIZATION, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GSG-2, IAEA, Vienna (2011))



Safe means meeting international standards. An exposure situation can be defined as safe:
If it will result in doses below the established GC (described in IAEA Safety Standards Series No. GSG-2) at which protective actions and other response actions are justified to avoid or to minimize severe deterministic effects and to reasonably reduce the risk of stochastic effects.

Below this level there will not be any severe deterministic effects or an observable increase in the incidence of cancer, even in a very large exposed group.

The risk of radiation induced cancers is too low to justify taking any action such as a medical screening.

Health hazard level: 'possibly dangerous to health'

- This level means that there is a possibility of radiation induced health effects that are life threatening or can result in a permanent injury that reduces the quality of life (severe deterministic effects)
- At this level there is also the small possibility of an observable increase in the incidence of cancer due to radiation induced cases, if the number of exposed people is more than a few hundred

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The radiological health hazard level 'possibly dangerous to health' means that there is a possibility of radiation induced health effects that are life threatening or can result in a permanent injury that reduces the quality of life (severe deterministic effects).
At this level there is also the small possibility of an observable increase in the incidence of cancer due to radiation induced cases, if the number of exposed people is more than a few hundred.

Advise participants that the technical basis of the system for placing the radiological health hazard in perspective, including the dosimetric basis for 'possibly dangerous to health' is given in Appendix III of EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013.

Health hazard level: ‘health concerns’

- This level means that the danger to health is very low
- However, there is a possibility of doses exceeding the international criteria that call for taking protective actions and other response actions including medical screening in order to further assess:
  - the small possible risk to pregnant women (fetus);
  - the small possible increase in the risk of radiation induced cancers

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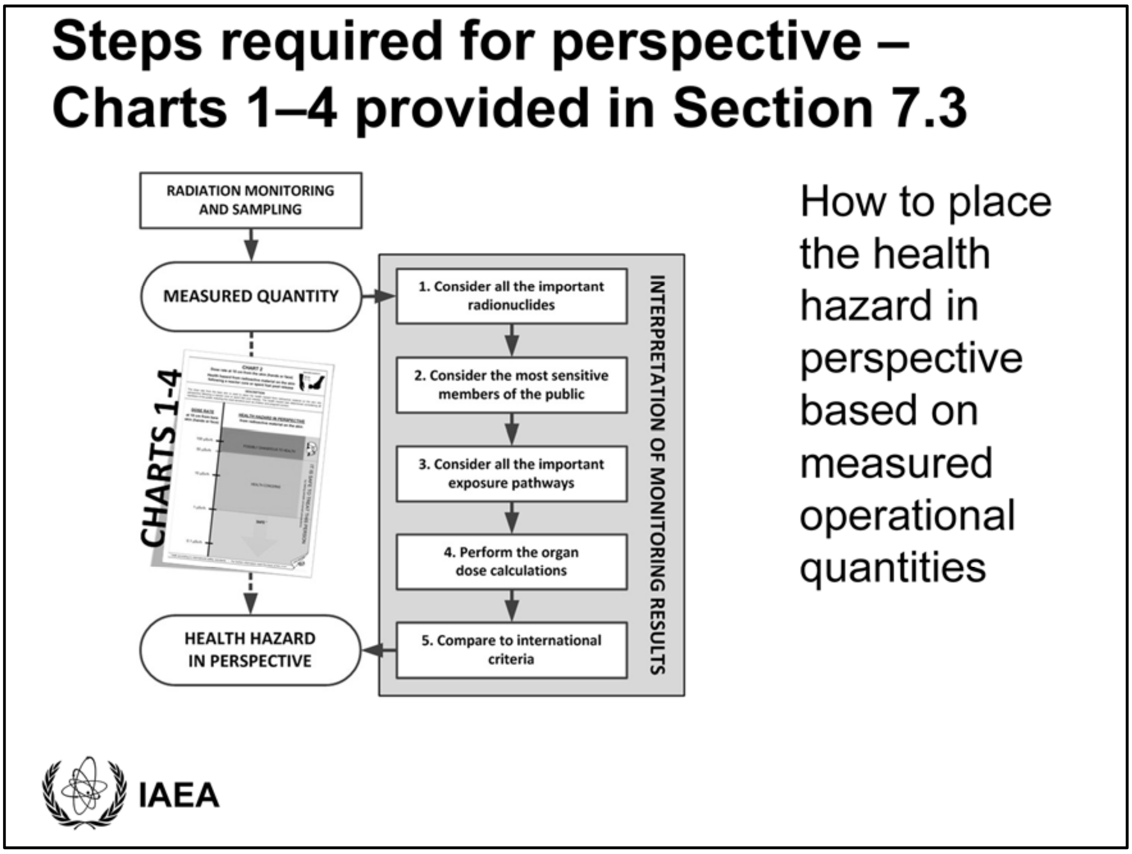
The radiological health hazard level ‘health concerns’ means the danger to health is very low. However, there is a possibility of doses exceeding the international criteria that call for taking protective actions and other response actions including medical screening in order to further assess:
–the small possible risk to pregnant women (fetus);
–the small possible increase in the risk of radiation induced cancers.

Advise participants that the technical basis of the system for placing the radiological health hazard in perspective, including the dosimetric basis for ‘health concerns’ is given in Appendix III of EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013.



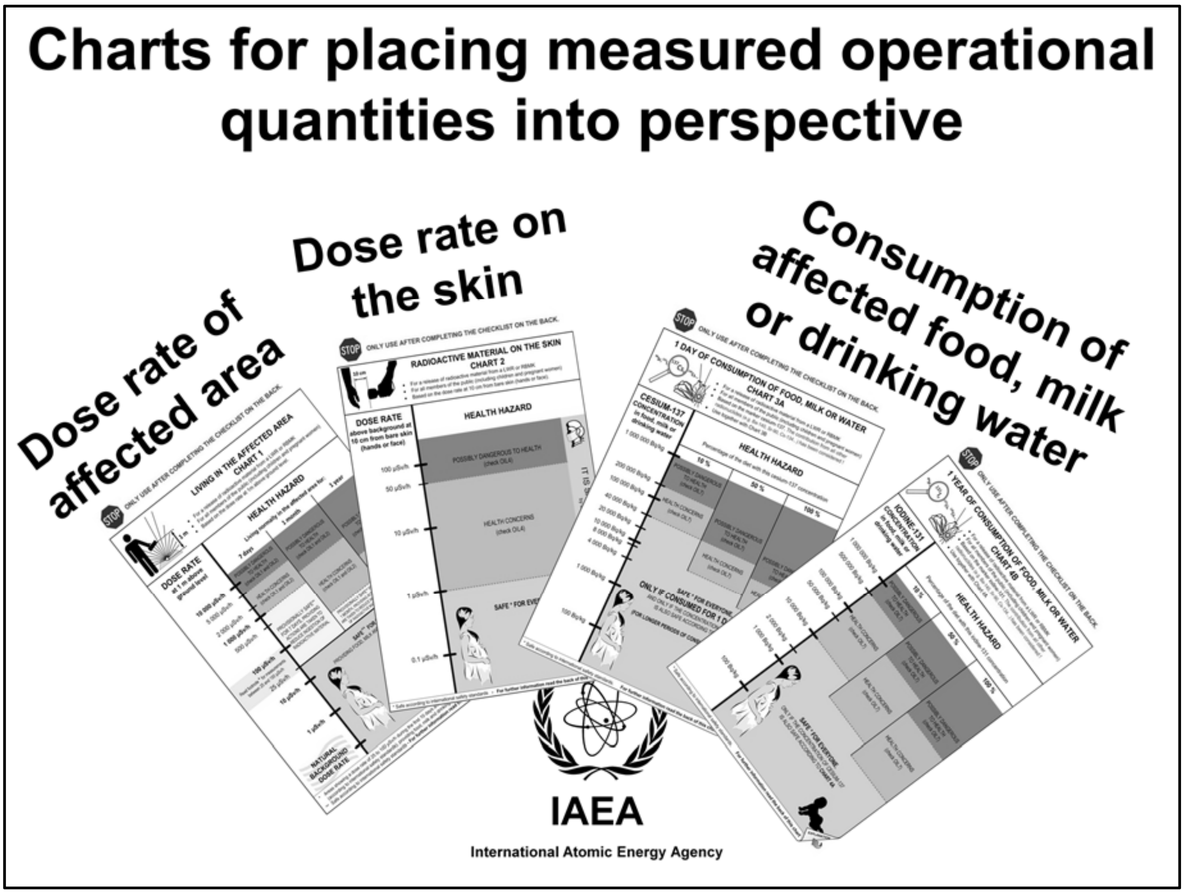
This slide presents the steps required for placing the radiological health hazard into perspective as explained in Section 7.3 of the publication Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor (EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013).

Measured quantities cannot be related to the health hazard to the public due to a radiation exposure without answering the following questions:

- What was measured?
- What are the important radionuclides?
- Who was exposed?
- How were they exposed?
- What is the risk in terms of the health effects?

For potential radioactive releases from a reactor core or spent fuel pool, these questions can be answered in advance because the characteristics of the releases and the various exposure pathways are understood. Therefore, the various measured (or operational) quantities can be related to the possible radiation induced health effects by the process shown in the image on the slide.

In order to simplify this process for application in an emergency, each step specified has been performed with reasonably conservative assumptions. The overall results are presented in Charts 1–4 found in Section 7.3. of the publication EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013. Therefore, Charts 1–4 are 'shortcuts' that allow the steps to be skipped.
The measured quantities are used as key indicators that are representative for the exposure scenario and resulting health hazard.



Charts 1–4 are in Section 7.3 of the publication EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013.

How to use the charts – Section 7.3.3.

0.5 mSv/h (at 1 m above ground)
was measured in my street
Am I safe?

TABLE 12. APPLICABILITY OF THE MEASURED QUANTITIES CHARTS

Exposure scenarios	Measured quantity	Chart No.
Living in an affected area for 7 days, 1 month or 1 year	Dose rate [µSv/h] at 1m above ground level in inhabited areas	1
Radioactive material on the skin	Dose rate [µSv/h] at 10 cm from the bare skin	2
1 day of consumption of food, milk or drinking water considering all radionuclides released	Cs-137 [Bq/kg] marker[b] concentrations in food, milk or drinking water	3A[a]
	I-131 [Bq/kg] marker[b] concentrations in food, milk or drinking water	3B[a]
1 year of consumption of food, milk or drinking water considering all radionuclides released	Cs-137[Bq/kg] marker[b] concentrations in food, milk or drinking water	4A[a]
	I-131 [Bq/kg] marker[b] concentrations in food, milk or drinking water	4B[a]

Ask participants to turn to Section 7.3.3. of the publication EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013.

This slide shows Table 12: 'Applicability of the measured quantities charts'.

- **Chart 1** is for the exposure scenario *living in an affected area for 7 days, 1 month or 1 year* and the measured quantity is dose rate [µSv/h] at 1 m above ground level in inhabited areas.
- **Chart 2** is for the exposure scenario *radioactive material on the skin* and the measured quantity is dose rate [µSv/h] at 10 cm from the bare skin.
- **Charts 3A and 3B** are for the exposure scenario ***1 day*** *of consumption of food, milk or drinking water considering all radionuclides released* and the measured quantity is Cs-137 and I-131 [Bq/kg] marker concentrations in food, milk or drinking water.
- **Charts 4A and 4B** are for the exposure scenario ***1 year*** *of consumption of food, milk or drinking water considering all radionuclides released* and the measured quantity is Cs-137 and I-131 [Bq/kg] marker concentrations in food, milk or drinking water.

How to use the charts – Section 7.3.3.

1. What quantity was reported? Dose rate (given in mSv/h)

2. What exposure scenario do you want to assess?

Exposure scenarios	Measured quantity	Chart No.
Living in an affected area for 7 days, 1 month or 1 year	Dose rate [μSv/h] at 1m above ground level in inhabited areas	1
Radioactive material on the skin	Dose rate [μSv/h] at 10 cm from the bare skin	2
1 day of consumption of food, milk or drinking water considering all radionuclides released	Cs-137 [Bq/kg] marker[b] concentrations in food, milk or drinking water	3A[a]
	I-131 [Bq/kg] marker[b] concentrations in food, milk or drinking water	3B[a]
1 year of consumption of food, milk or drinking water considering all radionuclides released	Cs-137[Bq/kg] marker[b] concentrations in food, milk or drinking water	4A[a]
	I-131 [Bq/kg] marker[b] concentrations in food, milk or drinking water	4B[a]

Use of charts for measured operational quantities

Obtain at least one of the following data sets along with an explanation of the quality of the data used**:**

- dose rates representative of those in areas where people are living;
- concentrations in food, milk or water representative of what is being consumed; or
- dose rates measured from the bare skin.

Select the appropriate chart

Select the chart based on what quantity was measured and which exposure scenario is being considered using Table 12. The previous slide stated '*0.5 mSv/h (at 1 m above ground) was measured in my street – Am I safe?'*

1. Which quantity was reported? 0.5 mSv/h
2. What exposure scenario do you want to assess? Living in an affected area

How to use the charts – Section 7.3.3.

3. Ensure that the measured quantities are in the same units as they appear on the chart

Multiply (reported unit)	By			To get (unit used in charts)
Sv/h	1 000 000	(or 10^6)	µSv/Sv	µSv/h
mSv/h	1 000	(or 10^3)	µSv/mSv	µSv/h
Bq/g	1 000	(or 10^3)	g/kg	Bq/kg
kBq/kg	1 000	(or 10^3)	Bq/kBq	Bq/kg
kBq/g	1 000 000	(or 10^6)	(Bq/kg)/(kBq/g)	Bq/kg
MBq/kg	1 000 000	(or 10^6)	Bq/MBq	Bq/kg
MBq/g	1 000 000 000	(or 10^9)	(Bq/kg)/(MBq/g)	Bq/kg

$$0.5\,\frac{mSv}{h} \times 1000\,\frac{\mu Sv}{mSv} = 500\,\frac{\mu Sv}{h}$$

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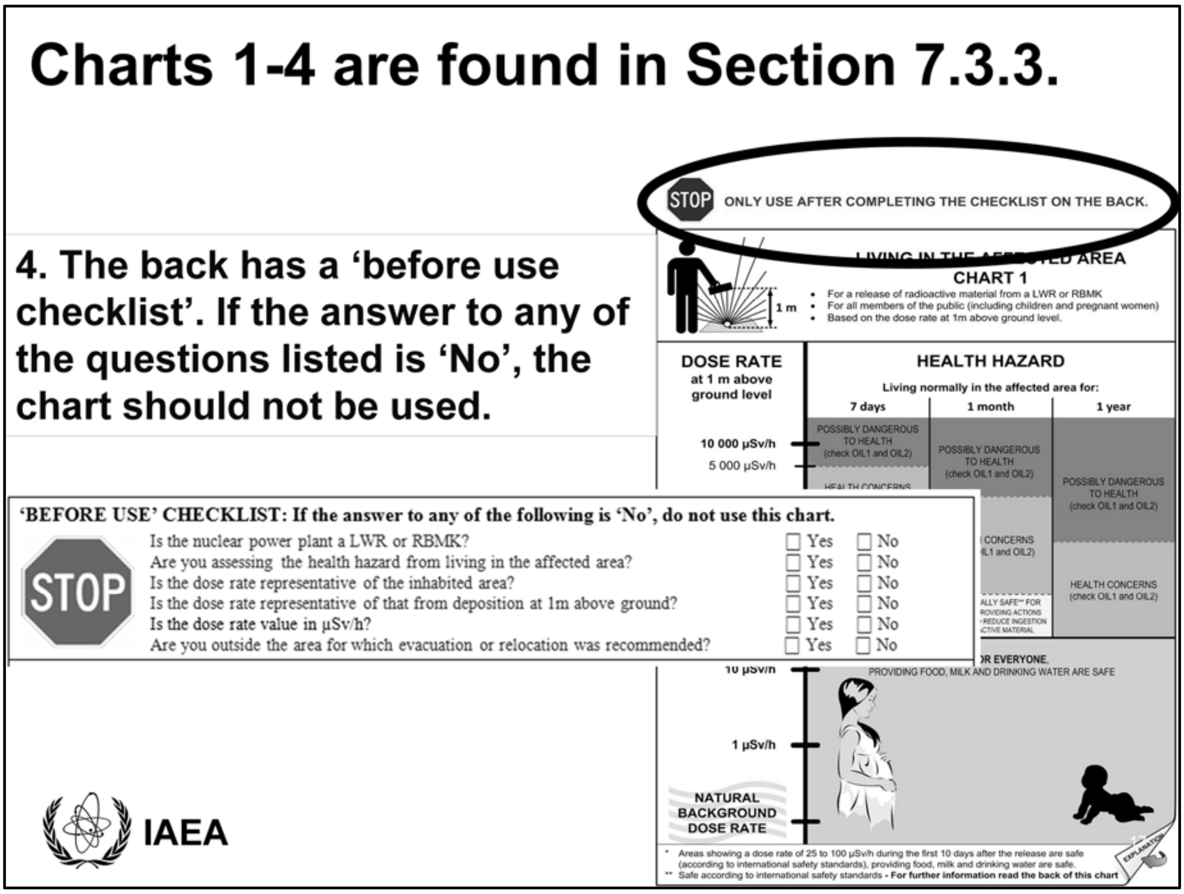
Convert the units of the measured quantity to those in the charts
Ensure that the measured quantities are in the same units as they appear on the selected chart (i.e. µSv/h or Bq/kg).

The steps for converting the units of the measured quantity to those in the charts can be found in Section 7.3.3. of EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013.

Remind participants that the measured quantity given in the question was 0.5 mSv/h (“*0.5 mSv/h (at 1 m above ground) was measured in my street. Am I safe?”*)
This needs to be converted to the same unit that is used in Chart 1 (µSv/h).
0.5 mSv/h × 1000 µSv/mSv = 500 µSv/h

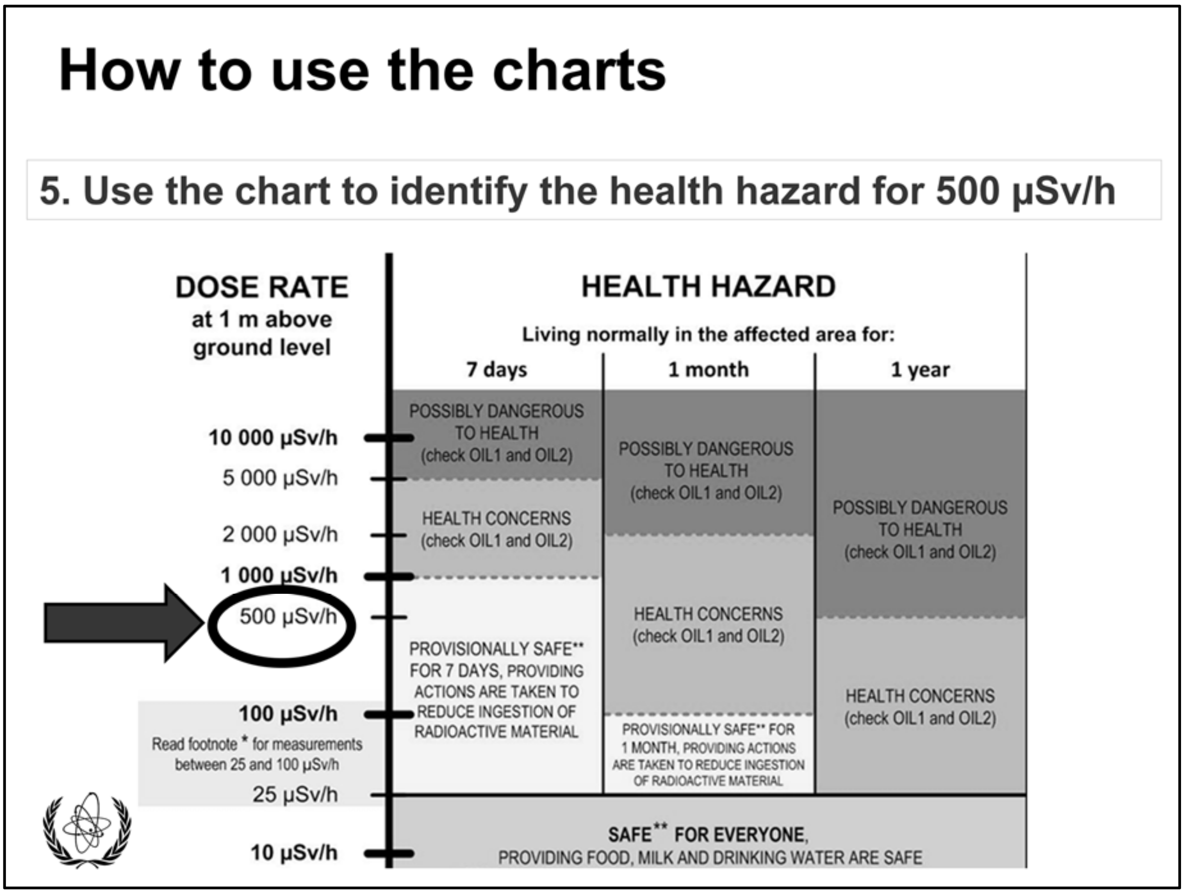


The front of each chart has a stop sign and warning that the chart can only be used after completing the checklist on the back.
If the answer to any of the questions listed in the 'before use checklist' is 'No', the chart should not be used.

In addition to the 'before use checklist', there is also an explanation of the chart's purpose, the measured quantity, exposure scenario, population considered, the possible health hazard placed into perspective and the protective actions and other response actions that may need to be taken.

Ask participants to read the 'before use checklist' and answer the questions. Explain that for the purpose of the exercise it is assumed that the release was from an LWR, the dose rate is representative of the inhabited area and from deposition at 1 m above ground and that the individual is in an area not already recommended for relocation or evacuation. (*Note to lecturer* – this is to ensure that participants are able to answer Questions 1, 3, 4 and 6 with yes). For Questions 2 and 5 participants will already be able to answer – "0.5 mSv/h (at 1 m above ground) was measured in my street" (Question 2) and the conversion to µSv/h made on the previous slide (Question 5).

1) Is the nuclear power plant an LWR or RBMK?
2) Are you assessing the health hazard from living in the affected area?
3) Is the dose rate representative of the inhabited area?
4) Is the dose rate representative of that from deposition at 1 m above ground?
5) Is the dose rate value in µSv/h?
6) Are you outside the area for which evacuation or relocation was recommended?



Ask participants to use the chart in order to answer the question: “*0.5 mSv/h (at 1 m above ground) was measured in my street. Am I safe?*”

What is the health hazard of 500 µSv/h for 7 days?

- **Provisionally safe:** This level means that it is safe and there are no hazards to health due to radiation exposure if remaining in the area is limited to the specific time period and these protective actions are implemented:
  - prevention of consumption of food, milk or water with concentrations greater than OIL7; and,
  - prevention of inadvertent ingestion by: washing hands before eating, not playing on the ground, or not doing other activities that could result in the creation of dust that could be ingested

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The health hazard for 500 µSv/h for 7 days is ‘provisionally safe’.
This level means that it is safe and there are no hazards to health due to radiation exposure if remaining in the area is limited to the specific time period and these protective actions are implemented:

- prevention of consumption of food, milk or water with concentrations greater than OIL7; and,
- prevention of inadvertent ingestion by: washing hands before eating, not playing on the ground, or not doing other activities that could result in the creation of dust that could be ingested.

How does Chart 1 relate to the IAEA's OILs?

- If an individual **is in an area** where conditions indicate the health hazard level is 'possibly dangerous to health' or 'health concerns', take protective actions and other response actions in accordance with IAEA guidance
  - for OIL1 and OIL2 in Table 7 of the IAEA publication: *Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor, EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013*.

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Activity 1 – Monitoring Results

Assess the following monitoring results and place the radiological health hazard in perspective:

GROUP A

0.9 mSv/h dose rate at 1 m above ground measured day 7 after a release

GROUP B

0.002 mSv/h dose rate at 10 cm from bare skin

GROUP C

0.1 kBq/kg of ^{137}Cs and 20 kBq/kg of ^{131}I in milk consumed for 1 year

GROUP D

0.9 mSv/h dose rate at 1 m above ground measured day 15 after a release

GROUP E

0.35 kBq/kg of Cs-137 and 230 kBq/kg of I-131 in milk consumed for 1 year

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Divide the participants into five groups and assign each group a question listed on this slide for them to answer using Charts 1–4 in the publication EPR-NPP PUBLIC PROTECTIVE ACTIONS , 2013.

Activity 1 – Answers

Assess the following monitoring results and place the health hazard in perspective:

GROUP A

0.9 mSv/h dose rate at 1 m above ground measured day 3 after a release – **PROVISIONALLY SAFE**

GROUP B

0.002 mSv/h dose rate at 10 cm from bare skin – **HEALTH CONCERNS**

GROUP C

0.1 kBq/kg of ^{137}Cs and 20 kBq/kg of ^{131}I in milk consumed for 1 year – **HEALTH CONCERNS**

GROUP D

0.9 mSv/h dose rate at 1 m above ground measured day 15 after a release – **HEALTH CONCERNS**

GROUP E

0.35 kBq/kg of Cs-137 and 230 kBq/kg of I-131 in milk consumed for 1 year – **HEALTH CONCERNS**

GROUP A

1. 0.9 mSv/h dose rate at 1 m above ground measured day 3 after a release = Chart 1
2. Convert mSv/h to µSv/h

$$0.9\,\frac{\text{mSv}}{\text{h}} \times 1000\,\frac{\mu\text{Sv}}{\text{Sv}} = 900\,\frac{\mu\text{Sv}}{\text{h}}$$

3. 900 µSv/h measured on day 7 after a release = provisionally safe (yellow) on Chart 1

GROUP B

1. 0.002 mSv/h dose rate at 10 cm from bare skin = Chart 2
2. Convert mSv/h to µSv/h

$$0.002\,\frac{\text{mSv}}{\text{h}} \times 1000\,\frac{\mu\text{Sv}}{\text{Sv}} = 2\,\frac{\mu\text{Sv}}{\text{h}}$$

3. 2µSv/h dose rate at 10 cm from bare skin = health concerns (orange)

GROUP C

1. 0.1 kBq/kg of ^{137}Cs and 20 kBq/kg of ^{131}I in milk consumed for 1 year = Charts 4A and 4B
2. Convert kBq/kg to Bq/kg

^{137}Cs $$0.1\,\frac{\text{kBq}}{\text{kg}} \times 1000\,\frac{\text{Bq}}{\text{kg}} = 100\,\frac{\text{Bq}}{\text{kg}}$$

^{131}I $$20\,\frac{\text{kBq}}{\text{kg}} \times 1000\,\frac{\text{Bq}}{\text{kg}} = 20\,000\,\frac{\text{Bq}}{\text{kg}}$$

3. ^{137}Cs 100 Bq/kg Chart 4A (safe – **<u>but must check Chart 4B also</u>**)
^{131}I 20 000 Bq/kg Chart 4A = health concerns (orange)

GROUP D

1. 0.9 mSv/h dose rate at 1 m above ground measured day 15 after a release = Chart 1
2. Convert mSv/h to µSv/h

$$0.9\,\frac{\text{mSv}}{\text{h}} \times 1000\,\frac{\mu\text{Sv}}{\text{Sv}} = 900\,\frac{\mu\text{Sv}}{\text{h}}$$

3. 900 µSv/h measured on day 15 after a release = health concerns (orange) on Chart 1

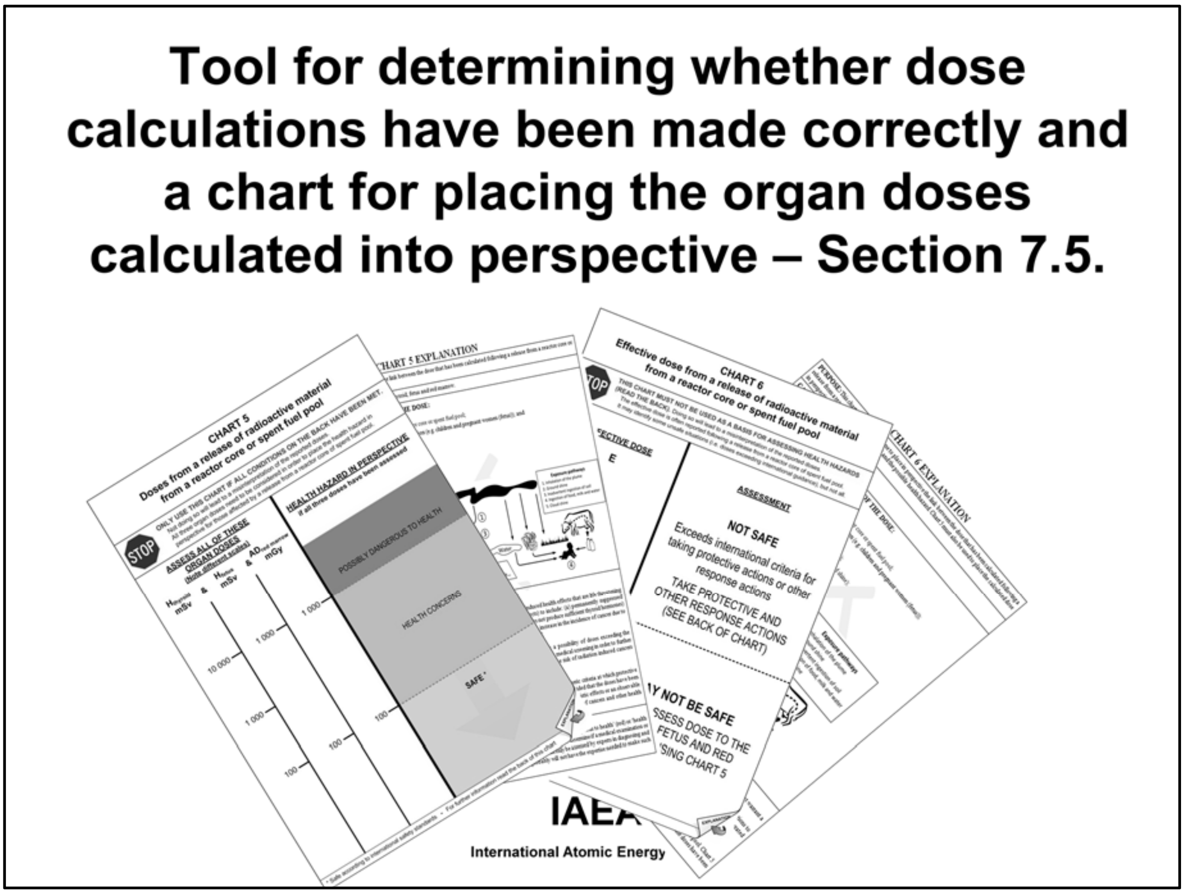
GROUP E

1. 0.35 kBq/kg of ^{137}Cs and 230 kBq/kg of ^{131}I in milk consumed for 1 year = Charts 4A and 4B
2. Convert kBq/kg to Bq/kg

^{137}Cs $$0.35\,\frac{\text{kBq}}{\text{kg}} \times 1000\,\frac{\text{Bq}}{\text{kg}} = 350\,\frac{\text{Bq}}{\text{kg}}$$

^{131}I $$230\,\frac{\text{kBq}}{\text{kg}} \times 1000\,\frac{\text{Bq}}{\text{kg}} = 230\,000\,\frac{\text{Bq}}{\text{kg}}$$

3. ^{137}Cs 350 Bq/kg Chart 4A (safe – **<u>but must check Chart 4B also</u>**)
^{131}I 230 000 Bq/kg Chart 4A = health concerns (orange)



Charts 5–6 are in Section 7.5. of the publication EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013.

The use of the charts for measured (or operational) quantities (Charts 1–4) are preferable over the use of calculated dose for putting the health hazard in perspective because of:

(a) the confusion that could arise from the different units and the variety of different doses with the same name (sieverts) and

(b) the complex steps that must be followed, as shown in this slide, in order to place dose into perspective in terms of the health hazards.

Use Charts 1–4 and not Charts 5–6 during an emergency

- Early on in a reactor core or spent fuel pool emergency it is not possible to formulate dose calculations with certainty owing to the limited and unreliable data that are available
- Experience in past emergencies has shown that doses will be calculated ad-hoc during an emergency regardless of the circum-stances, leading to wrong and unfounded dose estimations

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Early on in a reactor core or spent fuel pool emergency it is not possible to formulate dose calculations with certainty owing to the limited and unreliable data that are available.

Experience in past emergencies has shown that doses will be calculated ad-hoc during an emergency regardless of the circumstances, leading to wrong and unfounded dose estimations – this is why Charts 5 and 6 have been created as a tool to assess the dose estimations that will be made.

But it is important to emphasize that Charts 1–4 and not Charts 5–6 should be used whenever possible.

Charts 1–4 are preferable because:
- Of the complex and time consuming calculations that must be performed in order to place dose into perspective in terms of the health hazards
- It will require time and data that will not be available early on in a reactor core or spent fuel pool emergency and will not be any better than those assumed in Charts 1–4

Why was a projection of cancer deaths inappropriate?

"Cancer death toll from Fukushima could exceed 500 000"

Ask participants to discuss why this projection of cancer deaths was inappropriate.

Projections of cancer deaths were made for Fukushima: "The death toll from Fukushima could exceed 500,000."

Picture by: *Dana Sacchetti and Gill Tudor*
http://www.iaea.org/newscenter/focus/chernobyl/25years/

Answer

- Projections may do more harm than good – causing unnecessary fear and concern among the public.
- It is impossible to predict the possible number of cancers resulting from an emergency within the first months to years after the emergency.
- The only way to detect excess cancers with certainty is by studying cancer statistics for the population affected by high doses over a period of many years.

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As shown in Table 15 in Section 7.4. of EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013, projection of cancer deaths is a common error made in assessments of the health hazard during an emergency at an NPP.

Projections may do more harm than good – causing unnecessary fear and concern among the public. Projections of excess deaths are often based on the inappropriate use of the fatal risk coefficient (as "deaths per sievert of collective effective dose") given by the International Commission on Radiation Protection (ICRP) and others. This coefficient was intended to be used for the purposes of radiological protection only: its use for projecting health consequences was never intended, as stated by ICRP, for the following reasons:
Because of the uncertainty of health effects at low doses, the ICRP judges that it is not appropriate, for the purposes of public health planning, to calculate the hypothetical number of cases of cancer or heritable disease that might be associated with very small radiation doses received by large numbers of people over very long periods.
Assessments that project excess cancer deaths are unreliable. This is because it is impossible to predict the possible number of cancers resulting from an emergency within the first months to years after the emergency. The only way that excess cancers can be detected with certainty is by studying cancer statistics for the population affected by high doses over many years. At low doses (doses below the international generic criteria calling for protective or other response actions), there will not be an observable increase in the incidence of cancer, even in a very large exposed group.

[References: BUGLOVA E., KENIGSBERG J., MCKENNA T., "Reactor accidents and thyroid cancer risk: Use of the Chernobyl experience for emergency response", Proc. Int. Symp. on Radiation and Thyroid Cancer (THOMAS, G., KARAOGLOU, A., WILLIAMS, E.D., Eds), World Scientific (1999) 449-453; GONZÁLEZ, A.J., "The radiological health consequences of Chernobyl: the dilemma of causation", Nuclear Accidents – Liabilities and Guarantees (Proc. Symp. Helsinki, 1992) OECD, Paris (1993) 25-55; LIBMANN J., Elements of Nuclear Safety, IPSN, Paris (1996).]

Common errors in dose calculations – not considering:

- All applicable organ doses
- Released mixture of radionuclides
- All members of the public (i.e. including the individuals most sensitive to radiation, such as children and pregnant women)
- All relevant exposure pathways, or to only use the effective dose (which alone cannot be used as a basis for estimating the possible health hazard from radiation exposure in an individual)

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This slide lists some of the common errors made when making dose calculations, including not considering:

- All applicable organ doses
- Released mixture of radionuclides
- All members of the public (i.e. including the individuals most sensitive to radiation, such as children and pregnant women)
- All relevant exposure pathways, or to only use the effective dose (which alone cannot be used as a basis for estimating the possible health hazard from radiation exposure in an individual)

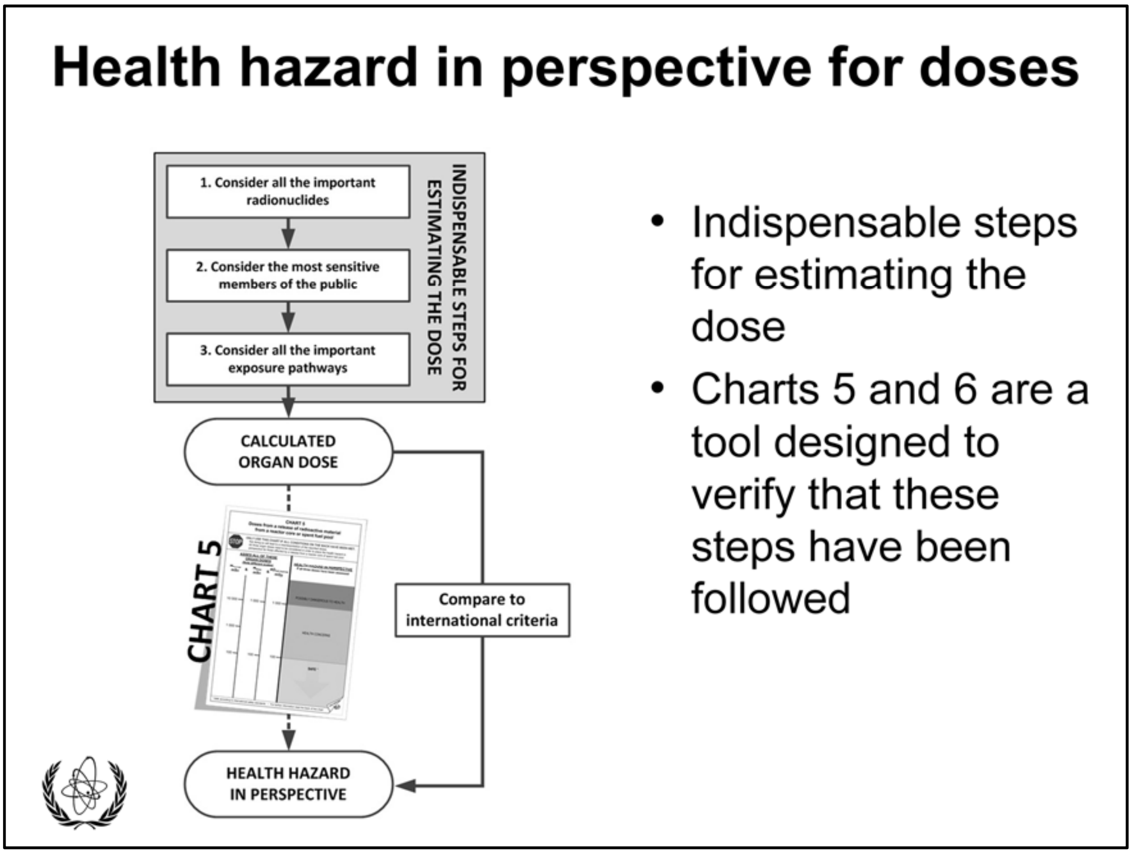
Dose reported – Is it reliable?

- Dose is a calculated quantity that must be determined in a very specific way in order to correctly place the associated radiological health hazard into perspective
- Assessments that do not explain in detail how the calculations were performed are unreliable
- Not all dose calculations may be useful in assessing possible radiation induced health effects and cannot be used with the charts provided

IAEA

Assessments that do not explain in detail how the calculations were performed are unreliable. Dose is a calculated quantity that must be determined in a very specific way in order to correctly place the radiological health hazard into perspective.

The publication EPR-PUBLIC PROTECTIVE ACTIONS, 2013 (Section 7.5.) provides tools for determining whether dose calculations have been made correctly and a chart for placing the organ doses calculated into perspective.



The diagram on this slide presents the indispensable steps that must be followed for dose estimations:
1. What are the important radionuclides?
2. Who was exposed? (i.e. were the most sensitive members of the public considered?)
3. How were they exposed? (i.e. were all the important exposure pathways considered?)
The organ dose then needs to be calculated.
This dose then needs to be compared to international criteria.

Organ doses that need to be assessed for a fission product release from an LWR or RBMK:

- Equivalent dose to the thyroid ($H_{thyroid,}$ mSv) from inhalation and ingestion;
- Equivalent dose to the fetus ($H_{fetus,}$ mSv) from all exposure pathways;
- RBE weighted absorbed dose to the red marrow ($AD_{red\ marrow,}$ mGy) from external exposure

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The dose to all of the following organs needs to be assessed in order to determine the possible health hazard from radioactive material released from a reactor core or spent fuel pool:
- Equivalent dose to the thyroid ($H_{thyroid,}$ mSv) from inhalation and ingestion;
- Equivalent dose to the fetus ($H_{fetus,}$ mSv) from all exposure pathways; and
- RBE weighted absorbed dose to the red marrow ($AD_{red\ marrow,}$ mGy) from external exposure.

How to use the charts

TABLE 16. DOSES TO BE CONSIDERED WHEN ASSESSING THE POSSIBLE RADIOLOGICAL HEALTH HAZARD AND PLACING THEM INTO PERSPECTIVE FOLLOWING A RELEASE FROM A REACTOR CORE OR SPENT FUEL POOL

Dose	Exposure pathways[a] to consider	Discussion	Chart No.
$H_{thyroid}$ Equivalent dose to the thyroid (mSv)	• Inhalation of the plume; • Inadvertent ingestion (e.g. soil on hands); and • Ingestion of food, milk or water.	The dose to the thyroid can be the principal concern in an emergency involving a reactor core or spent fuel pool because of large amounts of radioiodine that can be released and that concentrates in the thyroid. The dose to thyroid mainly comes from inhaling radioactive iodine released in the plume or from eating food, milk or water that has been affected by the plume. After the accident at the Chernobyl nuclear power plant, radiation induced cancers developed among children as a result of consuming contaminated milk.	5
H_{fetus} Equivalent dose in the fetus (mSv)	• External exposure from the plume; • External exposure from ground deposition during the period of exposure; • Inhalation of the plume; • Inadvertent ingestion (e.g. soil on hands); and • Ingestion of food, milk or water.	For a reactor emergency the dose from inhalation or ingestion of radioactive iodine can be the most important exposure pathway.	
$AD_{red\ marrow}$ RBE weighted absorbed dose to the red marrow (mGy)	• External exposure from the plume; and • External exposure from ground deposition during the period of exposure.	Used to assess the radiation induced health effects that result primarily from external exposure, to include effects to the fetus and reproductive organs. The $AD_{red\ marrow}$ (mGy) dose from external exposure can be estimated based on ambient dose rate (mSv/h) for a release from a reactor core or spent fuel pool (mSv/h ≈ mGy/h).	
E Effective dose (mSv)	• External exposure from the plume; • External exposure from ground deposition during the period of exposure; • Inhalation of the plume; • Inadvertent ingestion (e.g. soil on hands); and • Ingestion of food, milk or water.	Effective dose cannot be used to assess the possible radiation induced health effects to the individual; however it is often reported in an emergency. Effective dose may identify some situations that are not safe (but not all), such as those that result in doses that in accordance with international guidance require protective actions [1]; however, all the organ doses listed above need to be considered in order to assess the health hazard.	6[b]

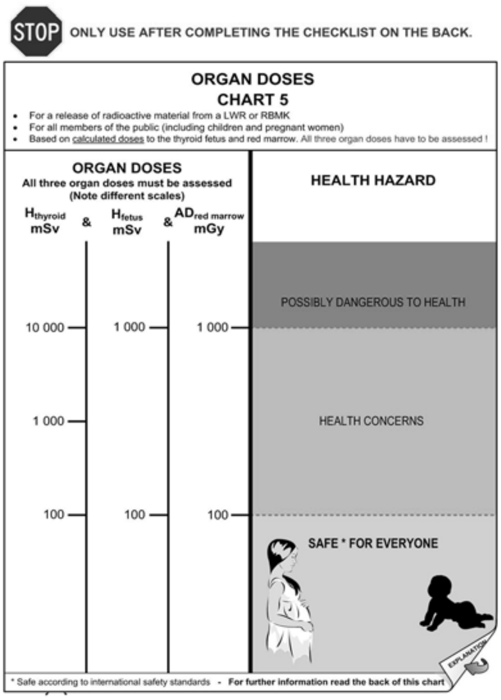
[a] For an explanation of the different exposure pathways important for a release from a reactor core or spent fuel pool, see Appendix II.

[b] The dose to the thyroid, fetus and red marrow needs to be determined and evaluated according to Chart 5 in order to assess the health effects.

- Use Table 16 (Section 7.5.) to select the appropriate chart based on which dose was calculated

Table 16, ‘Doses to be considered when assessing the possible health hazard and placing them into perspective following a release from a reactor core or spent fuel pool’, is in Section 7.5. of the publication EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013. Table 16 lists the doses and the exposure pathways that need to be assessed in order to place the health hazard in perspective following a release from a reactor core or spent fuel pool.

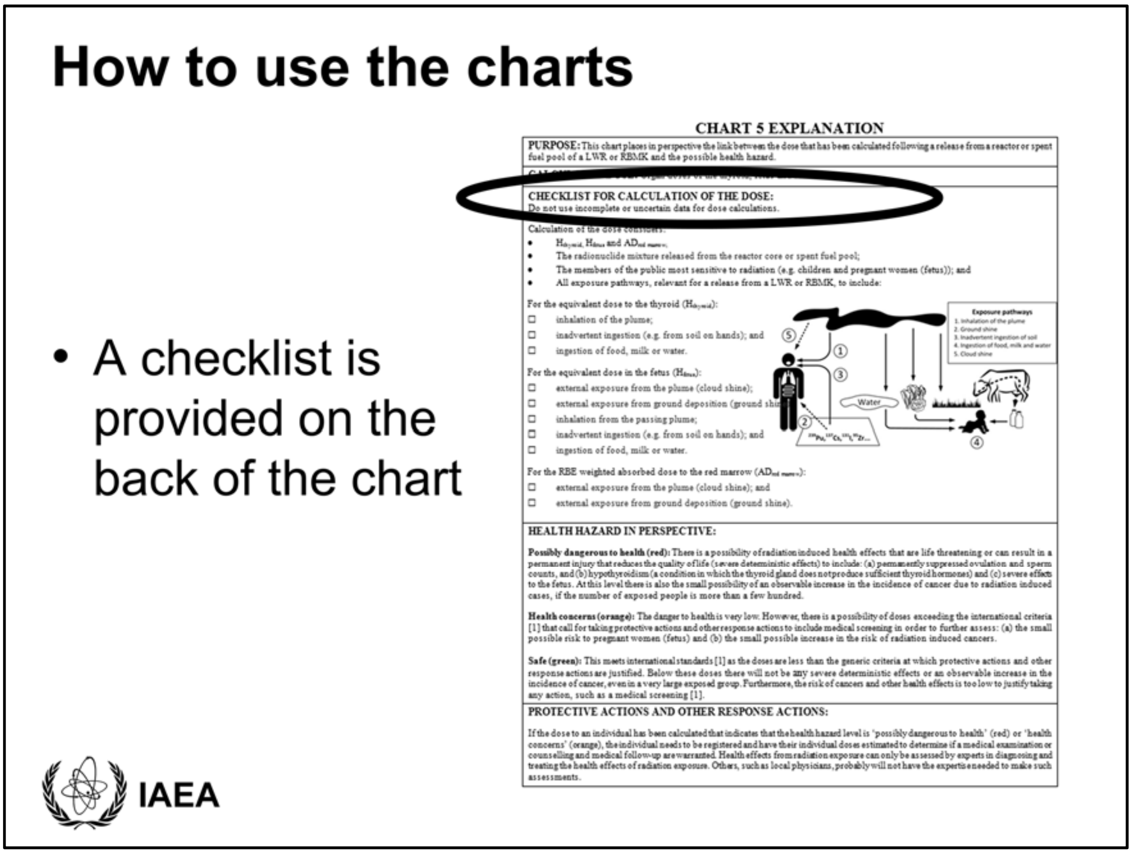
Chart 5 – Section 7.5.



- Placing the health hazard in perspective for organ doses calculated after a release from a reactor core or spent fuel pool
- All three organ doses need to be considered

Ask participants to go to Section 7.5. of the publication EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013, for Chart 5, Health hazard in perspective for organ doses calculated after a release from a reactor or spent fuel pool of a LWR or RBMK.

This chart places in perspective the link between the dose that has been calculated following a release from a reactor or spent fuel pool of an LWR or RBMK and the possible health hazard.
It should be emphasized to participants that Chart 5 can only be used if all of the following doses were calculated:
Equivalent dose to the thyroid ($H_{thyroid}$, mSv) from inhalation and ingestion;
Equivalent dose to the fetus (H_{fetus}, mSv) from all exposure pathways; and
RBE weighted absorbed dose to the red marrow ($AD_{red\ marrow}$, mGy) from external exposure.



Ask participants to go to Section 7.5. of the publication EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013 to see the back of Chart 5 (its explanation).
The back of the chart describes: the purpose of the chart, the doses that are being placed into perspective, a checklist of what needs to be considered for the calculation of the specified dose and an explanation of the health hazard in perspective.

The chart can only be used if it has been confirmed that all the doses were calculated correctly.
The checklist is used to confirm that the dose was calculated correctly for the purpose of placing the health hazards in perspective.

To ensure that all of the required organ doses were calculated considering:
- Radionuclide mixture
- Members of the public most sensitive to radiation (i.e. children and pregnant women (fetus))
- All relevant exposure pathways of the specified dose

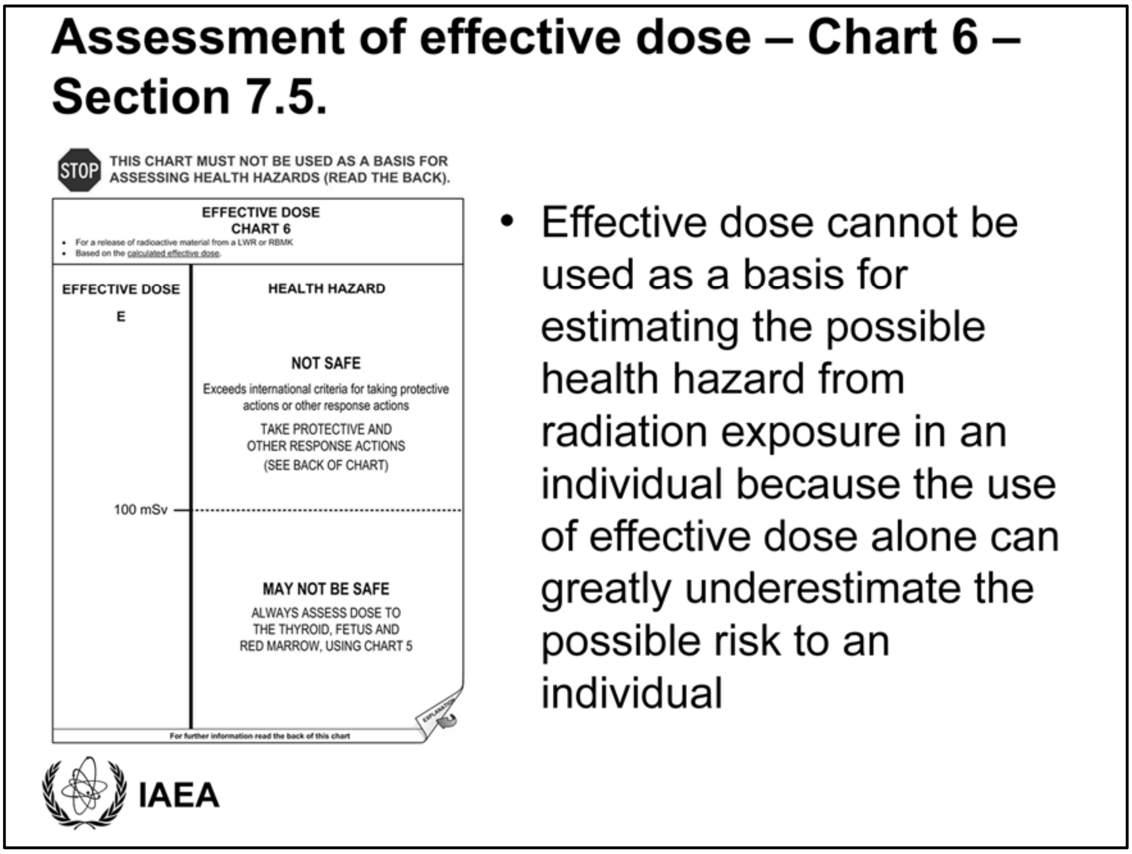
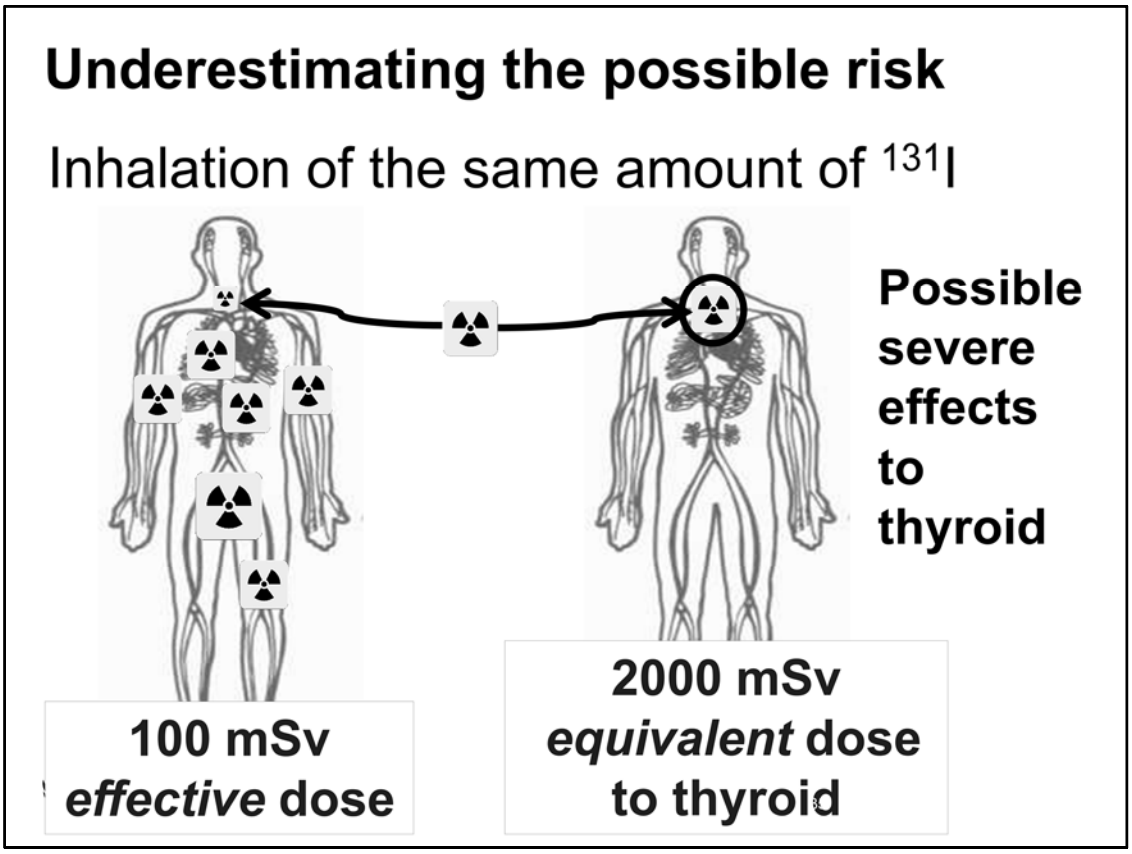


Chart 6, Assessment of effective dose calculated after a release from a reactor or spent fuel pool of an LWR or RBMK, can be found in Section 7.5. of the publication EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013.

Effective dose cannot be used as a basis for estimating the possible health hazard from radiation exposure in an individual because the use of effective dose alone can greatly underestimate the possible risk to an individual

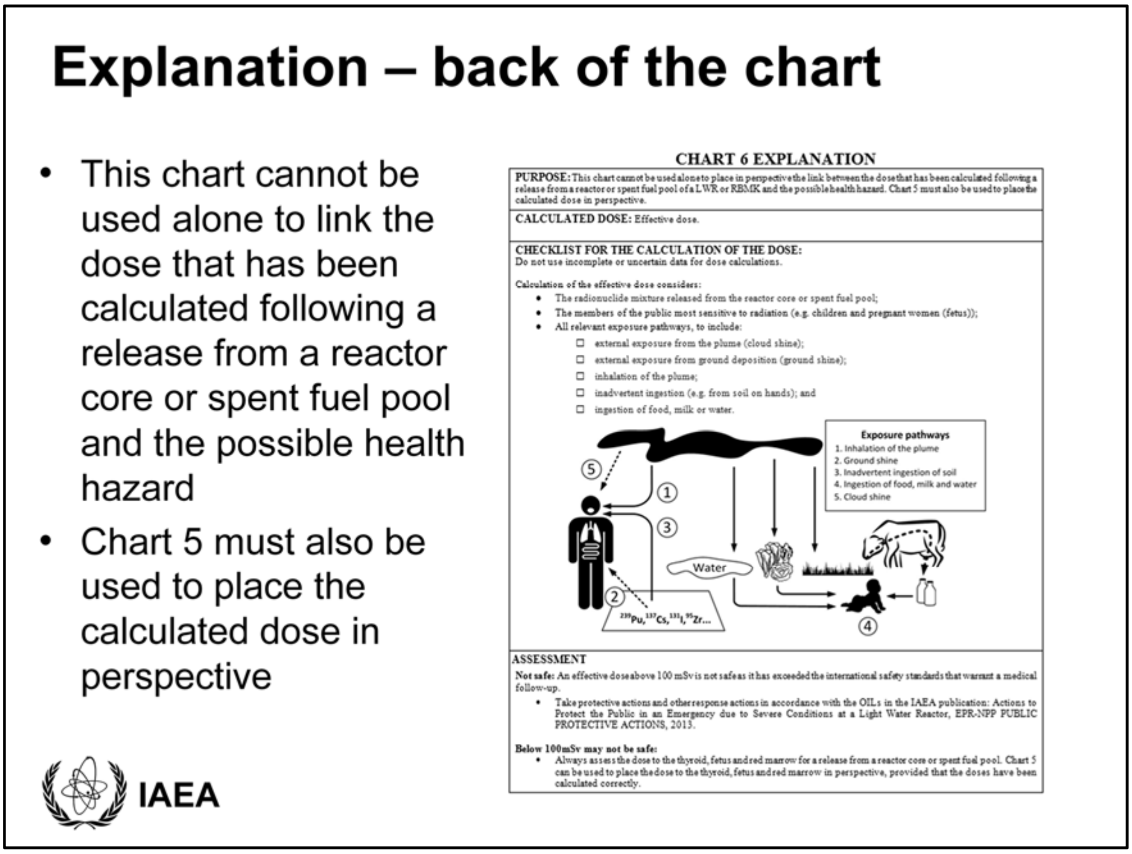


This shows the importance of knowing how someone was exposed and what type of dose is calculated.
The inhalation of the same amount of I-131, a major component of a fission product release from a reactor, can result in 100 mSv effective dose and 2000 mSv of equivalent dose to the thyroid.

Iodine in the fission products concentrates in the thyroid and thus provides a much higher equivalent dose to the thyroid.

Effective dose is a general dose that represents the total risk of cancers. Effective dose is calculated assuming that the dose to the thyroid contributes a small amount to total risk of cancers and therefore, only contributes a small amount to the effective dose.

The equivalent dose to the thyroid, however, represents the risk to that organ. In this case, the thyroid dose is much higher than the effective dose.
You may not expect anyone to get any health effects from 100 mSv effective dose but at above 2000 mSv equivalent dose to the thyroid, severe effects may occur.
Stating that someone has received 100 mSv effective dose does not tell you anything about their health risks unless you know how they were exposed and what they were exposed to.



Emphasize to participants the explanation that is provided on the back of Chart 6, which states that it cannot be used alone to place in perspective the link between the dose that has been calculated following a release from a reactor or spent fuel pool of an LWR or RBMK and the possible health hazard. Chart 5 must also be used to place the calculated dose in perspective.

Summary questions

- What data are required for making dose assessments following a release of radioactive material from a reactor core or spent fuel pool of an LWR or RBMK?
- Which organ doses need to be assessed following a release of radioactive material from a reactor core or spent fuel pool?

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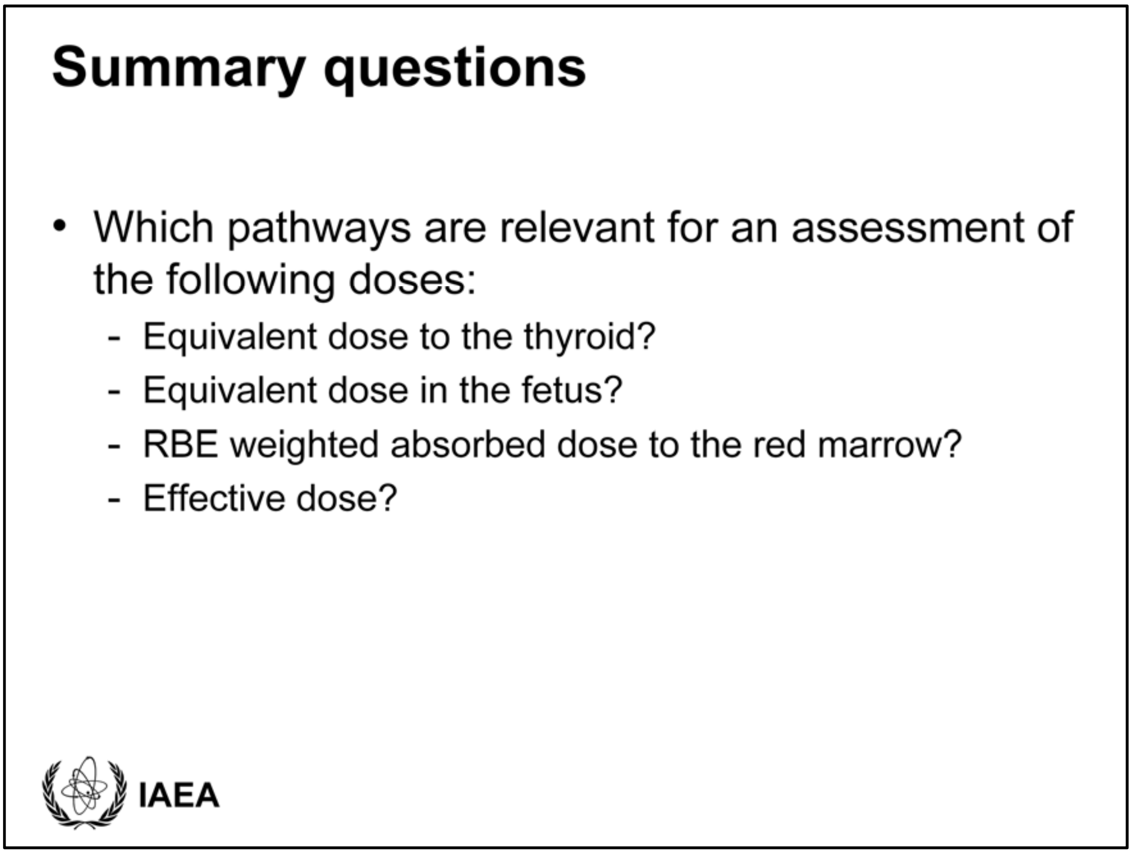
The next two slides provide participants the opportunity to answer three summary questions.
Ask participants the two summary questions provided on the slide, namely:
1. What data are required for making dose assessments following a release of radioactive material from a reactor core or spent fuel pool of an LWR or RBMK?
2. Which organ doses need to be assessed following a release of radioactive material from a reactor core or spent fuel pool?

Note to lecturer – answers:
1) What are the important radionuclides? Who was exposed? (i.e. were the most sensitive members of the public considered?) How were they exposed? (i.e. were all the important exposure pathways considered?)
2) Equivalent dose to the thyroid ($H_{thyroid}$, mSv); Equivalent dose to the fetus (H_{fetus}, mSv); and RBE weighted absorbed dose to the red marrow ($AD_{red\ marrow}$, mGy).



Ask participants to answer the following summary question provided on the slide:

3. Which pathways are relevant for an assessment of the following doses:
   - -Equivalent dose to the thyroid ($H_{thyroid}$)?
   - -Equivalent dose in the fetus (H_{fetus})?
   - -RBE weighted absorbed dose to the red marrow ($AD_{red\ marrow}$)?
   - -Effective dose (E)?

Note to lecturer – answers:

- Inhalation and ingestion for $H_{thyroid}$
- All exposure pathways for H_{fetus}
- External exposure for $AD_{red\ marrow}$
- All relevant exposure pathways, to include: external exposure from the plume; external exposure from ground deposition during the period of exposure; inhalation of the plume; inadvertent ingestion (e.g. soil on hands); and ingestion of food, milk or water.

Activity 2 – Am I safe?

An effective dose of 50 mSv was calculated

The calculation took into account:

- The radionuclide mixture released from the reactor core or spent fuel pool;
- The members of the public most sensitive to radiation (e.g. children and pregnant women (fetus));
- All relevant exposure pathways, including: external exposure from the plume (cloud shine), external exposure from ground deposition (ground shine), inhalation of the plume, inadvertent ingestion (e.g. from soil on hands); and ingestion of food, milk or water.

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Ask participants to answer the question asked by a member of the public: “I have an effective dose of 50 mSv – Am I safe?”

Explain to participants that the calculation of the dose took into account:
–The radionuclide mixture released from the reactor core or spent fuel pool;
–The members of the public most sensitive to radiation (e.g. children and pregnant women (fetus));
–All relevant exposure pathways, including: external exposure from the plume (cloud shine), external exposure from ground deposition (ground shine), inhalation of the plume, inadvertent ingestion (e.g. from soil on hands); and ingestion of food, milk or water.

Activity 2 – Answer

ANSWER: MAY NOT BE SAFE

- Always assess the dose to the thyroid, fetus and red marrow for a release from a reactor core or spent fuel pool.

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Ask participants to answer the question asked by a member of the public: "I have an effective dose of 50 mSv – Am I safe?"

Explain to participants that the calculation of the dose took into account:
–The radionuclide mixture released from the reactor core or spent fuel pool;
–The members of the public most sensitive to radiation (e.g. children and pregnant women (fetus));
–All relevant exposure pathways, including: external exposure from the plume (cloud shine), external exposure from ground deposition (ground shine), inhalation of the plume, inadvertent ingestion (e.g. from soil on hands); and ingestion of food, milk or water.

Answer: **MAY NOT BE SAFE**
Always assess the dose to the thyroid, fetus and red marrow for a release from a reactor core or spent fuel pool.

Activity 3 – Use Charts 5 and 6

- Using Charts 5 and 6, place the health hazard for the following doses* in perspective:
  - 75 mSv effective dose
  - 80 mSv $H_{thyroid}$
  - 0.05 Gy $AD_{red\ marrow}$
  - 120 mSv H_{fetus}

*All have been assessed using the checklist and are confirmed as being calculated correctly

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Activity 3 – Answers

HEALTH CONCERNS

- 75 mSv effective dose
- 80 mSv $H_{thyroid}$
- 0.05 Gy $AD_{red\ marrow}$ (50 mGy)
- 120 mSv H_{fetus}

This level means that the danger to health is very low. However, there is a possibility of doses exceeding the international criteria that call for taking protective actions and other response actions to include medical screening in order to further assess: (a) the small possible risk to pregnant women (fetus) and (b) the small possible increase in the risk of radiation induced cancers.

For activity 3, assess the following doses using Charts 5 and 6:
E 75 mSv
$H_{thyroid}$ 80 mSv
$AD_{red\ marrow}$ 0.05 Gy (50 mGy)
H_{fetus} 120 mSv

The answer is: **Health Concerns**

This level means that the danger to health is very low. However, there is a possibility of doses exceeding the international criteria that call for taking protective actions and other response actions to include medical screening in order to further assess: (a) the small possible risk to pregnant women (fetus) and (b) the small possible increase in the risk of radiation induced cancers.

Minimum Response Capabilities Checklist

Module 11

Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

IAEA

International Atomic Energy Agency

Lecture: L-11 Minimum Response Capabilities Checklist

Purpose: To explain the minimum response capabilities checklist provided in Table 17 of the publication EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013.

Learning objectives: Upon completion of this lecture, participants will:

- be familiar with the purpose and use of the Minimum Response Capabilities Checklist provided in Table 17 of EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013;
- state which item on the list is the priority;
- understand the importance of anyone living within the PAZ or UPZ receiving a warning and instructions on the urgent protective actions to take within about 1 hour of detection of conditions indicating actual or projected damage to fuel (EAL for declaration of General Emergency exceeded);
- be able to explain the steps taken in their region/ country for instructing and warning members of the public.

Duration: 1 hour

Module 11 – Introduction

- To explain the Minimum Response Capabilities Checklist
- Found in Table 17 of EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013

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Objectives of Module 11

- To familiarize participants with the checklist
- To know which item on the list is the priority
- Activity: participants will have the opportunity to share emergency preparedness and response arrangements in their region/country with the group

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Introduction – checklist

- Assess the readiness in the event of an emergency, should it take place tomorrow
- Identify where improvements may be required
- Identify which capabilities should be priority
- Assist in the development of an *interim* capability

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The purpose of the Minimum Response Capabilities Checklist (Table 17 in Section 8 of the IAEA publication EPR-NPP PUBLIC PROTECTIVE ACTIONS, 2013) is to:

- assess the readiness in the event of a severe reactor or spent pool fuel emergency should it take place tomorrow
- identify where improvements may be required
- identify which capabilities should be a priority
- assist in the development of an *interim* capability.

Most important from the checklist:

- Anyone living **within the PAZ or UPZ** will **receive a warning** and instructions on the urgent protective actions to take within **about 1 hour** of detection of conditions indicating actual or projected damage to fuel (EAL for declaration of General Emergency exceeded).

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Precautionary Action Zone (PAZ), Urgent Protective Action Planning Zone (UPZ) and Emergency Action Levels (EALs).

Why is this important?

- IAEA is concerned that the public will not be promptly notified of the urgent protective actions to take.

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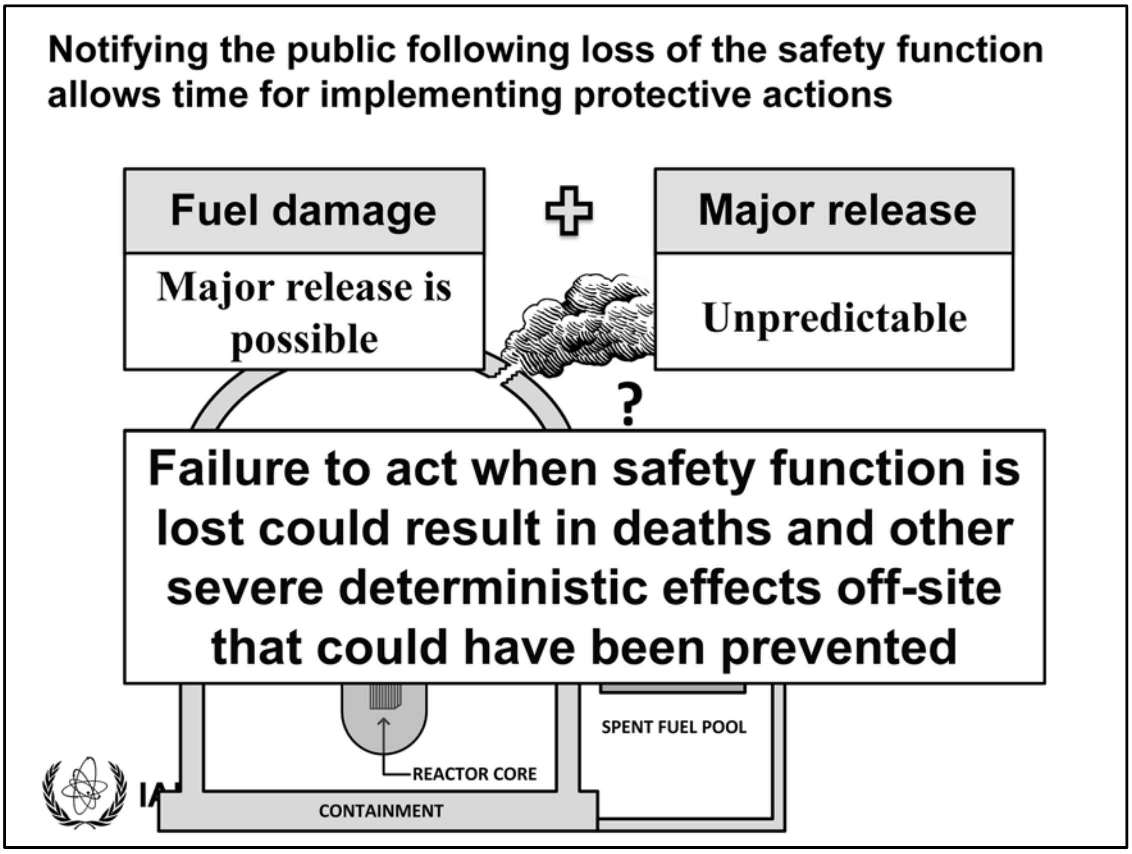

As indicated in Module 6, severe health effects off-site can occur if there is damage to the fuel in the core or spent fuel pool resulting in a major release. To be most effective, protective actions should be taken before the release occurs. Failure to carry out protective actions could result in deaths or other severe deterministic that might have been prevented. We can predict damage to fuel based on loss of safety functions which would occur before release. However, failure of the containment resulting in a release is unpredictable. Therefore, to best ensure that protective actions are initiated before a release, it is necessary to take action when the loss of the safety function is detected.

Example of steps taken – procedures for an NPP in U.S.A.

Local officials are required to notify the public within approximately 15 minutes of an event that may require the public to take protective actions.

The steps are:

1. Operator notifies local emergency response centre – staffed 24 hours a day, 7 days a week
2. Local emergency response centre authenticates notification (calls operator back to confirm emergency)

This slide provides an example of the steps taken for notifying the public for one of the nuclear power plants in the U.S.A. It can be used to help the lecturer explain the activity on the previous slide to participants.
For this particular NPP, local officials are required to notify the public within approximately 15 minutes of an event that may require the public to take protective actions.

- The operator notifies the local emergency response centre – staffed 24 hours a day, 7 days a week
- The local emergency response centre authenticates notification (calls the operator back to confirm the emergency).

Example of steps taken – procedures for an NPP in U.S.A

3. Local officials are notified by the local emergency response centre
4. Emergency sirens located within 16 km alert the public to turn on radio or television and listen for further instructions (considers meteorological conditions and time of day)
5. Emergency services vehicles equipped with public address systems also alert public

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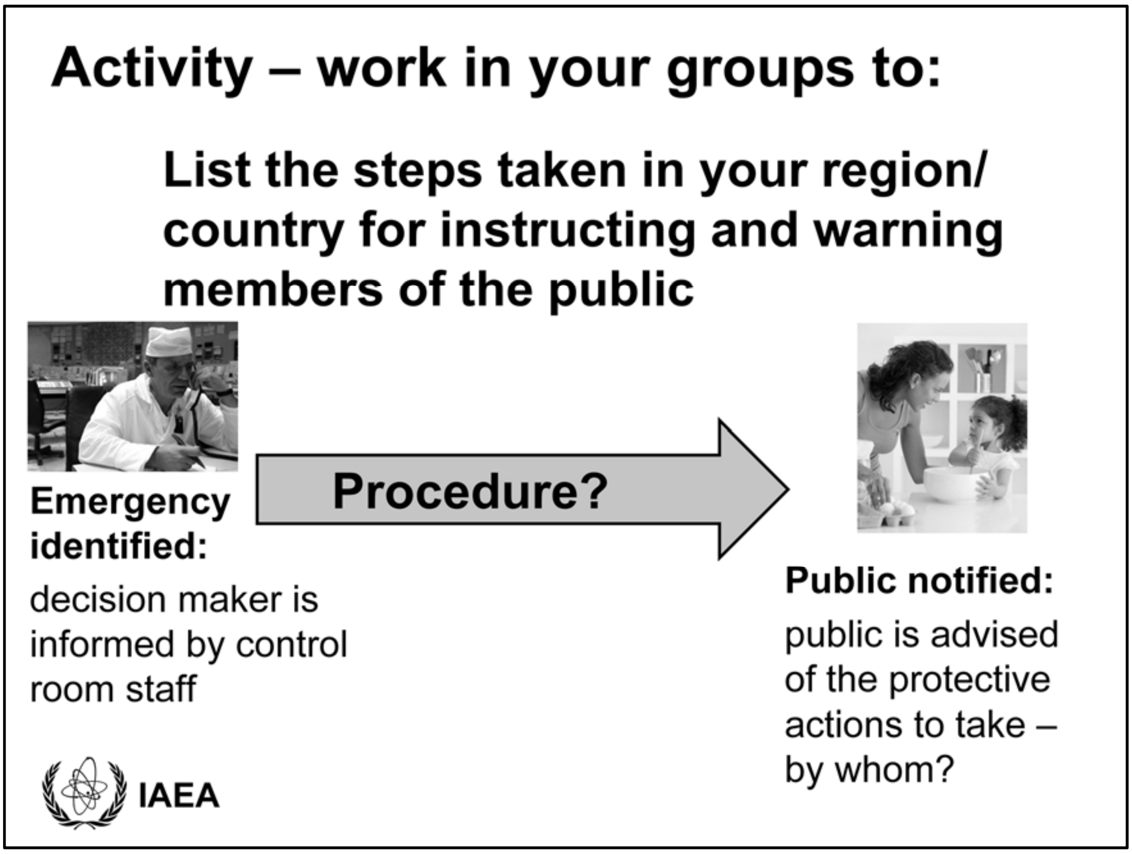
- Local officials are notified by the local emergency response centre
- Emergency sirens located within 16 km alert the public to turn on radio or television and listen for further instructions (instructions are given based on meteorological conditions and the time of day of the emergency – adverse weather (e.g. snow) evacuation may be required to be delayed until safe evacuation is possible. An emergency during the day when children are at school will require instructions on evacuation advising parents they are not required to collect their children from school. Parents should proceed to evacuate the area, as arrangements are in place for the children's evacuation and they will meet at the predesignated evacuation shelter.
- Emergency services vehicles equipped with public address systems also alert public

References: Dominion, Nuclear Emergency Preparedness,
https://www.dom.com/about/stations/nuclear/emergency-plans/index.jsp
https://www.dom.com/about/stations/nuclear/millstone/pdf/millstone_guidebook.pdf



Note to lecturer: Ask participants to work groups to:

– List the steps taken in their region/ country for instructing and warning members of the public.
– Consider the interval starting when the emergency is first identified and the time when the public is notified – who is responsible for launching the response?

Note to lecturer: Use the previous slide to help explain the activity to participants. It provides an example of the steps taken for an NPP in the USA for notifying the public.
Do not show the next 3 slides on 'strategies for notifying the public' until after the group discussions have been completed and the findings shared. The lecturer should give participants 15-20 minutes to discuss the different steps taken in their region/ country for instructing and warning members of the public. The lecturer should then ask a lead member from each group to share the findings of their group with all participants. It could be helpful for the lecturer to stand at the front of the room and write down the findings for everyone to read and take notes.

Picture by: *Dana Sacchetti and Gill Tudor*
http://www.iaea.org/newscenter/focus/chernobyl/25years/

Strategies for notifying the public

- Pre-distributed information on emergencies provided to the public
- Alarms and sirens
- Announcements possibly made in local languages (but with consideration given to the effective use of resources and also on how to inform those in the area that may not understand the language the announcement is being made in)

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Note to lecturer: Do not show these slides to participants until after the group discussion – the next 3 slides present 'strategies for notifying the public' that have been identified from group discussions during previous training courses.

Strategies for notifying the public

- Radio
- Identify the most popular (highest viewer rating) television channel
- Social media
- Use of mobile telephone device and GPS technology – to identify those within a specific geographic area
- Provide an optional emergency alert system for the public to sign up to

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Strategies for notifying the public

- Pre-establish triggers for on-site staff taking the step of notifying off-site authorities
- Set a target time for notification procedures to be completed (on-site and off-site)
- Establish an off-site notification point that is manned 24/7
- Draw up a checklist of procedures to be followed by off-site officials and target time for taking decisions
- Establish a dedicated communication system between local and national levels of government

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Conclusion

- Highest priority – Point One on the checklist:
- Ensure decisions can be made **quickly**
- And that the public is notified **fast**

- Checklist is a tool to identify where improvements may be required
- Test *interim* arrangements with drills and exercises

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The checklist in Table 17 is designed to assess readiness in the event of an emergency relating to a reactor core or spent fuel pool if it occurs tomorrow. The aim is to identify where improvements may be required and assist in the rapid development of the interim capability.

TABLE TOP

Lecture: Table top

Purpose:
The purpose of the table top is to provide an opportunity to apply the guidance provided in the EPR-NPP Public Protective Actions publication and in the associated training material.

Learning objectives:
The table top will give the participants a hands-on experience of the off-site decision making during a severe Nuclear Power Plant emergency, and how the guidance provided in the EPR-NPP Public Protective Actions publication and associated training material can be used to achieve an effective protection of the public.

Duration:
5.5 hours (without breaks)

Programme:
- Introduction [1/2 h]
- 1st Phase [1 h]
- 2nd Phase [1 h]
- Feedback and discussion on the 1st and 2nd phases [1 h]
- 3rd Phase [3/2 h]
- Feedback and discussion on the 3rd phase [1/2 h]

Guidelines:
- Introduction — *Instructor:* Use the 'TT-01 Introduction' power point presentation
- 1st and 2nd phase — *Players:* Use the 'TT-02 Player's package' and additional printout of maps
  Instructors: Use the 'TT-02 Instructor's package', distribute the 'TT-02 Message package' based on the simulated time, and prepare the clock
- Feedback and discussion on the 1st and 2nd phases
  Instructor: Use the 'TT-03 What happened' power point presentation
- 3rd Phase — *Instructor:* Use the 'TT-04 Addressing Public Concerns' power point presentation and distribute the 'TT-04 Addressing Public Concerns' word file
- Feedback and discussion on the 3rd phase
  Instructor: Use the 'TT04 Addressing Public Concerns' power point presentation

Author: Phillip VILAR WELTER
Reviewers: Thomas MCKENNA, Brian DODD, Eduardo LURASCHI

Table top
–
Introduction

Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

IAEA
International Atomic Energy Agency

Lecture:
TT-01 Introduction
Purpose:
The purpose of this table top is to provide an opportunity to apply the guidance provided in the EPR-NPP Public Protective Actions publication and in the associated training material .
Learning objectives:
The table top will give the participants a feeling about the development of a severe NPP or spent fuel pool emergency, and how the guidance provided in the EPR-NPP Public Protective Actions publication and associated training material can be used to support the effective protection of the public.

Duration: 0.5 hours
Author: Phillip VILAR WELTER
Reviewers: Thomas MCKENNA, Brian DODD, Eduardo LURASCHI

You (the player) are

The off-site decision maker responsible for protection of the public around South Bend nuclear power plant.

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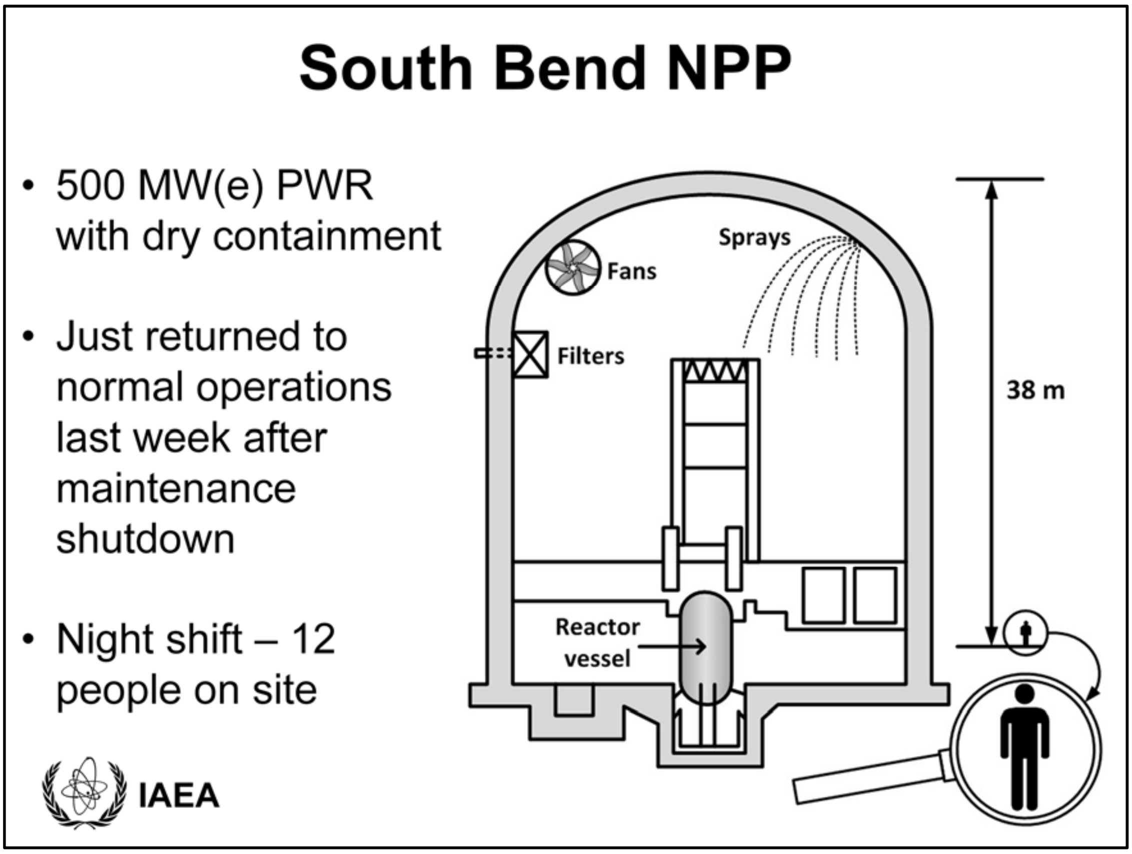

South Bend Nuclear Power Plant is equipped with a standard pressurized water reactor (PWR) of 500 MW(e) (1500 MW(th)) and a dry containment.

Response plan (on-site)

- Procedures for notifying off-site decision makers immediately are in place
- Full activation of the on-site response will take place in about two hours
- Monitoring teams can be deployed within two hours (vehicle borne dose rate monitoring)

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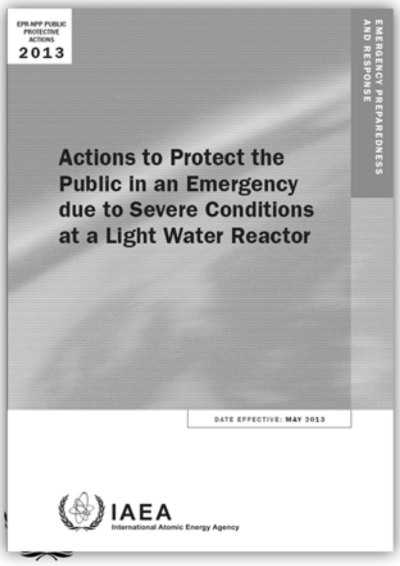
Response plan (off-site)

You are the off-site "decision maker" responsible for the entire response. Take actions such as:



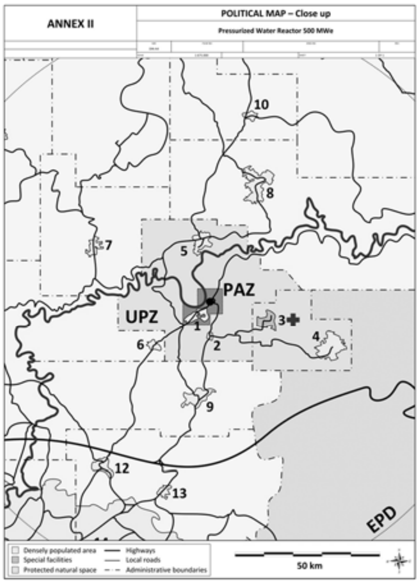
- classifying the emergency
- evacuation
- ITB
- sheltering
- restriction of food, milk and water
- communication with the public
- coordination of monitoring and sampling teams
- keeping other state organizations informed

(in accordance with the EPR-NPP Public Protective Actions publication)

The off-site response plan of South Bend NPP should be implemented in accordance with the EPR-NPP Public Protective Actions Publication, Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor. At this stage of the training course the players should be able to use the tools provided in the aforementioned publication.

Off-site area maps

You will be provided with the following maps:



These maps off-site area maps are included in the "Players' package". Further details, such as the number of inhabitants in each village, will be provided in the players' package.

Local conditions

- Living conditions: similar to those in the Vienna area (central Europe)
- Autumn
- Rain showers in the area are possible

The exercise has been developed assuming living conditions similar to those in central Europe. It is assumed to be a typical continental autumn with a possibility of rain showers at any time.

Responsibilities of the player

- Each group selects a decision maker
- Act as the “off-site decision maker” or his support staff
- Make decisions and respond to requests. Report your decisions to your controller and fill out the decision record (such as those given in Table 4 and 8 of the Manual).

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Responsibilities of the controller

- One controller will be assigned to each group (who will distributes messages at specific time intervals).
- The group can ask its controller for information from the NPP or other organizations. If feasible an answer will be provided after checking with the table top manager.
- Answers (if any) will be consistent with what you would expect during a real emergency!
- The controllers will record the questions and answers on their controller log.

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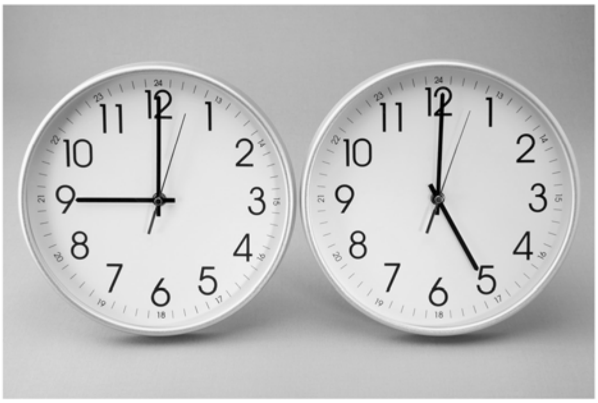
Simulated time

- The table top exercise will run according to simulated time (indicated on the screen)
- The 'speed' of the simulated time will be 1 to 1 to real time. There will be jumps in time during the breaks (you will be informed when this happens)



IAEA

The simulated time will be displayed in the course of the exercise. The player's and controller's packages are based on the simulated time.

Phases of the table top exercise

The exercise will be divided into three phases:

- **1st Phase**
- **2nd Phase**

Lunch break

- Feedback and discussion on the 1st and 2nd phases
- **3rd Phase**
- Feedback and discussion on the 3rd phase

IAEA

The table top exercise will span a whole day and will be divided into 3 phases, representative of the response during a severe emergency at an LWR or RBMK reactor or spent fuel pool.

Players, please open the *Player's package,* and organize into groups, arrange your seating and select a decision maker.

Controllers, open the C*ontroller's package*, prepare the *Message packets,* distribute printouts of maps and set the clock.

The table top will start in 10 minutes

IAEA

International Atomic Energy Agency

Players should be organized into small groups (e.g. 4–6 people).

TT-02 PLAYERS' PACKAGE

for the 1st and 2nd Phases of the Table top

Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

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Overview

Plant:

- South Bend Nuclear Power Plant (NPP)
- PWR with dry containment 500 MW€ (1500 MW(th))
- Just returned to normal operations last week after maintenance shutdown
- Night shift – 12 people on the site
- Procedures for notifying off-site officials immediately are in place
- The on-site response in fully activated in about two hours
- Monitoring teams can be deployed within two hours (vehicle borne dose rate monitoring).

Local conditions:

- Living condition - similar to those in the Vienna area (Central Europe)
- Autumn
- Rain showers in the area
- Weather data (wind direction and speed at NPP) will be provided by the plant operator.

Conduct of table top:

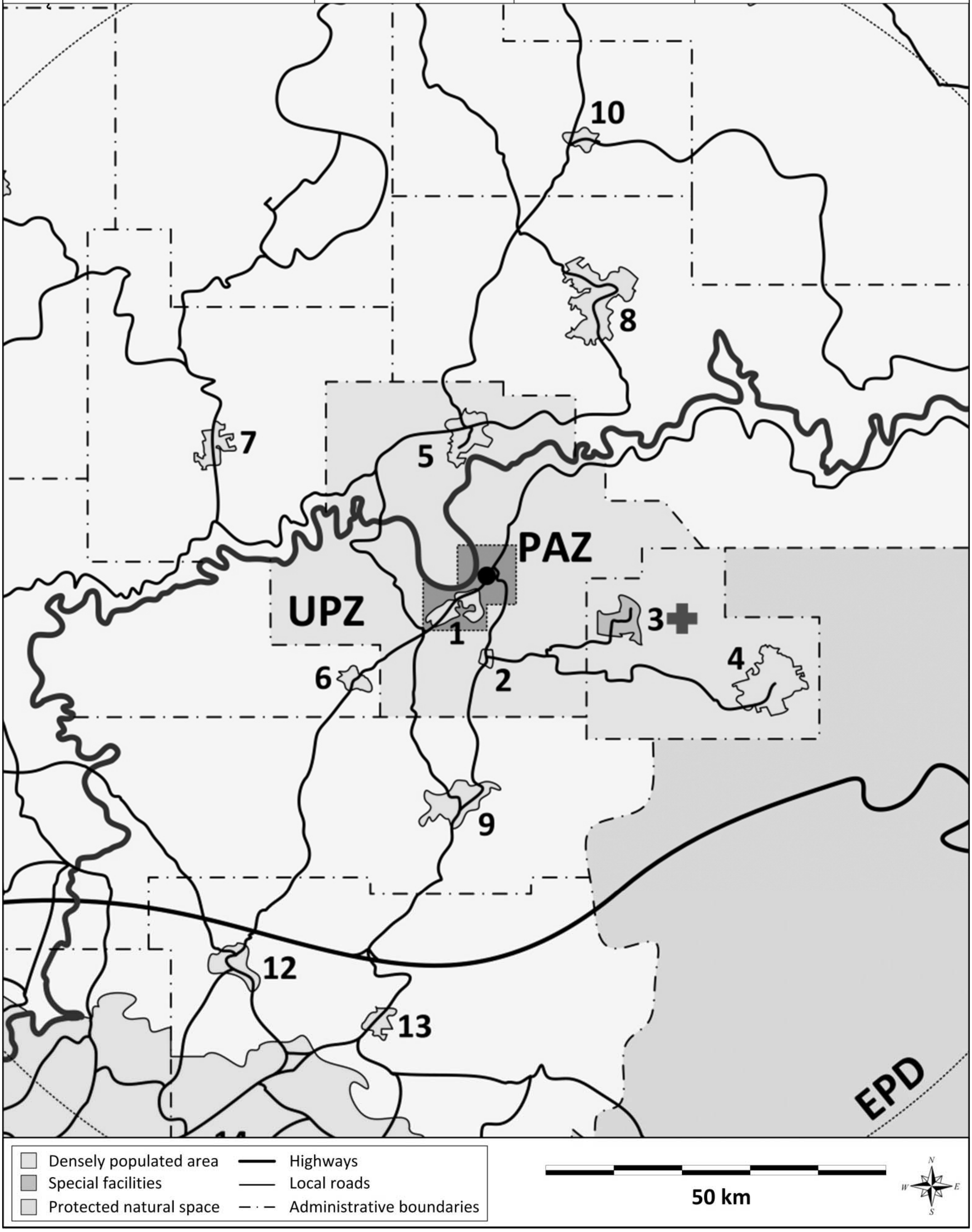
- Each group selects a decision maker
- Fill out the decision record by tracking the simulated time and the decision (such as those given in Tables 4 and 8 of the EPR-NPP Public Protective Actions document).
- One controller will be assigned to each group (distributes messages).
- The group can ask its controller for information from the NPP. If feasible, an answer will be provided after checking with the Table top manager. The controllers will record the questions and answers on their **Controller log.**

Decision maker record

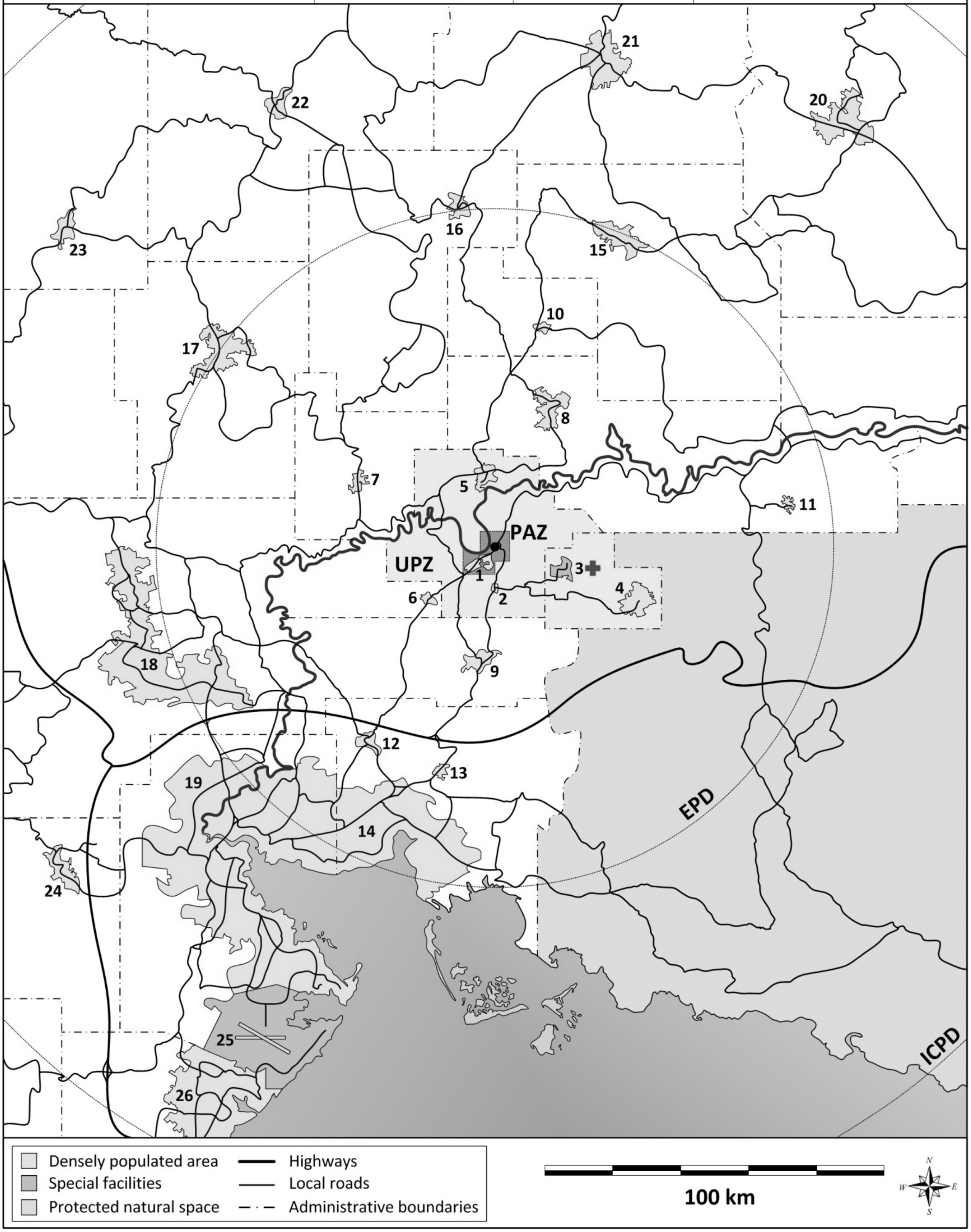
Action/decision taken by the decision maker	Simulated time

Action/decision taken by the decision maker	Simulated time

HANDOUT I	POLITICAL MAP – Close up			
	South Bend NPP (PWR 500 Mwe)			
	SIZE DIN A4	FSCM NO	DWG NO	REV
	SCALE 1:675.000		SHEET 1 OF 1	

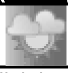
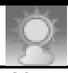
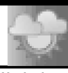


HANDOUT II	POLITICAL MAP
	South Bend NPP (PWR 500 Mwe)
	SIZE DIN A4 · FSCM NO · DWG NO · REV
	SCALE 1:1.350.000 · SHEET 1 OF 1



Weather predictions

Weather predictions

Day	1(today)	2	3	4	5	6	7
Weather:							
Description:	High level clouds	More sunny than cloudy	Mostly sunny with rainy intervals	Light rain	Flurries with more clouds than sun	High level clouds	Sprinkles and mostly cloudy
	Cool	Cool	Cool	Cool	Chilly	Chilly	Cool
High temperature [°C]:	17	16	17	12	6	8	11
Low temperature [°C]:	3	5	5	2	0	-3	3
Wind Speed [km/h]:	8	6	11	14	14	8	10
Wind Direction:	↙	↘	↘	↓	↓	↗	↖
Humidity [%]:	67	76	67	42	38	30	74
Chance of rain/snow [%]:	0	0	36	39	21	0	38
Amount Rain [mm]:	-	-	1.2	1.4	1.6	-	1.1
Amount Snow [mm]:	-	-	-	-	7.3	-	-
Sunrise:	07:29	07:30	07:32	07:33	07:34	06:36	06:38
Sunset:	17:52	17:51	17:49	17:47	17:45	16:44	16:42

Additional data

Towns and facilities	Population estimate
1	400
2	100
3 Hospital	300
4	100
5	500
6	200
7	200
8	110
9	800
10	100
11	100
12	400
13	200
14	9100
15	1900
16	800
17	2100
18	8400
19	13400
20	3600
21	3400
22	900
23	900
24	1500
25 Airport	2200
26	5900

3rd Phase of the Table Top Exercise

TT-04 Addressing public concerns

Training Course on Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor

Addressing public concerns

Under the assumption that there has been a release of radioactive material from South Bend NPP and that the appropriate urgent protective and other response actions have been implemented, provide a detailed answer for the following questions asked by the public, the media and decision makers. You will be asked to provide a public briefing on any of these questions in 1 hour:

1. **Medical doctor**: My patient shows 6 µSv/h at 10 cm from bare skin. Can I treat him?
2. **Mayor:** Around 10 000 µSv/h is being consistently measured in my district. Should I advise to take ITB?
3. **Concerned pregnant woman:** I have consumed milk from a farmer for 2 weeks that has now been restricted due to contamination. The content of cesium in the milk is 2 Bq/g. I do not want my child to be born with birth defects. Should I have an abortion?
4. **Mayor:** My town was evacuated early on in the emergency. More recent monitoring results indicate only a dose rate of 3 µSv/h at 1 m above ground. Is it safe to return to the town?
5. **Concerned citizen:** I was monitored with 10 µSv/h at 10 cm from bare skin. I have washed my skin many many times, but it has become very sensitive. I am scared. What should I do?
6. **Concerned parent:** My daughter had a skin contamination of 0.0005 mSv/h. Will she get cancer?
7. **Reporter:** 0.01 mSv/h is being measured at the main gate of the power plant shortly after the declaration of a general emergency. Is it safe to stay there?
8. **Mayor:** Only three vehicle borne monitoring results exceed OIL1 in Northbend-Village (approx. 3000 persons). Another five monitoring results are below OIL2. Where should I implement the protective actions warranted by OIL1?
9. **Citizen living in the PAZ:** I did not leave the PAZ despite the evacuation order because I am only measuring 10 µSv/h at 1 m above ground and your charts tell me I am safe. Why should I leave?
10. **Mayor:** No more than 10 µSv/h at 1 m above ground is being measured in this neighbourhood. Is it safe to live there?
11. **Mayor:** Prof. Rosenspitz pointed out in the beginning of the emergency that about 500 000 people could get cancer due to the long term effects of radiation. Is this true?!!! And what about the 100 mSv he was talking about?
12. **Concerned parent:** My daughter drank at least 3 litres of contaminated water with 3 kBq/kg of Cs-137. Will she be able to have babies in the future?
13. **Hospital manager in the UPZ:** Many members of staff and all patients who are able to are leaving. Should we evacuate the critically ill?