IAEA Technical Meeting
Amman, Jordan

Uranium Exploration and Mining Methods

Radiation Safety Aspects in the Uranium Production Cycle

IAEA
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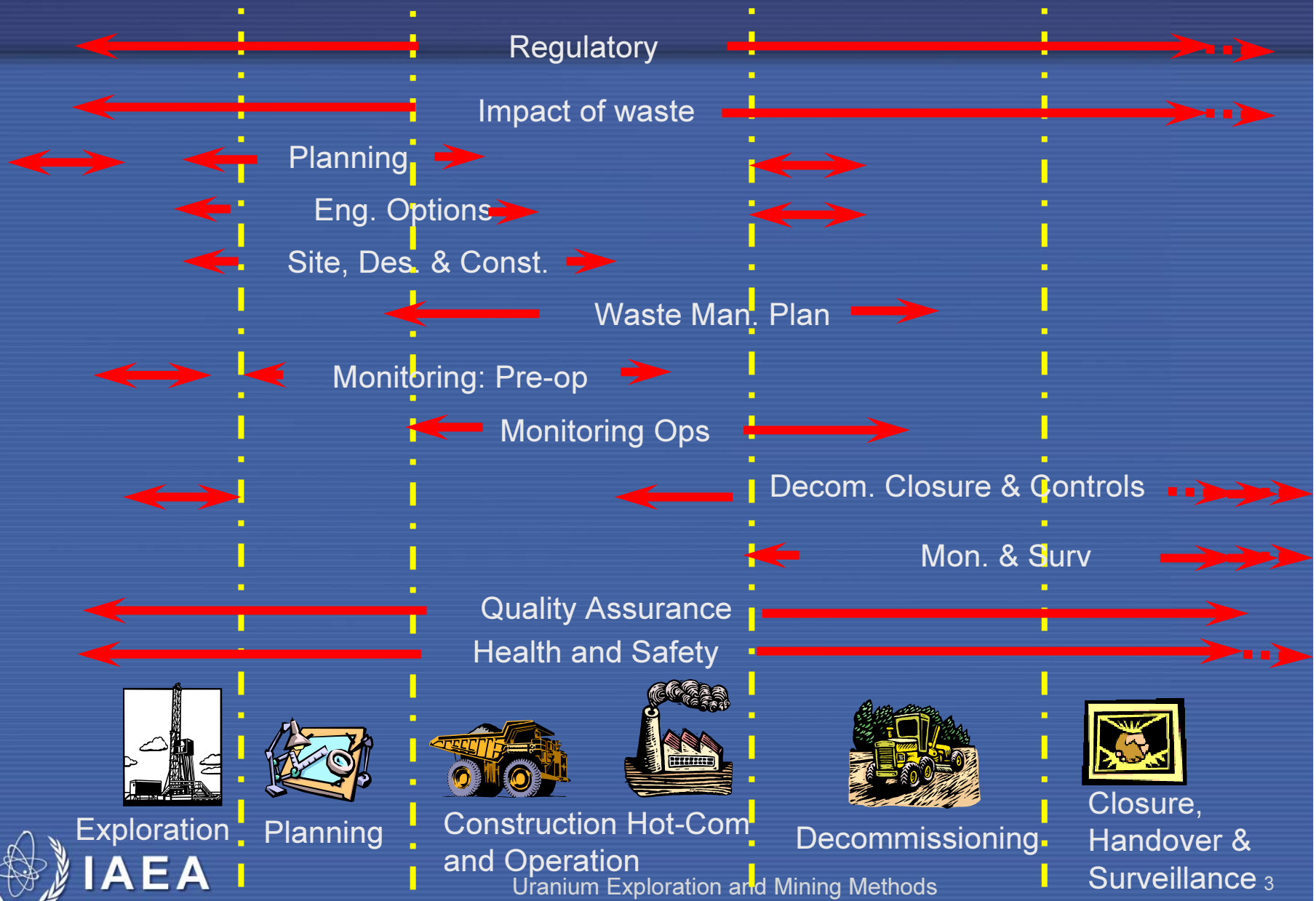
Overview

- Overview of uranium in mining and processing.
- Radiological characteristics.
- Potential health effects.
- Importance of advanced planning for an integrated Safety Culture in the project life cycle.
- Exposure pathways of Workers and the Public.
- Overview of the Radiation Protection Programme.
- Waste management.
- Tailings Siting and Design.

Planning and Safety Timelines: Facility Lifespan

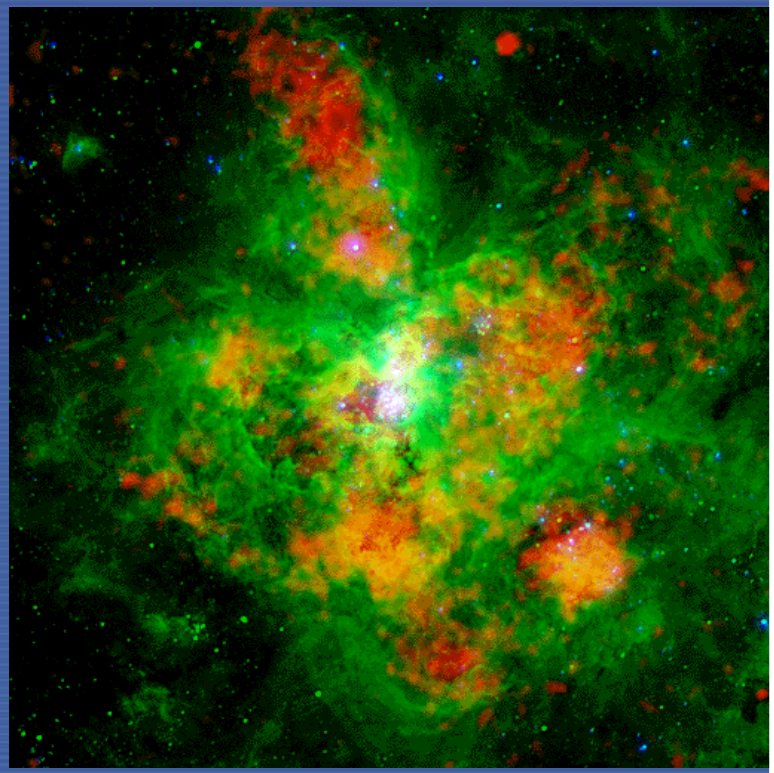


Uranium Mining and Processing

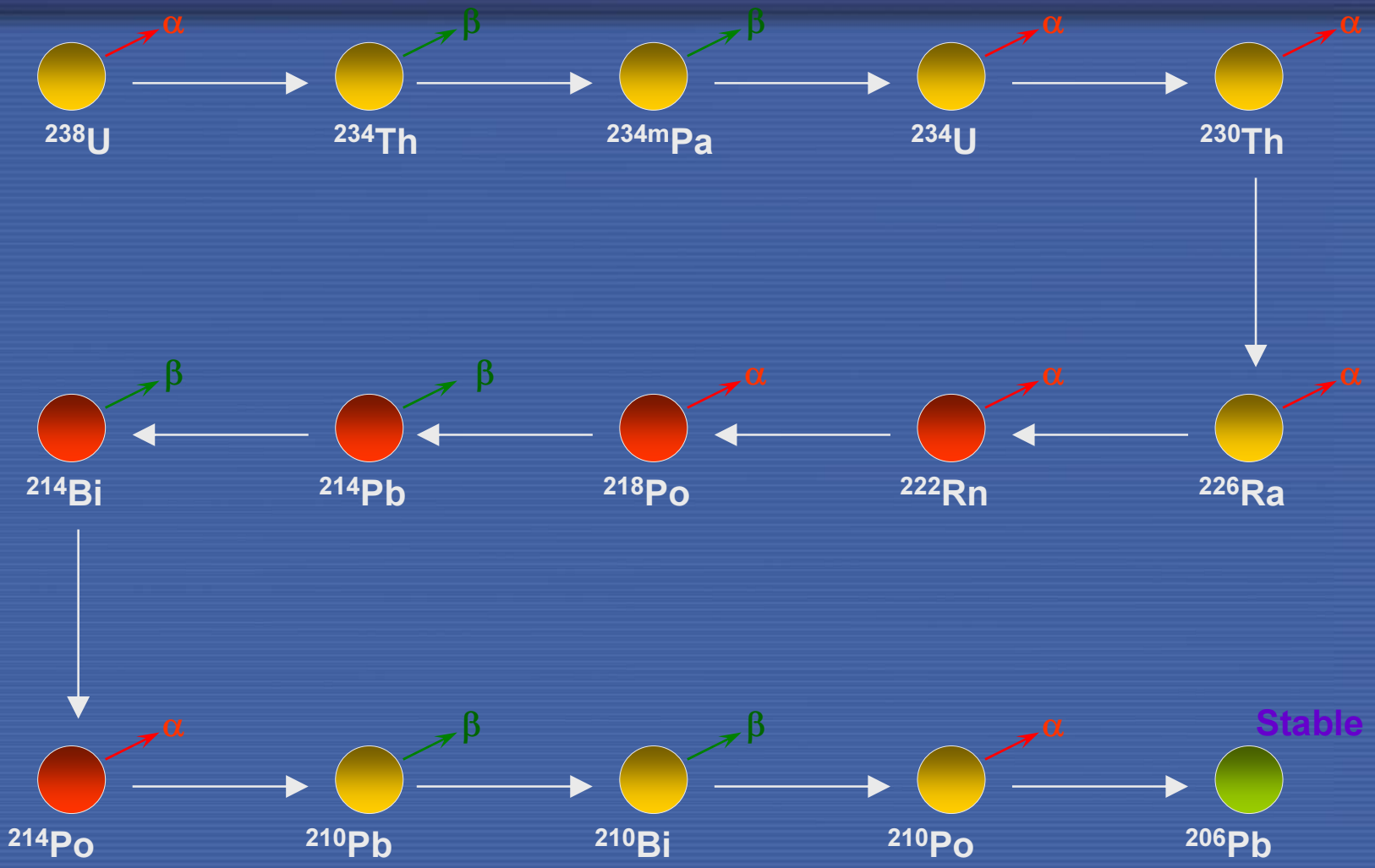
- A variety of methods are used e.g. open pit, underground and ISL.
- A wide variety of ore grades are exploited.
- Can be produced as by-product e.g. gold and copper mines in South Africa.
- Uranium and its residues are radioactive and emit ionizing radiation and are therefore potentially harmful to workers and the public.
- Long term issues with the tailings and waste rock after closure.
- Requires a Planned Lifecycle Safety Culture.
- Public concerns regarding safety.

Uranium and Radiation

- Uranium is a radioactive element
- It emits alpha, beta and gamma radiation
- Long half life of 4.5E9 years
- It is a primordial form of NORM
- In nature it is found in equilibrium with its 13 decay products (e.g. ^{226}Ra, ^{210}Po etc) and decays to stable lead
- Uranium product comprises ^{238}U, ^{234}U, and ^{235}U in their natural proportions
- Uranium product is a poison, its chemical toxicity damages the kidneys.



^{238}U decay chain



The Decay and Emissions of Important Radionuclides of the ^{238}U Decay Chain

Nuclide	Half-life	Mode of Decay
U-238	4.5×10^9 years	alpha
U-234	2.4×10^5 years	alpha
Th-230	7.7×10^4 years	alpha
Ra-226	1.6×10^3 years	alpha
Pb-210	22.3 years	beta
Po-210	138 days	alpha

Note: Alpha emitters are a significant internal hazard.

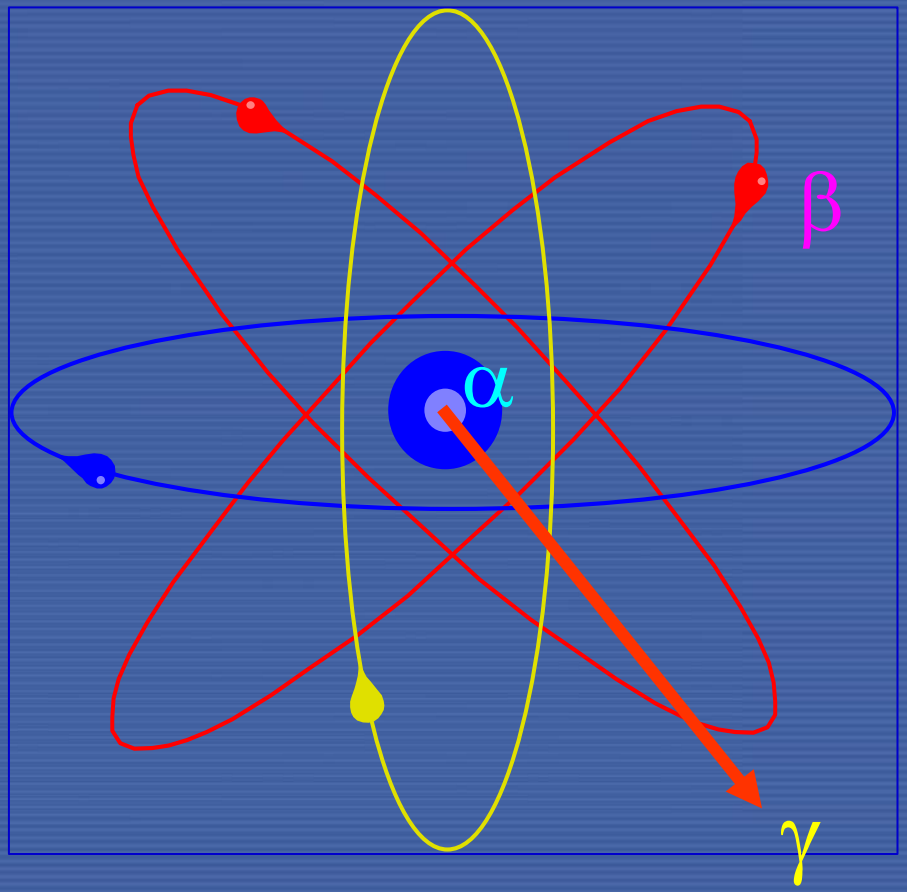
Radiation and Radioactivity

- Radioactivity is the property of certain materials to emit ionising radiation

- There are three principal types of ionising radiation:

  - alpha
  - beta
  - gamma radiation and also X-radiation (which is artificially produced)

  Uranium ores and product materials emit all three types of radiation



Radiation Quantities and Units

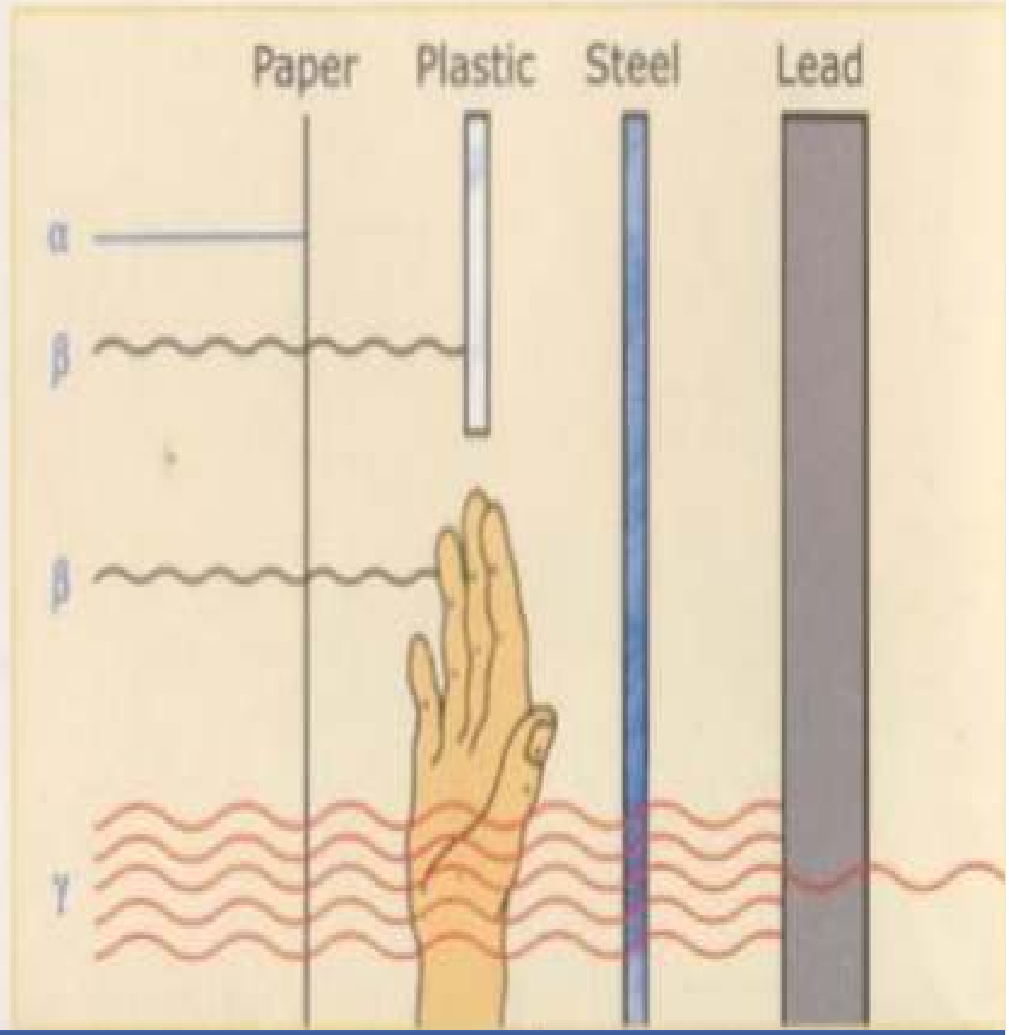
The quantities and units used in radiation protection and safety are based on the SI system for scientific units and are developed by the International Commission on Radiological Units (ICRU).

The main quantities of interest include:

- Activity e.g. the Becquerel (Bq)
- Dose e.g. the Sievert (Sv)

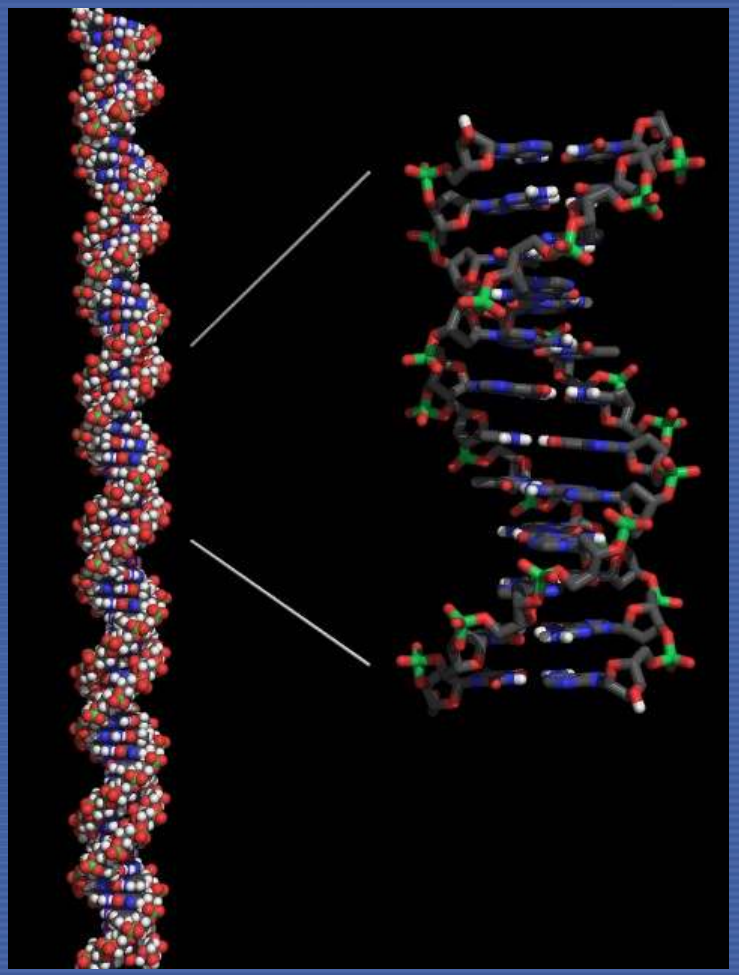
Penetrating Power of Radiation

Alpha particles travel only a few centimetres in air and are incapable of penetrating the skin. Beta particles have a range of more than one metre in air and up to one centimetre in tissue. Gamma rays can be very penetrating. They can pass through the walls of plant and equipment.



Harmful Effects of Radiation

- The damaging effects of ionizing radiation became apparent only a few years after the discovery of radiation (X-ray researchers burns and cancers).
- Extensive research carried out in many countries around the world has enabled increasingly detailed estimates of the effects of low doses of radiation to be made.
- Numerous studies indicate elevated lung cancer rates in underground miners.



Estimated Loss Of Life Expectancy From Health Risks

HEALTH RISK	ESTIMATED MEAN DAYS OF LIFE EXPECTANCY LOST
Overweight by 20%	985
Auto accidents	200
Smoking 1 cigarette/day	118
Alcohol consumption (US average)	130
Home accidents	95
20 mSv/year for 30 years (calculated)	60
Safest jobs (such as teaching)	30
Natural background radiation (calculated)	8
Medical X-rays (calculated from US average)	6

Nominal Cancer Risk

Exposed Population	Annual Effective Dose (mSv)	Project Lifetime (years)	Total Dose (Sv)	Nominal Risk Coefficients Per Sv (ICRP 2007)	Lifetime Cancer Risk
Worker	5	25	0.125	$4.1\ 10^{-2}$	0.005
Public	0.25	25	0.00625	$5.5\ 10^{-2}$	0.0003

Nominal Cancer Risk

Another way of expressing the risk is to assume that if a group of 1,000 individuals were exposed, how many would be expected to develop a cancer during their lifetime?

Workers: a total of 5 individuals would be expected to develop cancer.

Public: a total of 0.3 individuals would be expected to develop a cancer.

Approximately 41% of the US population will develop a cancer during their lifetime.

A total of 70% of all cancer mortalities occur after the age of 65.

Establishing a Safety Culture

- Radiation is one of many risks associated with uranium mining.
- A Safety Culture requires to be established at an early stage in the lifecycle of a project to control the risks to acceptable levels.
- Responsibility at Board Level to drive the process.
- Requires a competent well resourced Regulatory Authority.
- Compliance with Dose Limits.

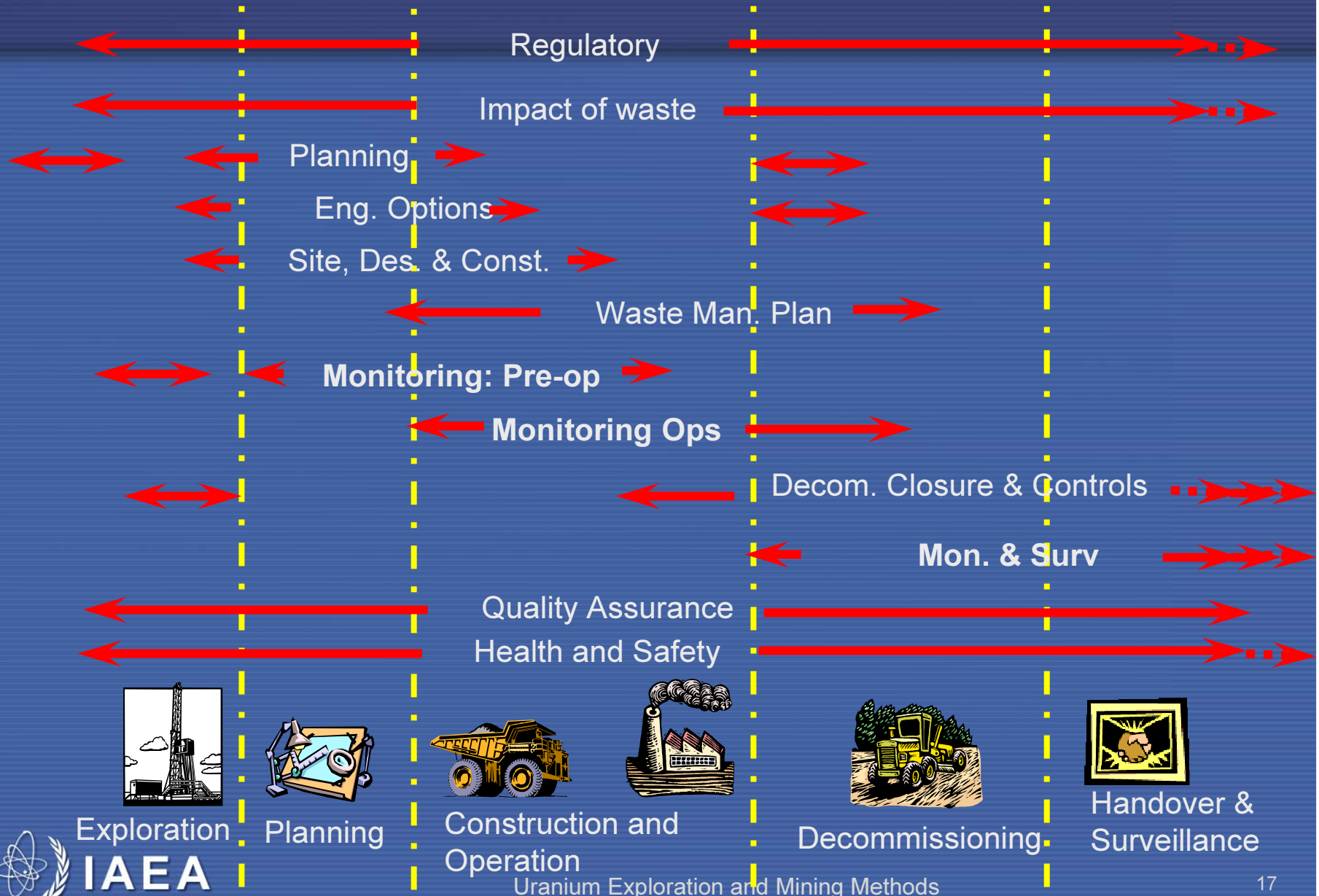
Establishing a Safety Culture

- An integrated management approach is required in order to ensure the optimisation of the overall Health, Safety and Environment Programme.

- The RPP forms an important part of the Health and Safety Management culture.

  - Requires advanced planning for safety.
  - Requires designing for safety.
  - Requires ongoing training.

Timelines: Facility Lifespan



Annual Dose Limits

Type	$mSv.y^{-1}$	Notes
Workers	20 (av) (100 over 5 years)	Above background*
Public	1	Above background
Alara	As low as reasonably achievable	Economic and social factors taken into account.

Natural background (2.4 $mSv.y^{-1}$)

Variation in Activity Concentrations

Material	^{238}U ($Bq.g^{-1}$)	^{226}Ra ($Bq.g^{-1}$)
Ore (130 ppm)	1.61	1.61
Waste rock	0.456	0.456
Tails	0.248	1.61
Product	12380	0
Scales (pipes, vessels, filter cloths, HDPE).	<1-12380	<1-50000
Natural soils	0.02-0.03	0.02-0.03

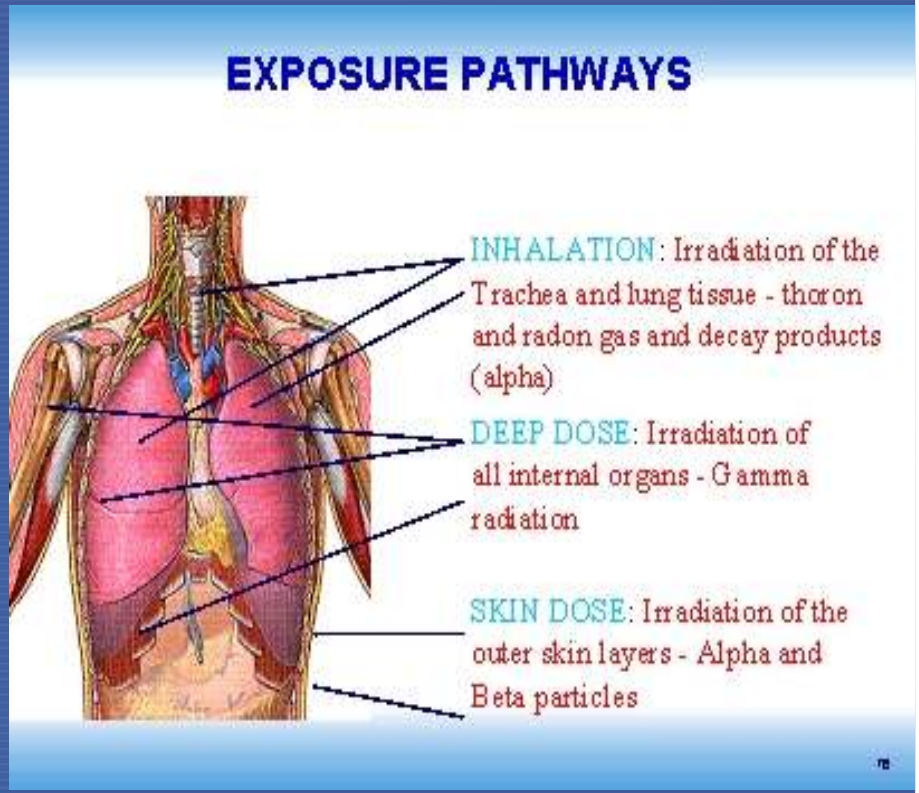
Human Exposure Pathways

- External exposure

  External exposure e.g. from gamma emitters in stockpiles and wastes e.g. ore, tailings and waste rock.

- Internal exposure

  Internal exposure e.g. ingestion and inhalation (radon gas, radon progeny and dusts) of alpha emitting materials e.g. open pit, mills, tails, product section



Occupational Exposure

- Can occur at any part of the lifecycle (e.g. from exploration to closure).
- Increases with ore grades.
- Higher exposures tend to occur in underground operations (e.g. radon) compared to open pit.

Worker and Public Exposure

- Exploration and prospecting teams.
- Construction crews.
- Workers at the open pit mining operations.
- Drivers transporting ore.
- Workers at the process plant.
- Drivers transporting uranium product.
- Workers at the mine site involved in the tailings and waste rock disposal operations.
- Visitors to the operations.
- Contractors working at the Project.
- Members of the public who live close to the mining and processing operations.

Occupational Exposure

In surface operations exposures occur at:

- Open pit.
- Stockpiles.
- Crushers and mills.
- Leach section.
- Product section.
- Tailings operations.
- Maintenance operations.
- Decommissioning and closure.

Occupational Exposure Pathways

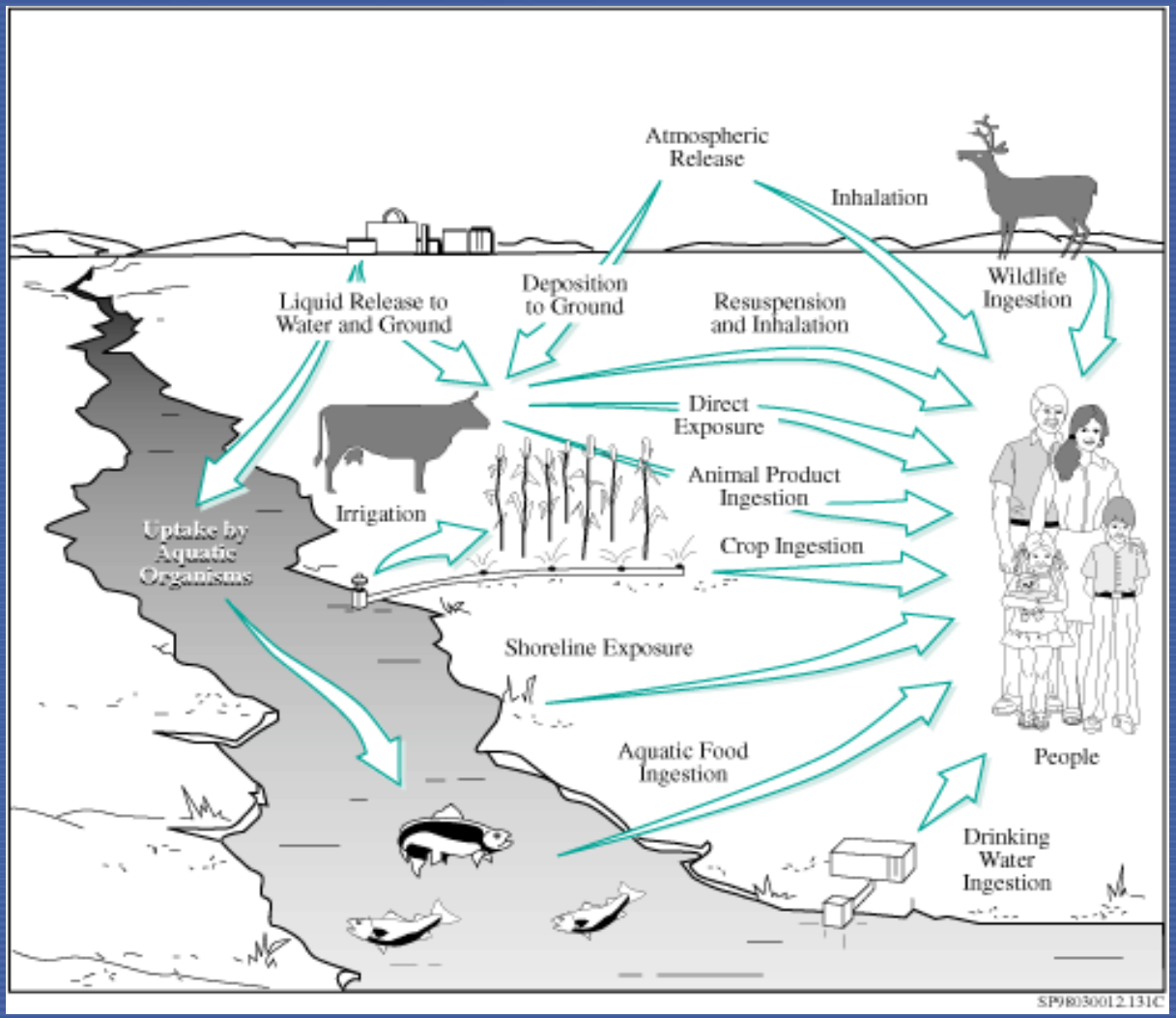
Exposure Pathway	Radiation Type	Exposure Locations
External	Gamma radiation	Ore body, ore, tailings, waste rock. Leaching section, precipitation, product section and stores.
External	Beta radiation Gamma radiation	Uranium product packing section. Uranium product store and transport.
Internal: inhalation-ingestion	Dust: Long-lived alpha and beta emitters	Uranium product packing section. Dry sections of the operations (e.g. mine, milling, tailings).
Internal: inhalation	Radon gas and decay products	Underground-Open pit.

Public Exposure

- Public exposure results from:
  - Discharges to air and water from:
    - Mining operations
    - Stockpiles.
    - Residues and wastes e.g. tailings and waste rock.
    - Contaminated scrap.

FIG. 2. Tailings pond in operation.

Overview of Public Exposure Pathways



Public Exposure Pathways

Exposure Pathway	Radiation Type	Exposure Locations
External	Gamma radiation	Fallout dust accumulating in the surface soils downwind of the tailings, ore and waste dumps.
Internal: inhalation	Long-lived alpha and beta emitters	Dusts released from the mine/pit, tailings, ore and waste rock dumps and the calciner stack.
Internal: inhalation	Radon gas and decay products	Radon gas released from the mine/pit, tailings, ore and waste rock dumps.
Internal: ingestion	Long-lived alpha and beta emitters	Through the consumption of groundwater that has been contaminated by seepage from the tailings, ore and waste rock dumps.

Radiation Protection and the Project Timelines

The various radiation protection aspects require to be planned for long before implimentation:

- Exploration and prospecting
- Construction
- Commissioning
- Operation
- Waste management
- Closure and remediation

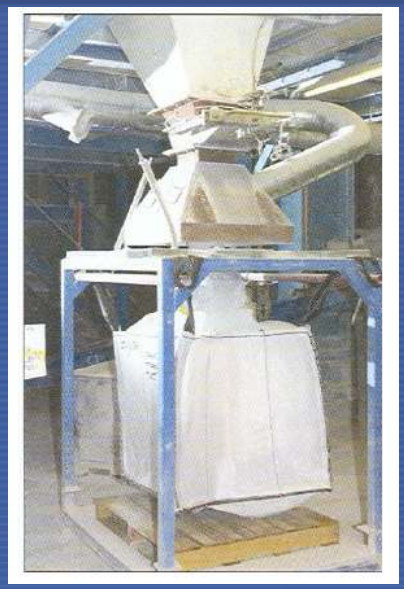
NB: A variety of safety assessments and radiological impact studies require to be carried out at various stages of the project.

Administrative Controls

- Radiation Protection programme.
- Records.
- QA and QM.
- Access controls.
- Protective clothing.
- Respiratory protection.
- Training.

Engineered/Design Controls

- Design of the plant to keep doses Alara.
- Dust control systems (open pit, crushers and mills).
- Ventilation systems.
- Product packing (ventilation, dust controls and automatic interlocks).
- Physical Security.



Radiation Protection Programme (RPP)

- The extent of the RPP is always tailored to the level of radiation risk to workers and the public arising from a specific project.
- The RPP and its associated controls are primarily concerned with control over the areas containing radioactive materials and the way humans interact with these radiation sources.
- The requirements of a RPP are clearly documented in a set of approved documents.
- The documents will comprise Programmes, Plans, Procedures, Records, Schedules, Reports and Electronic Databases.

Components of the RPP

- Safety assessments to determine the level of risk to workers and the public.
- Engineered and Administrative controls.
- The Occupational Radiation Protection Programme.
- The Public Radiation Protection Programme.
- Workplace monitoring programmes.
- Individual monitoring and a dosimetry programme for OEPs.
- A radiation training programmes for workers.

Components of the RPP

- Medical surveillance for OEPs.
- Health and dose registers for OEPs.
- Effluent and environmental monitoring programmes.
- The Waste Management programme.
- The Occurrence Reporting and Emergency Plan Programme.
- The Quality Management and Assurance Plan.
- The Site Decommissioning and Closure Plan.
- The Physical Security Programme.
- Transport Programme.
- The Radiation Protection GIS System and Database.

WASTE MANAGEMENT AND DISPOSAL OPTIONS

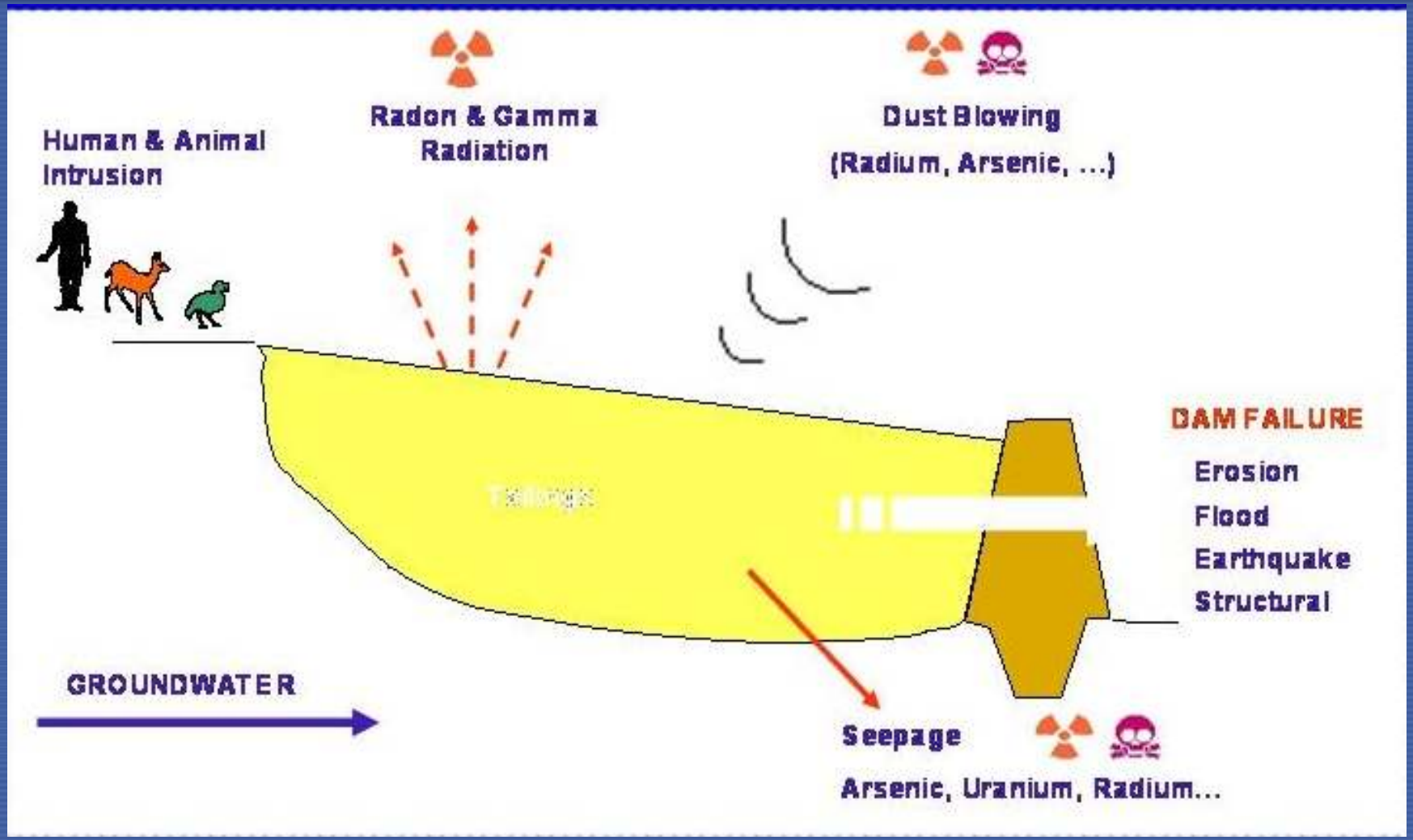
- The siting and design of the tailings is a critical issue. As there are long term implications for the public and the environment (e.g. legacy sites).

FIG. 1. Unstabilized tailings pile.

- The radiological implications and options require to be assessed at an early stage of the project.

- All radioactive waste streams require to be identified and characterized.

Tailings Impacts



Summary

- Uranium is a naturally occurring radioactive material (NORM).
- It emits ionizing radiation in the form of alpha, beta and gamma radiation.
- Human exposure to radiation involves both internal and external exposure pathways.
- Radiation doses require to be limited to reduce the risk of harmful effects.

Summary

- Exposure to ionizing radiation can occur at any point in the mine lifecycle.
- Higher ore grades mean higher exposures.
- A variety of administrative and engineered controls are used to limit exposures.
- Occupational and public doses must be kept ALARA.
- The siting and design of tailings is critical.
- Planning for Safety must begin at an early stage of the project.

Thank You


Everest
75
A portion of
the first S.A.
uranium ingot
UO_3
SPRAY
SATURATED
SPRAY CALCINED
CLEAN-UP AT WESTERN
PILOT PLANT
CABINET 1: URANIUM SAMPLES