Overview of Radiological Dose and Risk Assessment

Karen P. Smith
Environmental Science Division
Argonne National Laboratory

IAEA Training Course on Nuclear Facility Decommissioning & Environmental Remediation Skills

Held at Argonne, Illinois

4 – 15 April 2011

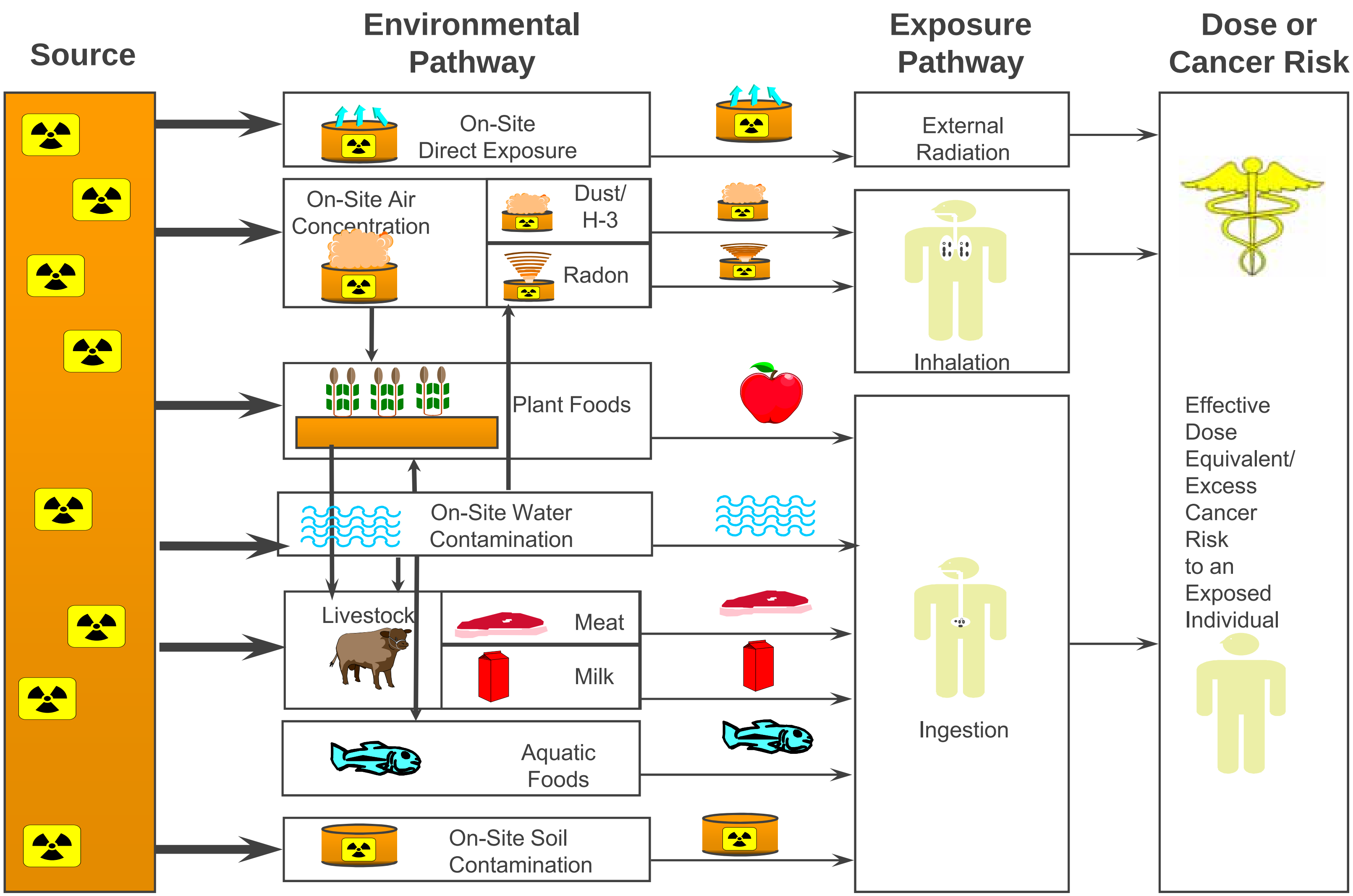
What is Radiological Dose Assessment?

- A radiological dose assessment calculates the amount of radiation energy that might be absorbed by a potentially exposed individual as a result of a specific exposure.
- External doses occur when the body is exposed to radioactive material outside the body; this is primarily a concern for gamma radiation.
- Internal doses occur from exposure to radioactive material taken into the body by inhalation or ingestion; this is a concern for alpha and beta radiation, as well as gamma radiation.
- Depending on the radionuclide, the dose can be localized to specific organs, or distributed across the whole body.

Radiological Dose Assessment Terminology

- Absorbed dose is measured in amount of energy absorbed per unit mass:
  - 1 rad = 100 erg/g
  - 1 gray (Gy) = 1 J/kg
  - 1 Gy= 100 rad
- Equivalent dose is a measure of the biological damage to living tissue resulting from exposure:
  - Expressed in units of rem or Sievert (Sv) (1 Sv = 100 rems)
  - For gamma and beta radiation: 1 rad = 1 rem = 0.01 Sv
  - For alpha radiation: 1 rad = 20 rems = 0.2 Sv
  - 1 mrem = 0.001 rem; 1 mSv = 0.001 Sv
- Effective dose is:
  - A measure of the whole body dose
  - The sum of the doses from both external and internal exposures

Pathway Analysis is Used to Calculate Radiological Dose



What Health Effects Can Result from Radiation Exposure?

- Detrimental effects of ionizing radiation include:
  - Carcinogenesis (can cause cancer)
  - Mutagenesis (can cause mutations in cells)
  - Teratogenesis (can cause birth defects)
  - Acute toxicity (can kill you)
- Large doses of radiation (600,000 – 1,000,000 mrem [6 – 10 Sv]) can cause severe health effects, including death.
- At normal environmental and occupational levels, the most important effect is the increase in the *potential* for developing a latent fatal cancer. (Latent means the cancer manifests itself later in life, long [often years] after the exposure to radiation occurs.)

Radiological Dose Limits

- International agencies have established recommended dose limits for both workers and the general public for different types of activities.
- National regulations have been adopted in many countries based on these recommendations.
- It is commonly accepted that efforts should be undertaken at all times to keep radiological doses "as low as reasonably achievable," which is referred to as the ALARA principle or requirement.
- Average exposure to natural sources of radiation in the U.S. is 3 mSv/yr (300 mrem/yr) – mostly from cosmic radiation and radon.
- Additional exposure can result from medical procedures (exposure from a chest x-ray is 0.1 mSv [~10 mrem]; a CT scan is 15 mSv [~1,500 mrem]).

Worker and Public Effective Dose Limits under Normal Operations (Planned Activities or Practices)

	IAEA	ICRP	EU
General Public	≤ 1 mSv/yr	≤ 1 mSv/yr	≤ 1 mSv/yr
Licensed Workers (over 18 yrs)	≤ 20 mSv/yr	≤ 20 mSv/yr	≤ 100 mSv over 5 consecutive yrs
Reference	Basic Safety Standards (Safety Series No. 15)	ICRP Pub. 60 & Pub. 103	96/29/Euratom Basic Safety Standards

For perspective: background in the U.S. is ~3 mSv/yr; an x-ray is ~0.1mSv, a CT scan is ~15 mSv.

U.S. Nuclear Regulatory Commission established a dose limit for license termination of 25 mrem/yr (0.25 mSv/yr) from residual radioactivity.

The general public dose limits are for exposures in addition to background exposures. ICRP recommends ≤ 0.3 mSv/yr from a single activity.

The IAEA and ICRP worker limit is for dose averaged over a defined 5-year period.

In all standards, the worker dose should not exceed 50 mSv in any single year. The limit for workers age 16-18 is 6 mSv/yr.

EU has established more stringent requirements for workers who might receive an effective dose over 6 mSv/yr (e.g., training, monitoring, recordkeeping).

EU proposes public limit of 0.3 mSv/yr for exposures from NORM industries (2009).

What is Radiological Risk Assessment?

- A radiological risk assessment is an estimate of the probability of a fatal cancer over the lifetime of an exposed individual.
- Radiation cancer health risks are expressed in terms of mortality (death) and morbidity (incidence).
- A risk of 1 x 10^{-4} means the potential for an exposed individual to have a fatal cancer is one in 10,000 or 0.0001.
- Some considerations:
  - The relationship between dose and development of cancer is well characterized for high doses of most types of radiation.
  - For lower doses, it is not well defined.
  - Risks from low levels of radiological exposure are estimated by extrapolating from data available for high dose exposures.
  - Risk estimates are typically based on a linear/no-threshold model (LNT) that assumes there is no level below which radiological doses are safe.

Dose to Risk Conversion

- Radiological dose can be converted to carcinogenic risk using radionuclide-specific risk coefficients (also called slope factors) developed by the U.S. EPA.
- Often the risk is calculated by applying a dose-to-risk conversion factor to the effective dose (the whole body dose).
- Dose-to-risk conversion factors are identified by organizations such as the International Commission on Radiological Protection (ICRP) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).
- Sample calculation:
  - Dose = 2.2×10^{-4} Sv
  - Dose-to-Risk Conversion Factor for Cancer Mortality = 5×10^{-2} per person-Sv
  - Risk of Cancer Mortality = (2.2×10^{-4} Sv) × (5×10^{-2} /Sv) = 1×10^{-5}

Many Different Types of Decisions Are Supported by Radiological Dose and Risk Assessment

What needs to be done to manage risk?

- Operational controls
  - What operational controls are needed to ensure radiation exposures are safe and acceptable?
  - Time limitations
  - Access controls
  - Personal protective equipment
  - Storage requirements

Many Different Types of Decisions Are Supported by Radiological Dose and Risk Assessment (cont.)

What needs to be done to manage risk?

- Remediation / decontamination objectives
  - How clean is clean?
  - What are the likely future uses of the site?
  - Can these be controlled?
  - How much remediation / decontamination is needed to ensure doses to future site users are low enough?

Many Different Types of Decisions Are Supported by Radiological Dose and Risk Assessment (cont.)

What needs to be done to manage risk?

- Remediation / decontamination actions
  - How do we get the site clean enough?
  - How effective will different remediation actions be in terms of limiting future radiation exposures?
    - Do nothing
    - Capping in place
    - Excavation
    - Burial
    - Entombment
    - Landfill
    - Groundwater pump and treat

Many Different Types of Decisions Are Supported by Radiological Dose and Risk Assessment (cont.)

What needs to be done to manage risk?

- Treatment, storage, and disposal facility design and operation
  - What are the necessary design and operation features for a facility
    - Protection of workers
    - Protection of the general public
    - During operations
    - Post facility closure

Many Different Types of Decisions Are Supported by Radiological Dose and Risk Assessment (cont.)

What needs to be done to manage risk?

- Addressing uncertainty (sensitivity analyses)
  - What is the uncertainty associated with key site and/or waste parameters?
  - What do we not know enough about in order to make reliable decisions?
- Risk-based standards and regulations
  - What are the appropriate management and cleanup requirements based on potential risk?

What Information is Needed to Conduct These Assessments?

- Characteristics of the source material
  - Specific radionuclides
  - Chemical and physical form
  - Concentration
  - Volume
  - Containment
- Physical setting and location
  - Distribution of the contamination
  - Hydrologic and geologic setting
  - Meteorological setting
  - What is the population density around the site?

What Information is Needed to Conduct These Assessments? (cont.)

- **Exposure Scenarios**
  - Which workers might be exposed?
  - What is the nature of the workers' activities?
  - How might members of the general public be exposed?
    - During remediation or D&D
    - Following closure of the site
  - What are the potential future uses of the site?
    - No future use
    - Agricultural
    - Recreational
    - Industrial
    - Residential
  - Intruder scenarios

What Information is Needed to Conduct These Assessments? (cont.)

- **Exposure Scenarios (cont.)**
  - What are the possible environmental pathways?
    - Onsite direct exposure
    - Surface water or groundwater contamination
    - Soil contamination
    - Plant uptake or ingestion by animals
  - What are the possible exposure pathways?
    - External radiation
    - Inhalation
    - Ingestion

Examples of Available Radiological Dose and Risk Assessment Tools

- RESRAD (RESidual RADioactivity) – Argonne
- TSD-DOSE (Treatment, Storage, Disposal) – Argonne
- RISKIND and RADTRAN (transportation) – Argonne and Sandia National Laboratories
- SimER (Simulation of Environmental Risks) – UK National Nuclear Laboratory
- ReCLAIM – UK National Nuclear Laboratory
- U.S. EPA models: CAP88, COMPLY, PRESTO, GENII-NESHAPs, DCAL
- SAFRAN (Safety Assessment Framework) – Facilia