IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Occupational Radiation Protection during High Exposure Operations

Sources of High Exposure Operations

Contents

- Nuclear accident sources
- Radiological accident
- Transport accident sources

NPP accidents

- Accident scenario (LWR – TMI or Fukushima):
  Reactor decay heat is not removed
  Release from the core to the containment
  Release from the containment to the environment

  Chernobyl (RKBM): Direct release of fuel to the environment including volatile product and non-volatile fission products and fuel particles

Radionuclides

- Longer lived radionuclides built up in the fuel with operation (for example, Cs which is volatile at high temperature)

- Short lived – Quick decay after shut down (volatile I, Te, most of noble gases)

Release from the core to the containment volatiles and non-volatiles (NUREG – 1465)

Noble gases:	**100 %**	**Xe, Kr**	
Halogens:	**40 %**	**I, Br**	**Note: Iodine - 95 % in particulate, 4.85% elementary and 0.15 % in organic form**
Alkali metals:	**30 %**	**Cs, Rb**	
Tellurium group:	**5 %**	**Te, Sb, Se**	
Barium, Strontium:	**2 %**	**Ba, Sr**	
Noble metals:	**0.25 %**	**Ru, Rh, Pd, Mo, Tc, Co**	
Lanthanides:	**0.02 %**	**La, Zr, Nd, Eu, Nb, Pm, Pr, Sm, Y, Cm, Am**	
Cérium group:	**0.05 %**	**Ce, Pu, Np**	

(Accident Source Terms…., NRC, 1995)

Radiological accidents

Uncontrolled dangerous source

- The categorization system is based on the concept of “dangerous sources” which are quantified in terms of “D values” (see RS-G-1.9.”Categorisation of Radioactive Sources)
- The D value is the radionuclide specific activity of a source which, if not under control, could cause severe deterministic effects for a range of scenarios that include both external exposure from an unshielded source and internal exposure following dispersion of the source material.
- The D_1-value is the activity of radionuclide in a source that, if uncontrolled but *not* dispersed, might result in an emergency that could cause severe deterministic health effects by external exposure
- The D_2-value is the activity of radionuclide in a source that, if uncontrolled and dispersed, might result in an emergency that could cause severe deterministic health effects by internal and external exposure
- The D-value is the lowest-value of the D_1 - and D_2 -values for a radionuclide

Minimal values of activity which can induce deterministic effects (D_1-, D_2-, D-values)

Radionuclide	D_1-value [TBq]	D_2-value [TBq}	D-value [TBq]
^{3}H	Not	2000	2000
^{32}P	10	20	10
^{60}Co	0.03	30	0.03
^{90}Sr	4	1	1
^{131}I	0.2	0.2	0.2
^{137}Cs	0.1	20	0.1
^{192}Ir	0.08	20	0.08
^{210}Po	8000	0.06	0.06
Natural U	Not	Not	Not
^{235}U (enriched <10%)	0.0008	0.0008	0.0008
^{238}Pu	300	0.06	0.06
^{239}Pu	1	0.06	0.06
^{241}Am	8	0.06	0.06
^{252}Cf	0.02	0.1	0.02
^{239}Pu-^{9}Be	1	0.06	0.06
^{241}Am-^{9}Be	1	0.06	0.06

Uncontrolled dangerous source

The IAEA has established 5 dangerous categories of sources corresponding to ratio activity of source to D-value, A/D:

I	A/D ≥ 1000	Extremely dangerous to the person
II	1000 > A/D ≥ 10	Very dangerous to the person
III	10 > A/D ≥ 1	Dangerous to the person
IV	1 > A/D ≥ 0.01	Unlikely to be dangerous to the person
V	0.01 > A/D	Most unlikely to be dangerous to the person

IAEA's Categorization of radioactive sources

Dangerous category of sources	Activity ratio A/D	Source	Typical radionuclide
I	A/D ≥ 1000	Radioisotope Thermoelectric Generator - RTGs Irradiators, Tele-theraphy Gamma-knife	^{90}Sr, ^{238}Pu, ^{60}Co, ^{137}Cs

Radioisotope Thermoelectric Generator - RTGs

Irradiators

Tele-therapy

Gamma-knife

IAEA's Categorization of radioactive sources

Dangerous category of sources	Activity ratio A/D	Source	Typical radionuclide
II	1000 > A/D ≥ 10	Industrial gamma Radiography H/M dose rate brachytherapy	^{60}Co, ^{75}Se, ^{192}Ir, ^{169}Yb, ^{137}Cs

Industrial gamma Radiography

H/M dose rate brachytherapy

IAEA's Categorization of radioactive sources

Dangerous category of sources	Activity ratio A/D	Source	Typical radionuclide
III	10 > A/D ≥ 1	Fixed industrial gauges that incorporate high activity sources Well logging gauges	^{60}Co, ^{137}Cs, ^{252}Cf, ^{241}Am-Be

Fixed industrial gauges

Well logging gauges

IAEA's Categorization of radioactive sources

Dangerous category of sources	Activity ratio A/D	Source	Typical radionuclide
IV	1 > A/D ≥ 0.01	Low dose rate brachytherapy TL gauges; Portable gauges Bone densitometers; Static eliminators	^{226}Ra, ^{252}Cf, ^{125}I, ^{137}Cs, ^{192}Ir, ^{198}Au, ^{141}Pm, ^{244}Cm, ^{85}Kr, ^{90}Sr, ^{241}Am, ^{252}Cf, ^{226}Ra, ^{241}Am-Be, ^{109}Cd, ^{153}Gd, ^{210}Po

Low dose rate brachytherapy

Portable gauges

Bone densitometers

; Static eliminators

IAEA's Categorization of radioactive sources

Dangerous category of sources	Activity ratio A/D	Source	Typical radionuclide
V	0.01 > A/D and A > Except	Low dose rate brachytherapy-eye, X ray fluorescence devices Electron capture devices Mossbauer spectrometry PET	^{90}Sr, ^{106}Ru-Rh, ^{103}Pd, ^{55}Fe, ^{109}Cd, ^{57}Co, ^{63}Ni, ^{3}H, ^{57}Co, ^{68}Ge

Low dose rate brachytherapy

X ray fluorescence devices

Electron capture devices

Misuse of industrial and medical dangerous source

- In radiological accidents caused by the misuse of industrial/medical dangerous sources, the most important pathways of exposure for the victims are external exposure and inadvertent ingestion.
    - However for the emergency workers, the most important pathways are external exposure and internal contamination.

- Members of searching team should be supplied by
    - individual dose monitors,
    - protective clothes,
    - radiation measuring devices with wide range of dose rates,
    - remote control handling equipment and
    - shielded container.

Uncontrolled dangerous source

- For radiological emergencies, an airborne release of radioactive material is of concern primarily if a dispersible dangerous source is contained in a fire or explosion.
- The distance at which such a release is hazardous depends on many factors such as the size of the source, the amount of material dispersed into the air, its dilution, the movement of the plume and the size and nature of the particles.
- These factor should also be taking into account during an emergency.

- For airborne release from facilities the significant pathways of exposure for personnel are mainly:

  - ✓ External gamma radiation from radioactive material deposited on the ground, called ground shine
  - ✓ Inhalation of radioactive material contained in the plume
  - ✓ Deposition of radioactive material on the skin

Uncontrolled dangerous source

- Radiation monitoring is carried out during emergency actions on site and on zones boundaries:
  - with the aim of preventing transfer of radionuclide,
  - retrospective estimation of applied measures and
  - prospective estimation of occupational doses for planned measures.

- Radiation monitoring is intended for
  - assessment of individual and collective doses,
  - efficiency of emergency response and
  - identification of involved persons needed in medical treatment or follow up.

Transport accident of dangerous source

Two typical situations can occur during transportation:

1)The movement of all radioactive materials according to standards of regulatory, administrative, safety and engineering controls

2)Either deliberate or inadvertent movements of radioactive materials outside of the regulatory and legal framework

- Regulations require that exposure from handling, storage and transport of radioactive material shall be kept as low as reasonably achievable taking into account social and economic factors.
- Also past events and their analysis should be useful for typical source considerations.

Adoption of the INES scale for transport events

Level of INES scale	INES-2008 edition	INES for transport event
7	Major accident	Major accident
6	Serious accident	Severe accident
5	Accident with wider consequences	Accident with significant radiological consequences
4	Accident with local consequences	Accident with appreciable radiological consequences
3	Serious incident	Accident with limited radiological consequences
2	Incident	Incident with complications, affecting safety functions but no release
1	Anomaly	Incident resulting in some disruption of normal transport, without affecting safety functions
0	Below scale	Non-incident (e.g. false alarm)

Transport accident of dangerous source

- When a radiation hazard is suspected or known, it is essential that an inner cordon be established around the radioactive source and all persons be evacuated from within the inner cordon control area.

- The inner cordon should be set up at a distance where the external dose rate level does not exceed 0.1 mSv/h.

- Airborne radioactivity should be measured or estimated in order to set up the area of inner cordon control.

Transport accident of dangerous source

- If the first responder encounters any of the following conditions, the scene is likely to require prompt radiological evaluation to assess the magnitude of the radiation hazards:
    - Radiation level greater than 0.1 mSv/h at distance of 1 m from a surface or object
    - The confirmed detection of neutron radiation that is not from a legal shipment of radioactive materials
    - Contamination indicated by loose, spilled or leaking radioactive materials
- The first responder should establish the location of the radioactive material.
- The next step is to identify the radioactive material.
- The topography of the scene is a critical factor in the determination of the most effective means of seizing the radioactive materials and bringing them under control.