Radiological Emissions-I

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Overview of the Presentation

- Explanation of some terms used in radiation protection
- Nuclear fuel cycle
- NukPacts

Becquerel (Bq)

Becquerel is the basic unit of radioactivity.

One Becquerel is equal to one disintegration per second.

1 Bq=2.7E-11 Ci

One Ci = 3.7E+10 Bq

Absorbed Dose

When ionizing radiation interacts with the human body, it gives its <u>energy</u> to the body tissues. The amount of <u>energy absorbed per unit weight</u> of the organ or tissue is called *absorbed dose.*

Absorbed dose is expressed in units of gray (Gy). One gray dose is equivalent to one joule radiation energy absorbed per kilogram of organ or tissue weight.

Rad is the old and still used unit of absorbed dose. One gray is equivalent to 100 rads. (1 Gy = 100 rads)

Equivalent Dose

- Equal doses of all types of ionizing radiation are not equally harmful.
- Alpha particles produce greater harm than do beta particles, gamma rays and x rays for a given absorbed dose.
- To account for this difference, radiation dose is expressed as *equivalent dose.*
- *Equivqlent Dose* is equal to "absorbed dose" multiplied by a "radiation weighting factor" (WR).
- Equivalent Dose is measured in Sievert (Sv).
- The dose in Sv (Equivalent Dose) = Dose x WR.
- Prior to 1990, this weighting factor was referred to as Quality Factor (QF).

Some Recommended Radiation Weighting Factors

Gamma rays and x rays	1
Beta particles	1
Neutrons, energy	
< 10 keV	5
> 10 keV to 100 keV	10
> 100 keV to 2 MeV	20
Alpha particles	20

Conversion between units

The old unit of
"dose equivalent" or "dose" was rem.

Dose in Sv	=	Absorbed Dose in Gy x radiation weighting factor (WR)
Dose in rem	=	Dose in rad x QF

1 Sv	=	100 rem
1 rem	=	10 milli Sievert

Tissue Weighting Factors

dose = sum of [organ doses x tissue weighting factor]

Tissue weighting factors represent sensitivity of organs for developing cancer.

Tissue Weighting Factors for Individual Tissues and Organs			
Tissue or Organ	**Tissue Weighting Factor (WT)**	**Tissue or Organ**	**Tissue Weighting Factor (WT)**
Ovaries	0.20	Liver	0.05
Bone marrow	0.12	Thyroid gland	0.05
Colon	0.12	Skin	0.01
Lung	0.12	Bone surfaces	0.01
Stomach	0.12	Remainder**	0.05
Bladder	0.05	Whole body	1.00
Breast	0.05		

** The remainder is composed of the following additional tissue and organs: adrenal, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus and uterus.

Effects of Different Doses of Radiation on Human Health

The effects of being exposed to large doses of radiation at one time (acute exposure) vary with the dose. Here are some examples:

10 Sv – Risk of death within days or weeks

1 Sv – Risk of cancer later in life (5 in 100)

100 mSv – Risk of cancer later in life (5 in 1000)

Limits of Exposure to Radiations

- The ICRP (International Commission on Radiological Protection) , a non-governmental body of experts establishes basic principles for, and issues recommendations on, radiation protection.

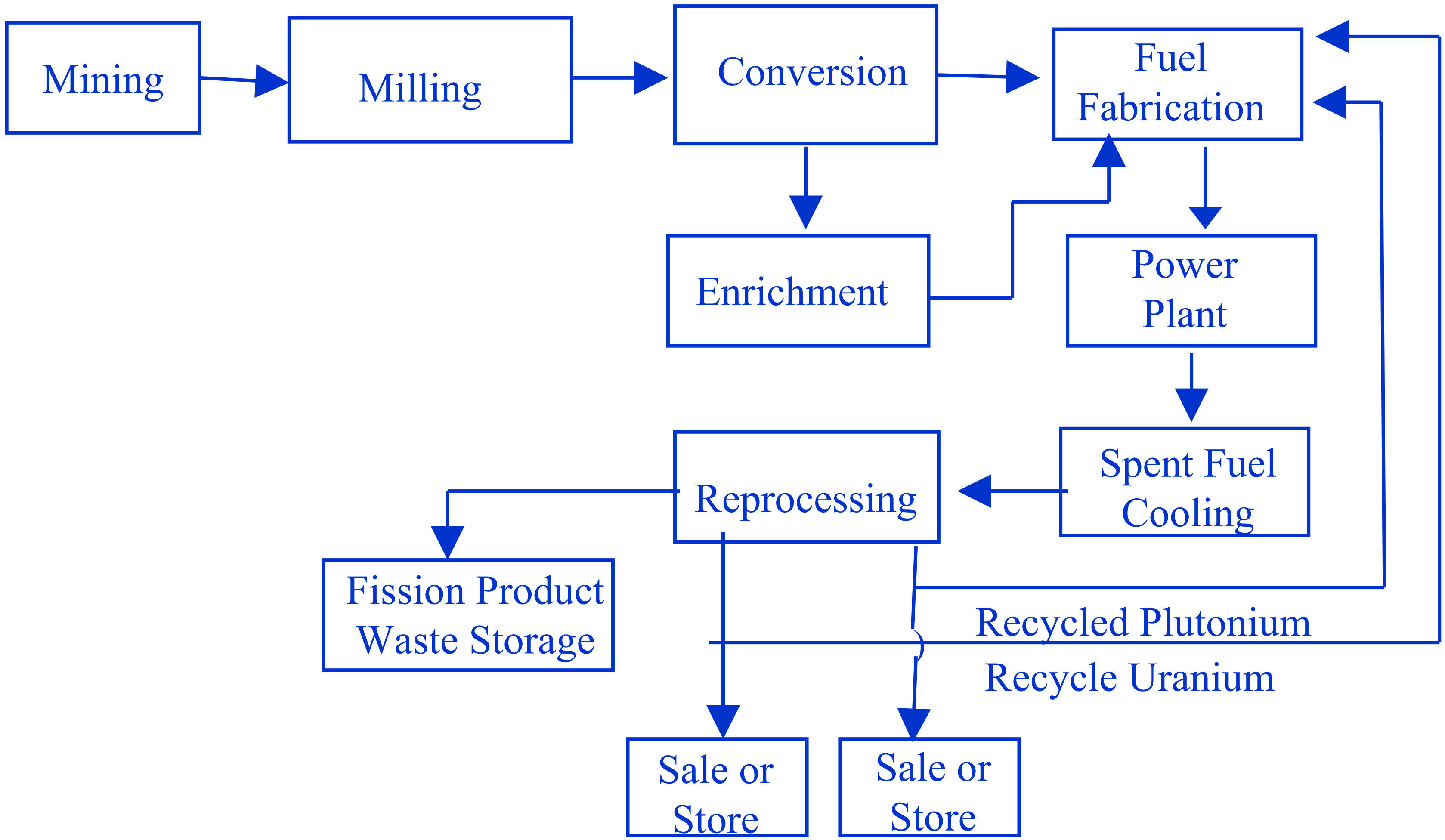
- The ICRP recommends that any exposure above the natural background radiation should be kept as low as reasonably achievable, but below the individual dose limit.

- For general public ICRP recommends 1mSv per year.

- For radiation workers ICRP recommends 100 mSv over 5 years

Nuclear Fuel Cycle

Nuclear Fuel Cycle



Radioactive Releases from Nuclear Fuel Cycle

- Mining and Milling

  Gaseous: Rn-222, U-234, U-235, U-238

  Liquid: U-234, U-235, U-238

- Conversion,Enrichment, Fuel Fabrication

  Gaseous: U-234, U-235, U-238

  Liquid: U-234, U-235, U-238

Radioactive Releases from Nuclear Fuel Cycle

- Electricity Generation

  Gaseous: H-3, C-14, Co-58, Kr-85, I-131, I-133, Xe-133, Cs-134, Cs-137

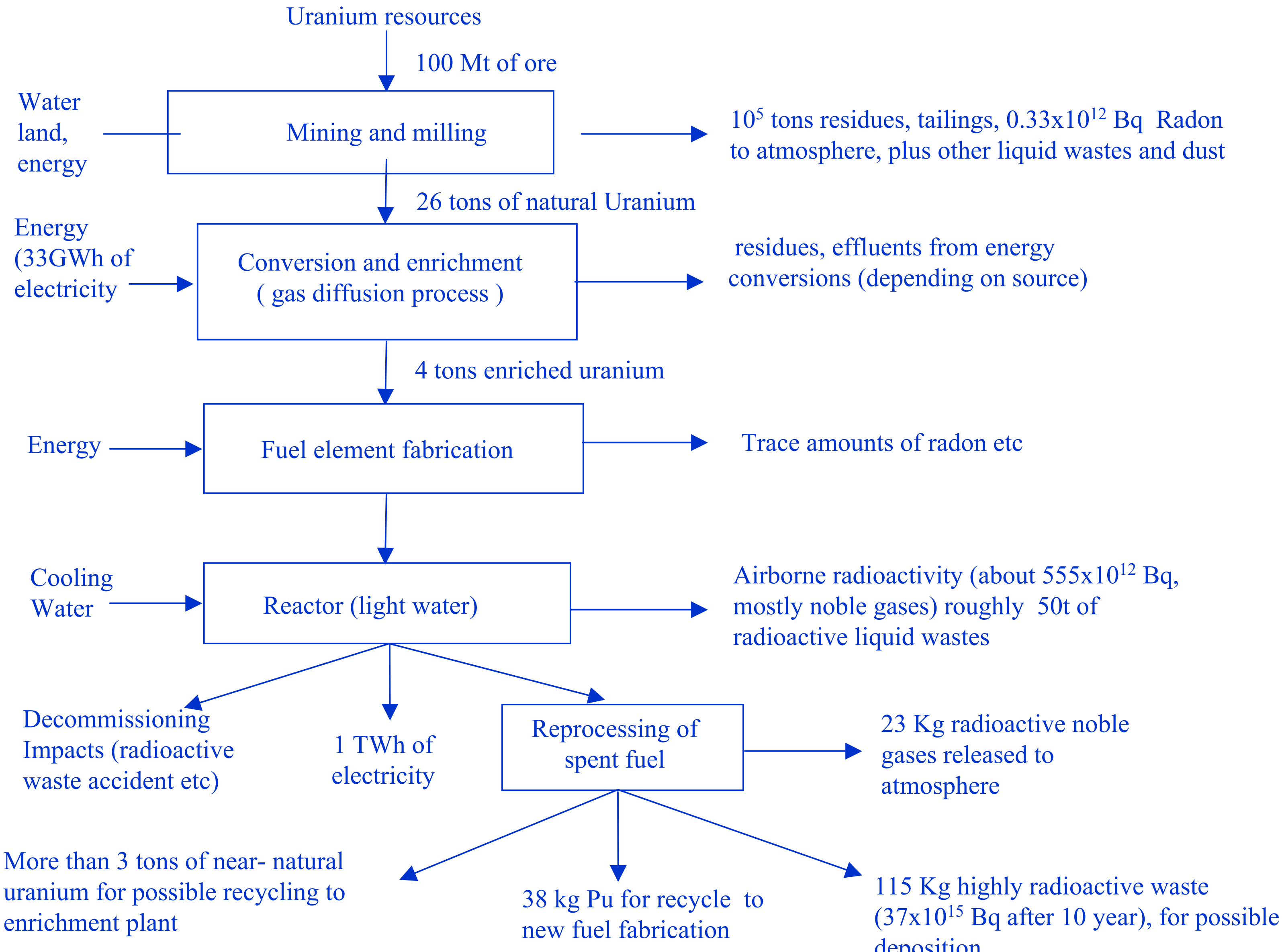
  Liquid: H-3, Mn-54, Co-58, Ag-110, Sb-124, I-131, Cs-134, Cs-137

- Reprocessing

  Gaseous: H-3, C-14, Kr-85, I-129, I-131,I-133, Pu-238, Pu-239

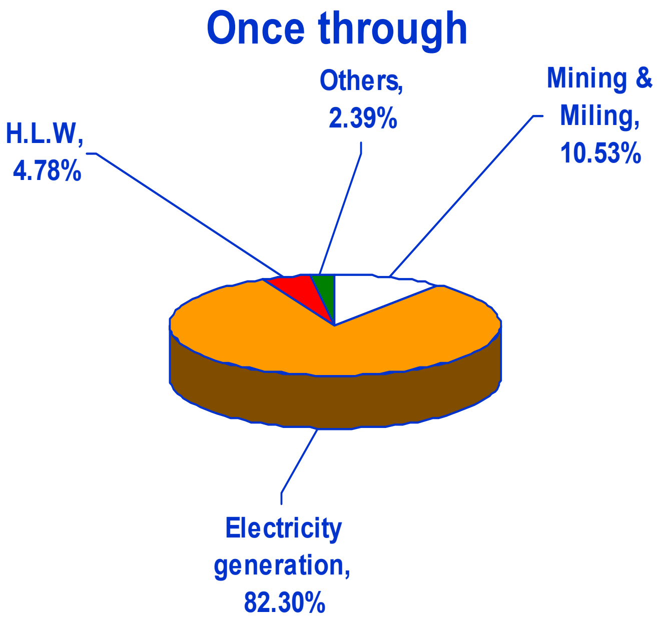
  Liquid: H-3,C-14,Co-60,Sr-90, Ru-106, I- 129, Sb-125, Cs-134,Cs-137, U-238, Pu-238 Pu-239, Am-241

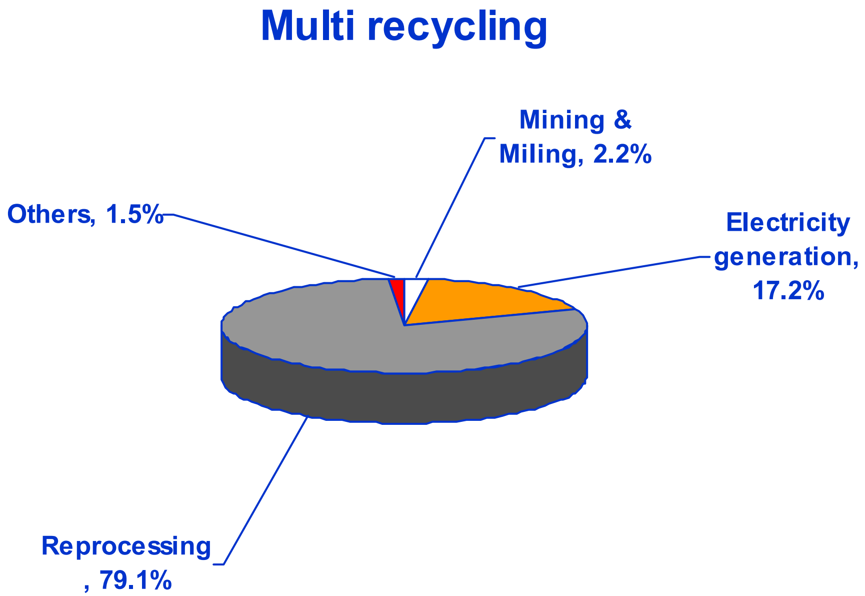
Uranium usage chain for 1 TWh of electricity generation



Source: [see note]

Collective Doses (%) for the Stages of the Nuclear Fuel Cycle





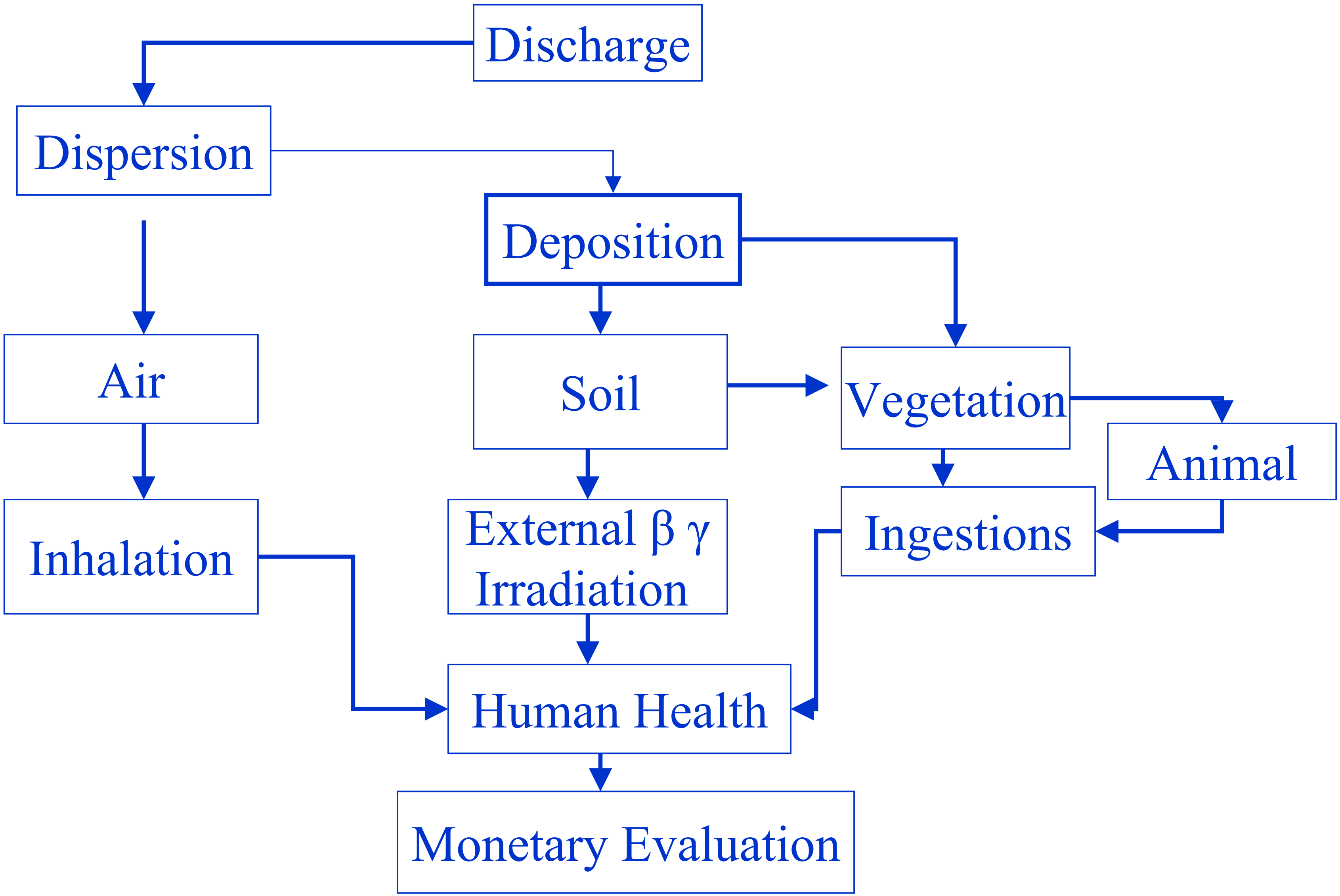
Source: ExternE (1995)

Nuclear Power Plants in World

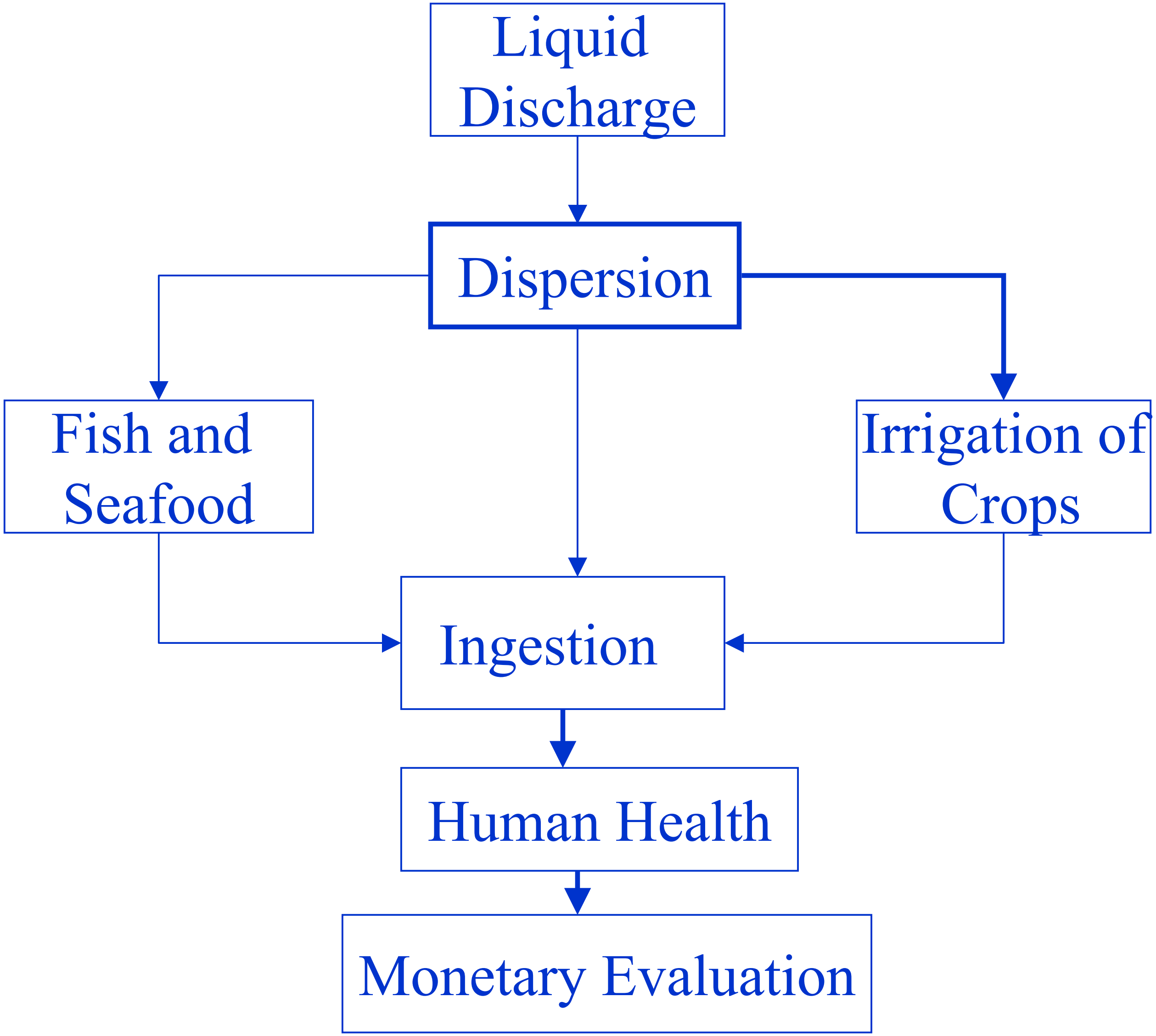
Type	Operational		Under Construction	
	Units	GWe	Units	GWe
Total Of which	437	358	33	27
PWR	48.7%	56.6%	24.2%	28.3%
BWR	21.1%	22.5%	15.2%	23.6%
WWER	11.4%	9.2%	30.3%	30.7%
PHWR	8.0%	4.8%	27.3%	14.0%
GCR	5.9%	3.0%	-	-
Others	4.8%	3.8%	3.0%	3.4%

Source: IAEA (2003)

Pathways for the Atmospheric Releases of Radionuclides



Pathways for the Liquid Discharge of Radionuclides into Aquatic Environment



NukPacts

Scope of NukPacts (1/3)

- Mining and Milling

  Gaseous: Rn-222, U-234, U-235, U-238

  Liquid: U-234, U-235, U-238

- Conversion,Enrichment, Fuel Fabrication

  Gaseous: U-234, U-235, U-238

  Liquid: U-234, U-235, U-238

Scope of NukPacts (2/3)

- Electricity Generation
  - Gaseous: H-3, C-14, Co-58, Kr-85, I-131, I-133, Xe-133, Cs-134, Cs-137
  - Liquid: H-3, Mn-54, Co-58, Ag-110, Sb-124, I-131, Cs-134, Cs-137
- Reprocessing
  - Gaseous: H-3, C-14, Kr-85, I-129, I-131,I-133, Pu-238, Pu-239
  - Liquid: H-3,C-14,Co-60,Sr-90, Ru-106, I- 129, Sb-125, Cs-134,Cs-137, U-238, Pu-238 Pu-239, Am-241

Scope of NukPacts (3/3)

Environmental releases of nuclear power plant

- Routine operation
  - Atmospheric emission * ✓
  - Effluent ✕
  - Solid waste** ✕
  - Spent fuel ✕
- Accident ✕

* Excluding Global Impacts

** Contaminate protective clothing, filters, resins, etc.

Methodology of NukPacts

Impact Pathway for the Atmospheric Discharge of Nuclear Power Plant

Source

Transport & Dispersion

Deposition

Human Exposure

Expected Health Impacts

Monetary Valuation

Radionuclide Released in the air from a PWR

Radionuclide	Half-life	Radionuclide	Half-life
Kr-85	**10.7 y**	I-134	52.6 min
Kr-87	76.3 min	I-135	6.6 h
Kr-88	2.8 h	**Cs-134**	**2.1 y**
Xe-133	**5.2 d**	Cs-136	13.1d
Xe-135	9.2 h	**Cs-137**	**30 y**
Xe-138	14.0 min	**Co-58**	**71 d**
I-131	**8.1 d**	**Co-60**	**5.3 y**
I-132	2.3 h	**C-14**	**5710 y**
I-133	**21 h**	**H-3**	**13.3 y**

Impact Pathway for the Atmospheric Discharge of Nuclear Power Plant

Source

Transport & Dispersion

Deposition

Human Exposure

Expected Health Impacts

Monetary Valuation

The most important radionuclide releases in the air from 4x900 MWe PWR unit at Tricastin in 1991 (for 20.84 TWh)

Radionuclide	MBq/year
H-3	3.5 million
Co-58	11.3
Co-60	11.3
Kr-85	1.75 million
I-131	67.1
I-133	135
Xe-133	24.5 million
Cs-134	11.3
Cs-137	11.3
C-14*	0.3 million

* estimates

Source: ExternE (1995)

Impact Pathway for the Atmospheric Discharge of Nuclear Power Plant

- Source
- Transport & Dispersion
- Deposition
- Human Exposure
- Expected Health Impacts
- Monetary Valuation

The annual average air concentration (Bq/m^3) is calculated using the Gaussian plume dispersion model.
The basic data required to estimate ground-level concentrations of radionuclide

- The emission strength of each radionuclide,
- The average annual wind speed;
- The effective release height; and
- The appropriate "Pasquil-Gifford Stability Categories

Wind Speed at Release Height

$$\text{Wind Speed at release height} = Vk \times \left[\frac{hk}{hr} \right]^{p}$$

Vk = Wind speed at known height (m/see)
hk = known height
hr = release height
p = exponent which varies with atmospheric stability

Stability Class	Urban	Rural
A	0.15	0.07
B	0.15	0.07
C	0.20	0.10
D	0.25	0.15
E	0.40	0.35
F	0.60	0.55

Estimation of Pasquill Stability Classes

Stability class	Example	Wind speed at 10m	Weather
A - very unstable	1%	1.0 to 2.5	very sunny
B - moderately unstable	5%	1.0 to 5.0	sunny
C - slightly unstable	15%	2.0 to 6.0	part cloud (day)
D - neutral	65%	2.0 to >10.0	overcast
E - stable	6%	2.0 to 5.0	part cloud (night)
F - very stable	8%	2.0 to 3.0	clear night
Total	100%		

Impact Pathway for the Atmospheric Discharge of Nuclear Power Plant

- Source
- Transport & Dispersion
- Deposition
- Human Exposure
- Expected Health Impacts
- Monetary Valuation

$$W_i = C_i \times V_d$$

W_i = average flux of radionuclide i ($Bq/m^2.s$)

Ci = annual average air concentration of radionuclide i (Bq/m^3), determined by Gaussian Plume model

V_d = average wet and dry deposition velocity (m/s)

Impact Pathway for the Atmospheric Discharge of Nuclear Power Plant

- Source
- Transport & Dispersion
- Deposition
- Human Exposure
- Expected Health Impacts
- Monetary Valuation

The most important pathways for health of the general public resulting from atmospheric releases are :

i. The inhalation of radionuclides in the air;
ii. The external irradiation from cloud exposure;
iii. The external irradiation from ground deposition, and
iv. The ingestion of radionuclides in food.

The irradiation from inhalation

First Step: Estimation of individual intake of radionuclides

The annual average intake by inhalation of nuclide i from air Concentration =

$$I_i = C_i \times Br$$

Ci = radionuclide concentration in the air (Bq/m^3)
Br = average annual breathing rate of a person (m^3/y)
Ii = The average annual individual intake of radionuclide i (Bq/y)

The irradiation from inhalation

Second Step: Estimation of average individual dose

The average individual dose =

$$HI\ inh = \sum_{i} I_i \times EDE\ (i)$$

HI inh = The average individual dose from inhalation of all the radionuclides (Sv/year)

Ii = The average annual individual intake of radionuclide i (Bq/y)

EDE (i) = The effective dose conversion for inhalation (Sv per Bq) over 50 year

Dose Conversion Factor for Inhalation (Sv/Bq)

Radionuclide	Sv/Bq
H-3	1.173E-11
Co-58	2.90E-09
Co-60	5.60E-08
Kr-85	..
I-131	1.30E-08
I-133	2.30E-09
Xe-133	--
Cs-134	1.20E-08
Cs-135	8.50E-09
C-14*	5.60E-10

Source: ExternE (1995)

The irradiation from inhalation

Third Step: Estimation of total collective dose

The total collective dose (man-sv) =

The average individual dose from inhalation of all the radionuclides (Sv/year)

multiplied by

Population at risk

The external irradiation from radionuclides immersed in the air

The dose to the population from the external irradiation of radionuclides immersed in the air =

$$HEP_i = Ci \text{ x } Hexp$$

$$H_{EP} = HEP_i \text{ x } Nh$$

Ci = radionuclide concentration in the air (Bq/m^3)
$Hexp_i$ = effective dose equivalent from exposition to the cloud (Sv per Bq/m^3)
Nh = number of inhabitants
HA_i = man-sv

Dose Conversion Factor for External Irradiation from cloud (Sv per Bq/m^3)

Radionuclide	Sv per Bq/m^3
H-3	1.1E-11
Co-58	1.4E-06
Co-60	4.4E-06
Kr-85	4.4E-09
I-131	4.9E-07
I-133	1.0E-06
Xe-133	5.5E-08
Cs-134	2.8E-06
Cs-137	9.2E-07

Source: ExternE (1995)

The external irradiation from ground deposition

For calculation of external exposure due to deposition, time must be taken into consideration in the assessment to account for the rate of decay and rate of migration of the radionuclides away from the ground surface.

$$HG_i = \sum_t W_i \times H_{i,t} \times Nh$$

W_i = average deposition rate ($Bq/m^2.s$)

$H_{i,t}$ = effective dose equivalent from external exposure to the ground integrated to time t (Sv per $Bq/m^2.s$)

Nh = number of inhabitants

HG_i = Total dose due to ground deposition (man.Sv)

Dose Conversion Factor for External Exposure from Ground (Sv per Bq/m^2·s)

Radionuclide	Dose conversion factors for ground exposure (Sv per Bq/m^2·s)			
	1 y	50 y	100 y	100000 y
H-3	-	-	-	-
Co-58	1.25E-01	1.70E-01	1.70E-01	1.70E-01
Co-60	0.692	6.84	6.84	6.84
Kr-85	-	-	-	-
I-131	8.3E-03	8.6E-03	8.6E-03	8.6E-03
I-133	1.5E-03	1.5E-03	1.5E-03	1.5E-03
Xe-133	-	-	-	-
Cs-134	0.436	2.28	2.28	2.28
Cs-137	0.18	3.8	4.0	4.1

Ingestion of radionuclides in food

The human consumption pathway via agricultural products is due to:

- direct deposition of radionuclides on the surface of vegetation,
- transfer of the radionuclides into vegetation through the soil to the roots and
- transfer of the radionuclides into meat and milk through vegetation.

Impact Pathway for the Atmospheric Discharge of Nuclear Power Plant

Source

Transport & Dispersion

Deposition

Human Exposure

Expected Health Impacts

Monetary Valuation

Dose-response relationship

The key risk factors are the following (cases per man Sv)

Fatal cancer	0.05
Non-fatal cancer	0.12
Severe hereditary effects	0.01

Source: (ExternE 1995, ICRP 1991

Impact Pathwayfor the Atmospheric Discharge of Nuclear Power Plant

Source

Transport & Dispersion

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Human Exposure

Expected Health Impacts

Monetary Valuation

Monetary units ($, €, etc)
Normalizations ($/kWh, €/kWh, etc).

Model has inbuilt data for Economic Unit Values of Radiological Health Impacts for various countries
You can use that data or you can enter your own values.

Global Impacts

- For the majority of radionuclides released from nuclear plants, dispersion in the environment is limited to a radius of 1,000 km from the emission source (i.e. the ‘local’ or ‘ regional’ zones). A few radionuclides, including tritium (H – 3), Carbon – 14 and Krypton – 85, however, may become widely dispersed throughout the global atmosphere and oceans.

Global Impacts

- H - 3, with a half-life about 12 years, mixes into the global hydrogen cycle. Carbon – 14, with a half-life over 5,700 years, mixes with the global carbon cycle. Krypton – 85, a noble gas with a half-life of about 10 years, does not deposit and consequently is able to disperse throughout the global atmosphere.

Global Impacts

- Several models are available for predicting the global dispersion of H – 3, C – 14 and Kr – 85. Using these models, the IAEA (1985) have developed coefficients which permit easy calculation of the total collective dose, resulting from the emission of each of these three radionuclides to the atmosphere.

Estimation of Global Collective Dose

$$H_{global}^{TCD}\left(\text{H-3, C-14, Kr-85}\right) = Q\left(\text{H-3, C-14, Kr-85}\right) \times EDE_{global}\left(\text{H-3, C-14, Kr-85}\right)$$

where

$H_{\text{global}}^{TCD}\left(\text{H-3, C-14, Kr-85}\right)$ = The **total global collective dose,** integrated over 100,000 years, from the release of H – 3, C – 14 and Kr – 85 to the atmosphere (man Sv per year of releases).

$Q\left(\text{H-3, C-14, Kr-85}\right)$ = The release rate of H – 3, C – 14 and Kr – 85 (M Bq per year).

$EDE_{global}\left(\text{H-3, C-14, Kr-85}\right)$ = The **(collective) effective dose equivalent**, integrated over 100,000 years, resulting from the release of 1 M Bq of H – 3, C – 14 and Kr – 85 into the atmosphere (man Sv per M Bq per year).

Collective Effective Dose Equivalent from the Release of 1 M Bq of H – 3, C – 14 and Kr – 85 into the Atmosphere

Radionuclide	**Collective Effective Dose**
	(Man Sv per M Bq)
H – 3	9.42E-09
C – 14	1.42E-04
Kr – 85	9.30E-11

Source: IAEA (1985) in CEC (1995, p 49, 50 and 51)

Next

- Ms. Leonort will give presentation on:
- Details of Ingestion Pathway
- Environmental Impacts of
    - Liquid Wastes
    - Solid Wastes
    - Nuclear Accident