Fusion Power Plant Licensing and Waste Management

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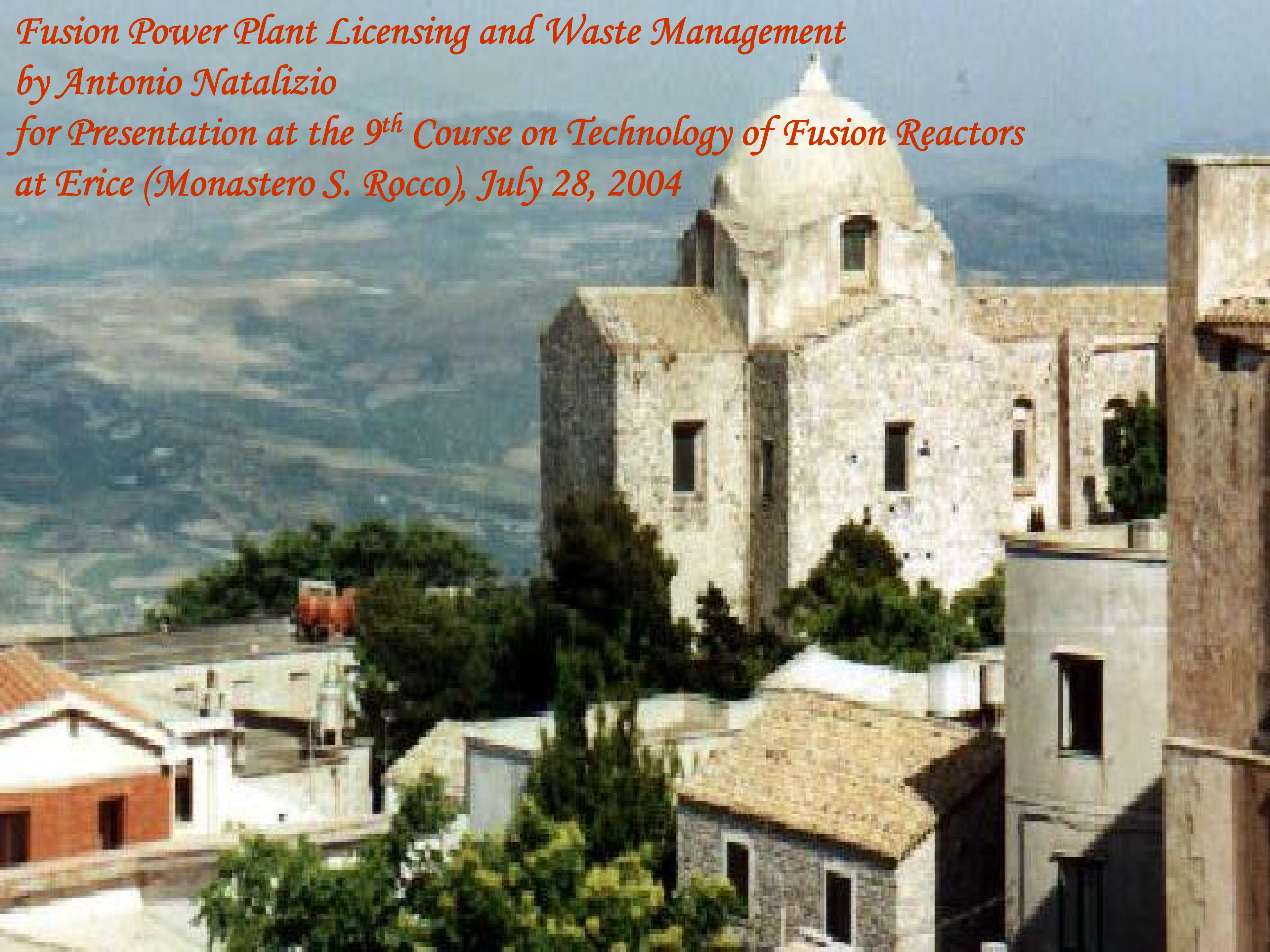
for Presentation at the 9th Course on Technology of Fusion Reactors

at Erice (Monastero S. Rocco), July 28, 2004

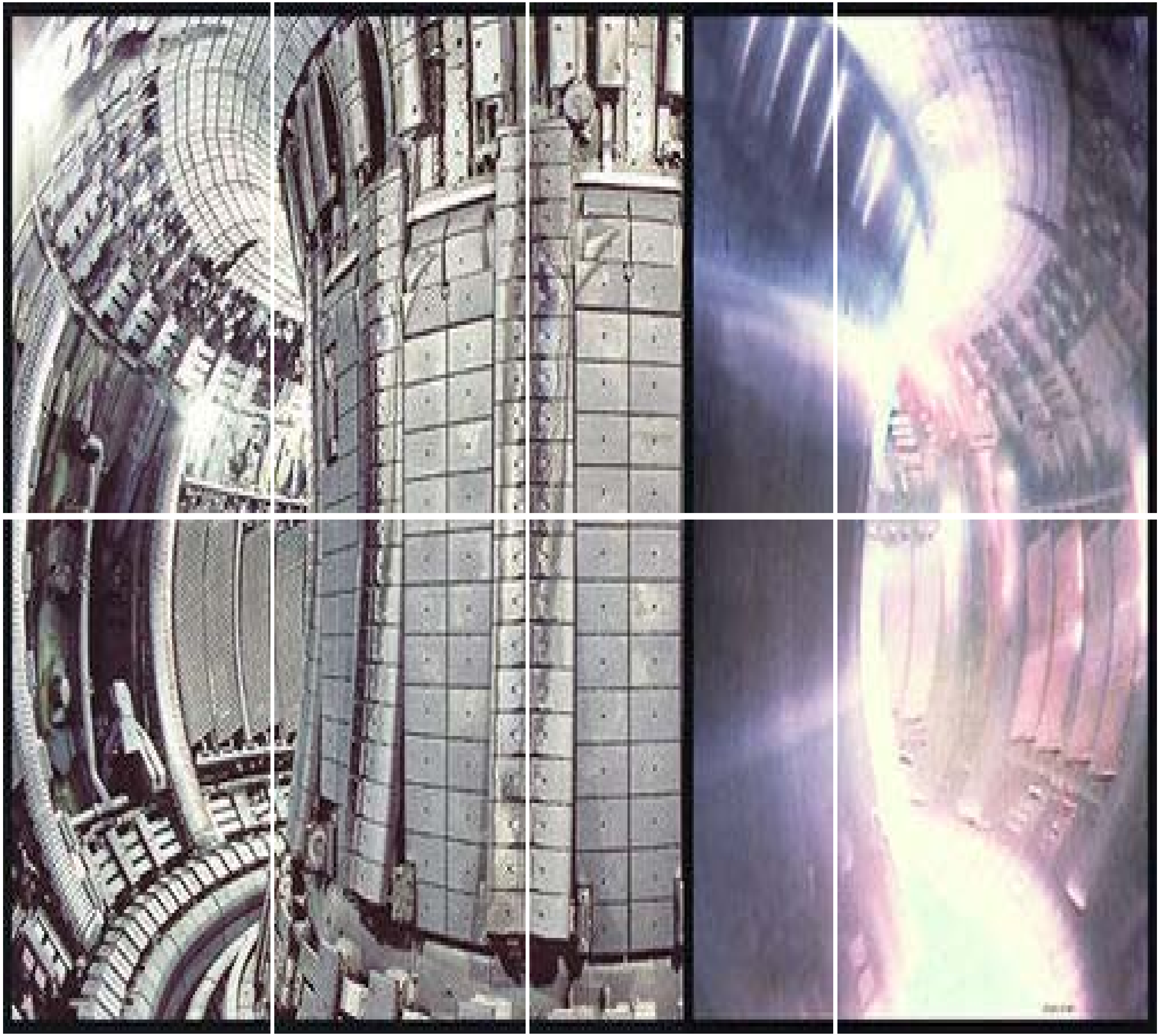


Topics Covered

- Introduction
- Waste Management
    - Radio-Toxicity Index
    - Fusion RTI
    - Fission RTI
- Licensing
    - Worker Health & Safety
    - Public Health & Safety
- Summary & Conclusions



Bringing fusion down to earth



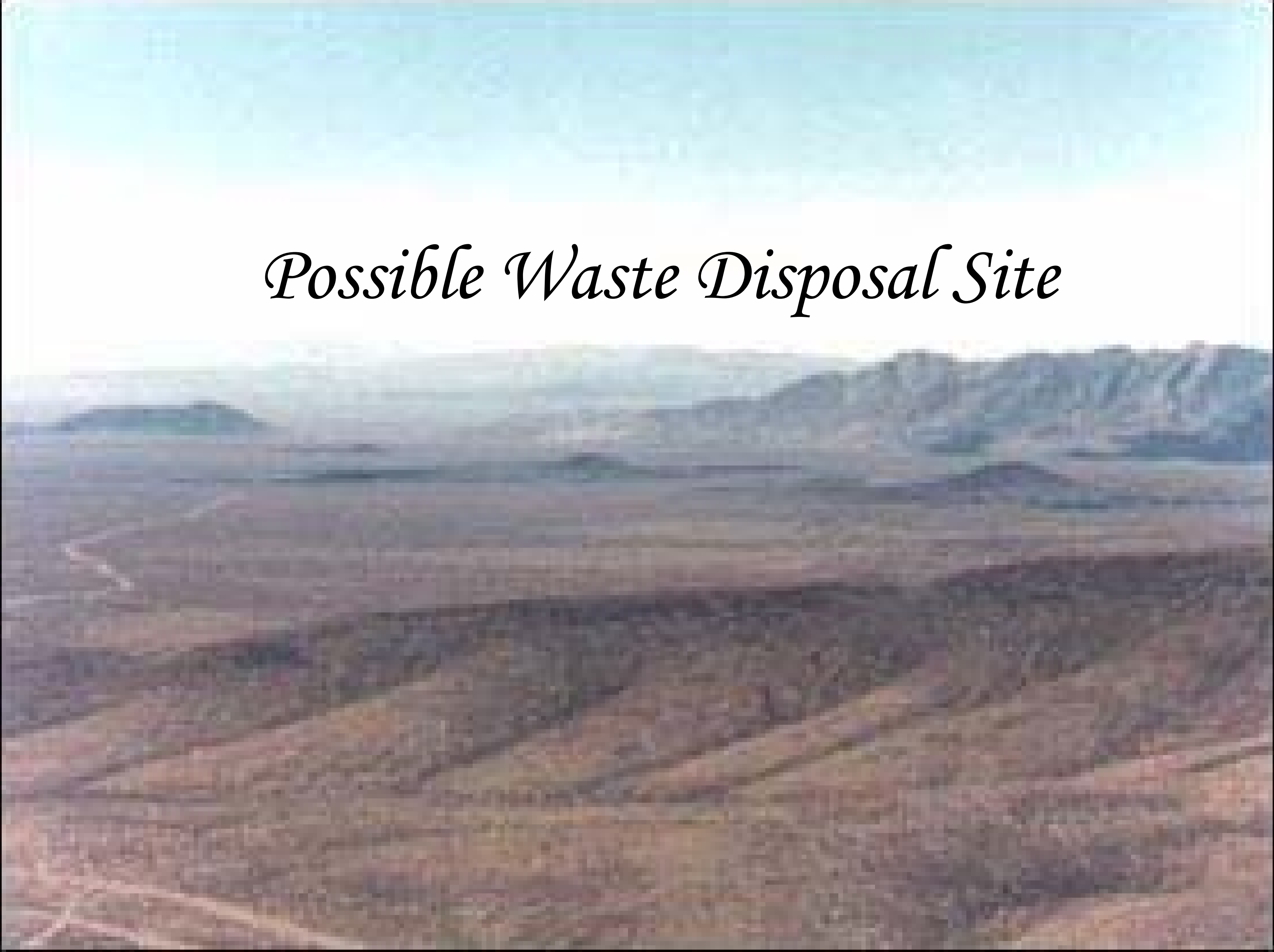
Social and Environmental Considerations

Technical Considerations

The NIMBY & NIMTOO Syndromes


Licensing & Waste Management
Etna 2002

Possible Waste Disposal Site



Open-pit Uranium Ore Mine

Radio-Toxicity of Uranium Ore

5.5 mSv/kg

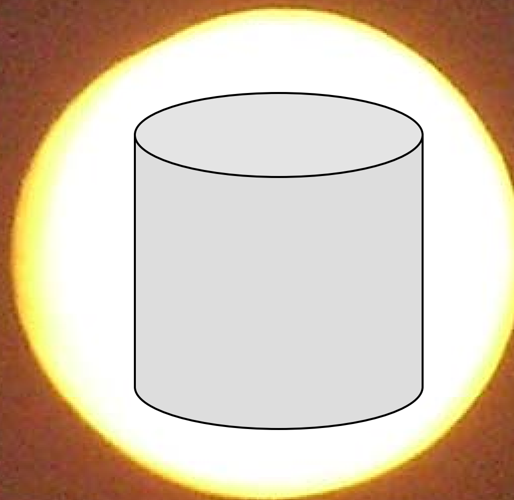
refined uranium ore
(yellowcake)

Radiotoxicity of Used PWR Fuel

1 kg of used PWR Fuel

=

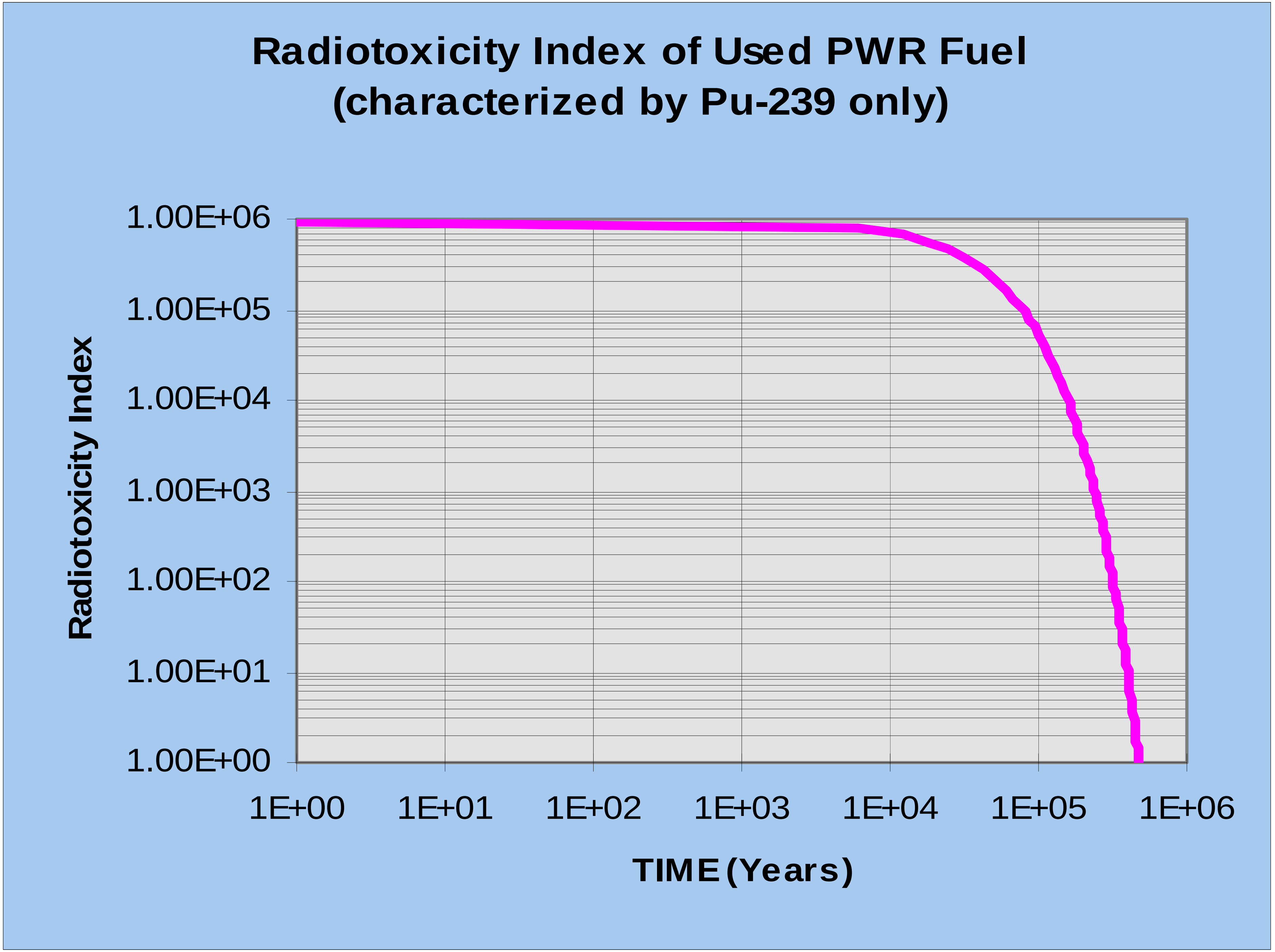
9 g of actinides



Radiotoxicity

=

5.2x103 Sv/kg


Radiotoxicity Index of Used PWR Fuel
(characterized by Pu-239 only)
Radiotoxicity Index
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1E+00
1E+01
1E+02
1E+03
1E+04
1E+05
1E+06
TIME (Years)

Radio-Toxicity of Uranium Metal

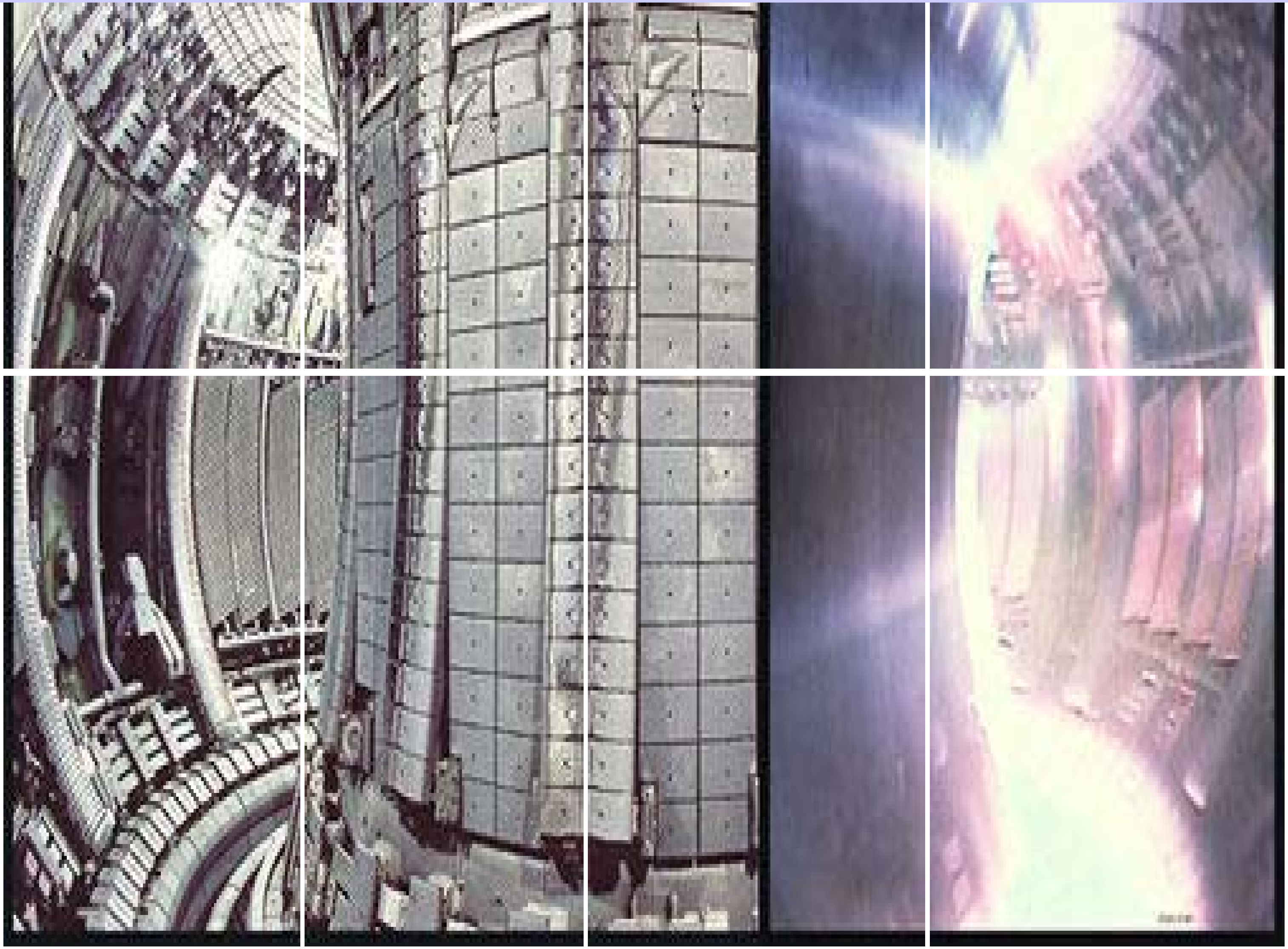
Uranium Metal

RTI = 100

Uranium Metal Uses

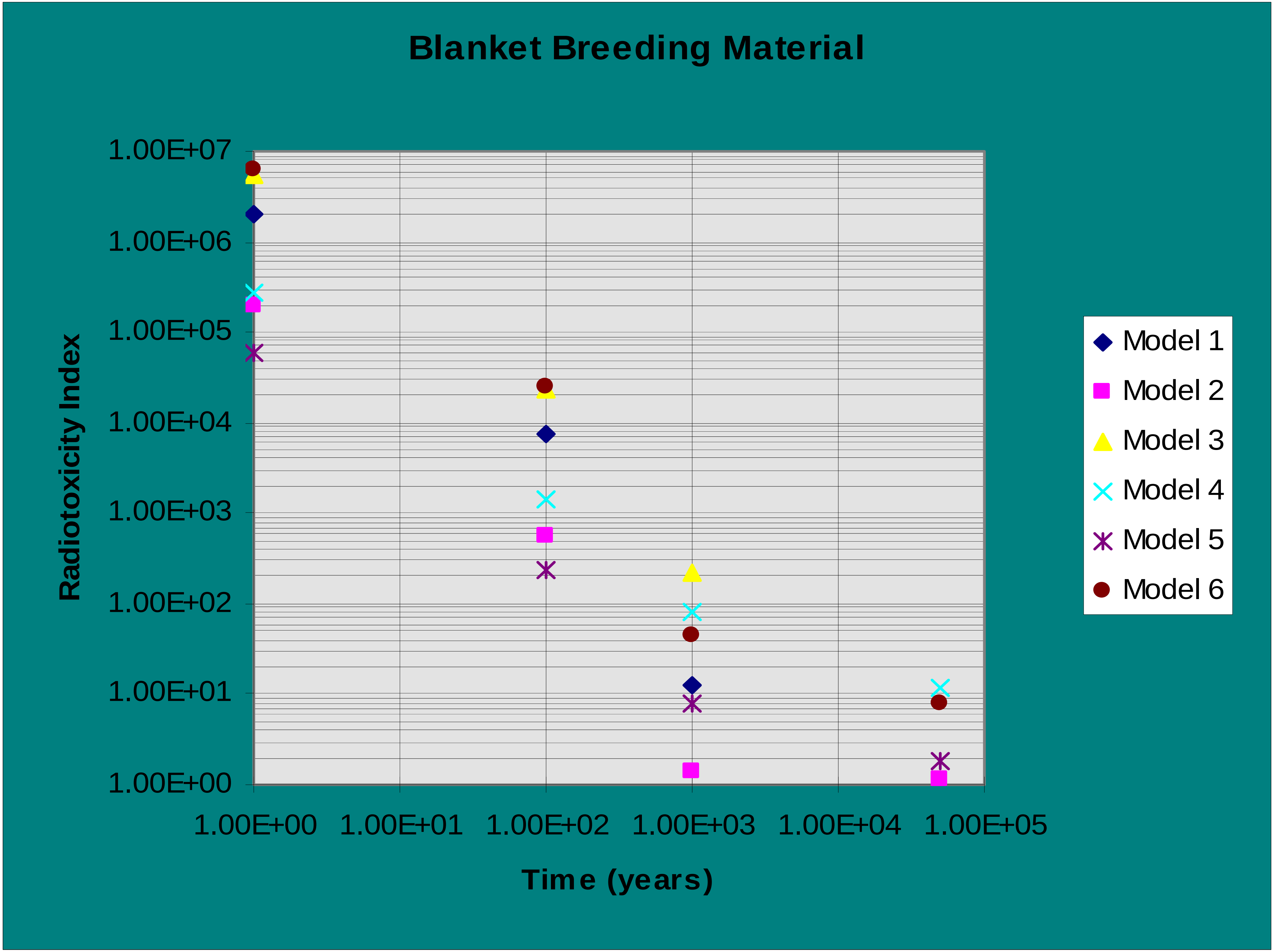
Pure Uranium is a by-product of the uranium enrichment industry, which separates U-235 from U-238

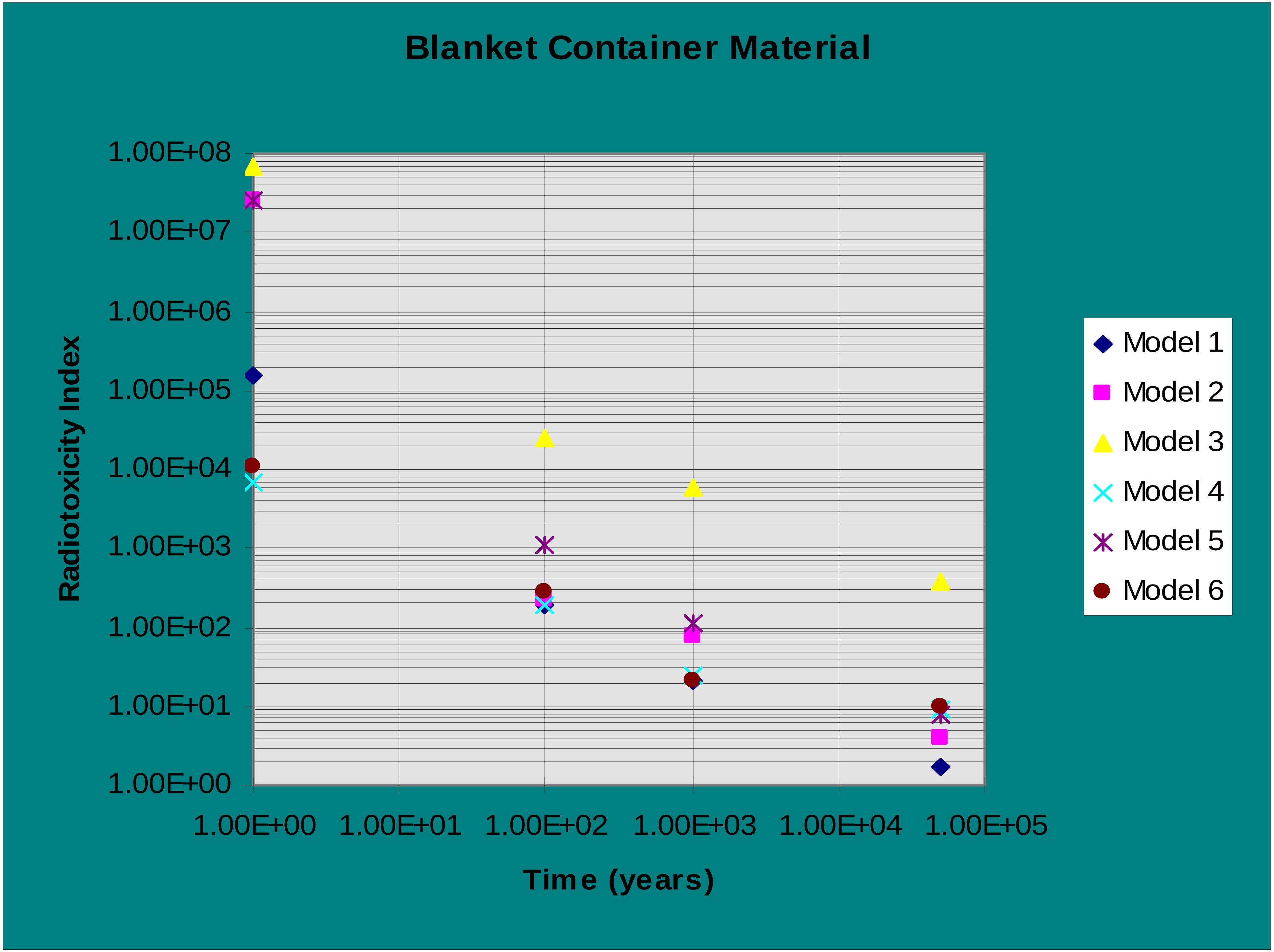
Potential Fusion Reactor Waste

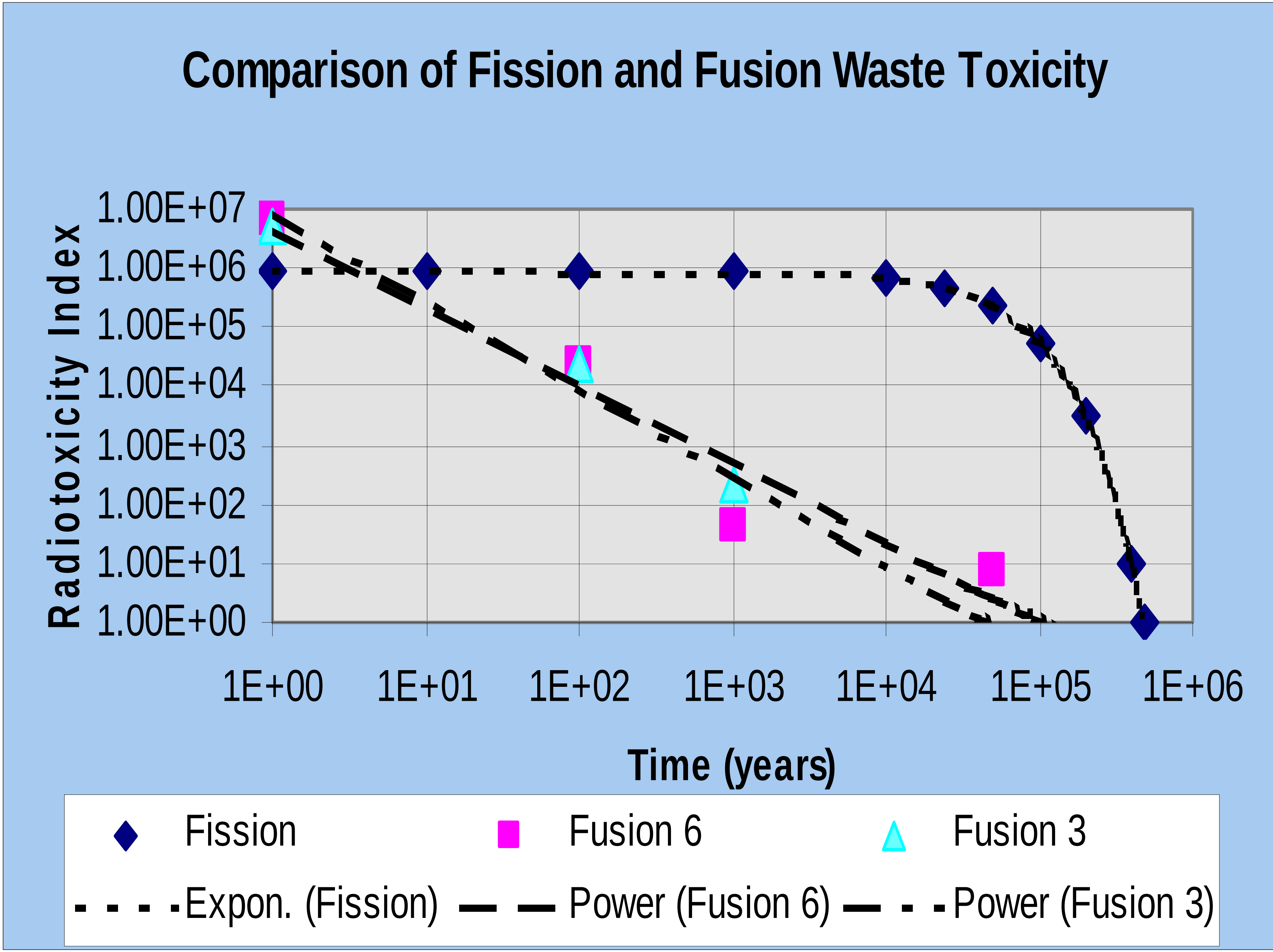


Potential Operational Waste Materials

Reactor Model	Blanket Container	Breeding Material
1	V Alloy	Li_2O
2	LAM	Li-Pb
3	LAM	Li_4SiO_4
4	SiC/SiC	Li-Pb
5	LAM	Li-Pb
6	LAM	Li-Pb


Blanket Breeding Material
Radiotoxicity Index
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E+00
1.00E+01
1.00E+02
1.00E+03
1.00E+04
1.00E+05
Time (years)
Model 1
Model 2
Model 3
Model 4
Model 5
Model 6


Blanket Container Material
Radiotoxicity Index
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E+00
1.00E+01
1.00E+02
1.00E+03
1.00E+04
1.00E+05
Time (years)
Model 1
Model 2
Model 3
Model 4
Model 5
Model 6



Comparison of Fission and Fusion Waste Toxicity
Radiotoxicity Index
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1E+00
1E+01
1E+02
1E+03
1E+04
1E+05
1E+06
Time (years)
Fission
Fusion 6
Fusion 3
Expon. (Fission)
Power (Fusion 6)
Power (Fusion 3)

Proven Waste Disposal Facility


Licensing

Regulatory Responsibilities

Protection of public health

Protection of public safety

Protection of worker health

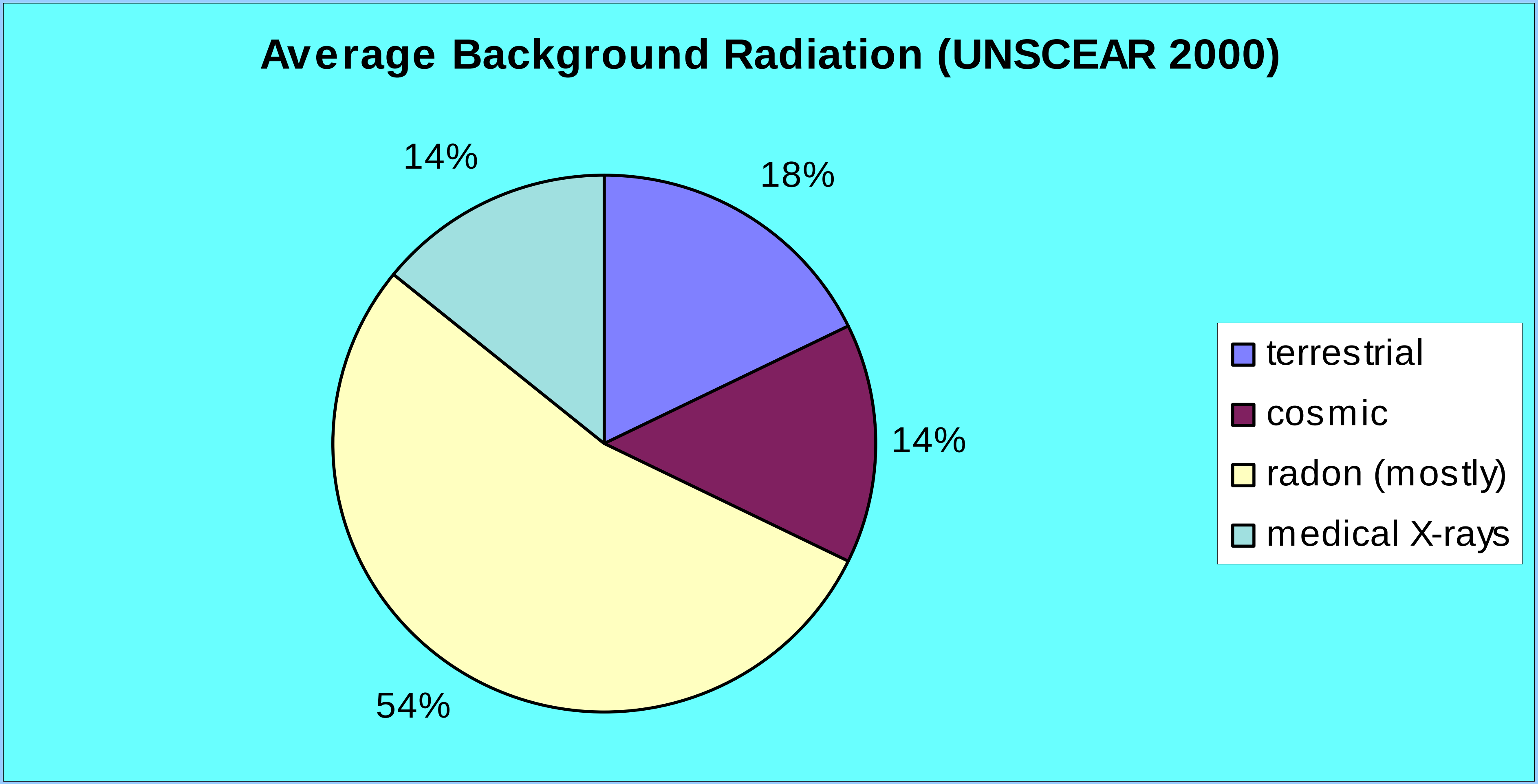
Protection of worker safety

Protection of the environment

Protection of Public Health

The ICRP has recommended that the dose to any member of the general public, arising from the operation of a nuclear facility, be limited to 1 mSv/a [ICRP60].

Sources of Background Radiation



Natural Background radiation

Table 1
Average radiation dose from natural sources

Source	*Worldwide average annual effective dose (mSv)*	*Typical range (mSv)*
External exposure		
Cosmic rays	0.4	0.3-1.0 [a]
Terrestrial gamma rays	0.5	0.3-0.6 [b]
Internal exposure		
Inhalation (mainly radon)	1.2	0.2-10 [c]
Ingestion	0.3	0.2-0.8 [d]
Total	2.4	1-10

a Range from sea level to high ground elevation.
b Depending on radionuclide composition of soil and building materials.
c Depending on indoor accumulation of radon gas.
d Depending on radionuclide composition of foods and drinking water.

UNSCEAR 2000 Report

Contribution from Medical X-ray Examinations

Table 2
Radiation exposures from diagnostic medical x-ray examinations

Health care level	*Population per physician*	*Annual number of examinations per 1,000 population*	*Average annual effective dose to population (mSv)*
I	<1 000	920	1.2
II	1 000-3 000	150	0.14
III	3 000-10 000	20	0.02
IV	>10 000	<20	<0.02
Worldwide average		330	0.4

UNSCEAR 2000 Report

Variation in Background Radiation

Table 11
Areas of high natural radiation background

1000 nGy/h = 8.76 mGy/a

Country	*Area*	*Characteristics of area*	*Approximate population*	*Absorbed dose rate in air* [a] *(nGy h⁻¹)*	*Ref.*
Brazil	Guarapari Mineas Gerais and Goias Pocos de Caldas Araxá	Monazite sands; coastal areas Volcanic intrusives	73 000 350	90–170 (streets) 90–90 000 (beaches) 110–1 300 340 average 2 800 average	[P4, V5] [A17, P4] [V5]
China	Yangjiang Quangdong	Monazite particles	80 000	370 average	[W14]
Egypt	Nile delta	Monazite sands		20–400	[E3]
France	Central region Southwest	Granitic, schistous, sandstone area Uranium minerals	7 000 000	20–400 10–10 000	[J3] [D10]
India	Kerala and Madras Ganges delta	Monazite sands, coastal areas 200 km long, 0.5 km wide	100 000	200–4 000 1 800 average 260–440	[S19, S20] [M13]
Iran (Islamic Rep. of)	Ramsar Mahallat	Spring waters	2 000	70–17 000 800–4 000	[S21] [S58]
Italy	Lazio Campania Orvieto town South Toscana	Volcanic soil	5 100 000 5 600 000 21 000 ~100 000	180 average 200 average 560 average 150–200	[C12] [C12] [C20] [B21]
Niue Island	Pacific	Volcanic soil	4 500	1 100 maximum	[M14]
Switzerland	Tessin, Alps, Jura	Gneiss, verucano, ^{226}Ra in karst soils	300 000	100–200	[S51]

a Includes cosmic and terrestrial radiation.

Public Health Protection in Perspective

Max. dose to member of general public = 1 mSv/a

Average background radiation = 2.4 mSv/a

Average range of background radiation = 1 – 10 mSv/a

Average background radiation in Madras = 16 mSv/a

Max. background radiation anywhere = 788 mSv/a
(on the beaches of Guarapari, Brasil)

1 mSv/a translates into a release of about 20 g/a of tritium as HTO and about 150 g/a of tokamak dust.

Compliance with Public Health Requirement

Analyses performed for various power plant models suggest that tritium and tokamak dust releases from future fusion power plants should be well within the limits:

20 g/a of HTO, and

150 g/a of tokamak dust

Moreover, operating experience from JET and TFTR confirms such expectations.

Worker Health Protection

The ICRP has recommended that occupational radiation exposures be limited to 100 mSv per rolling five-year period.

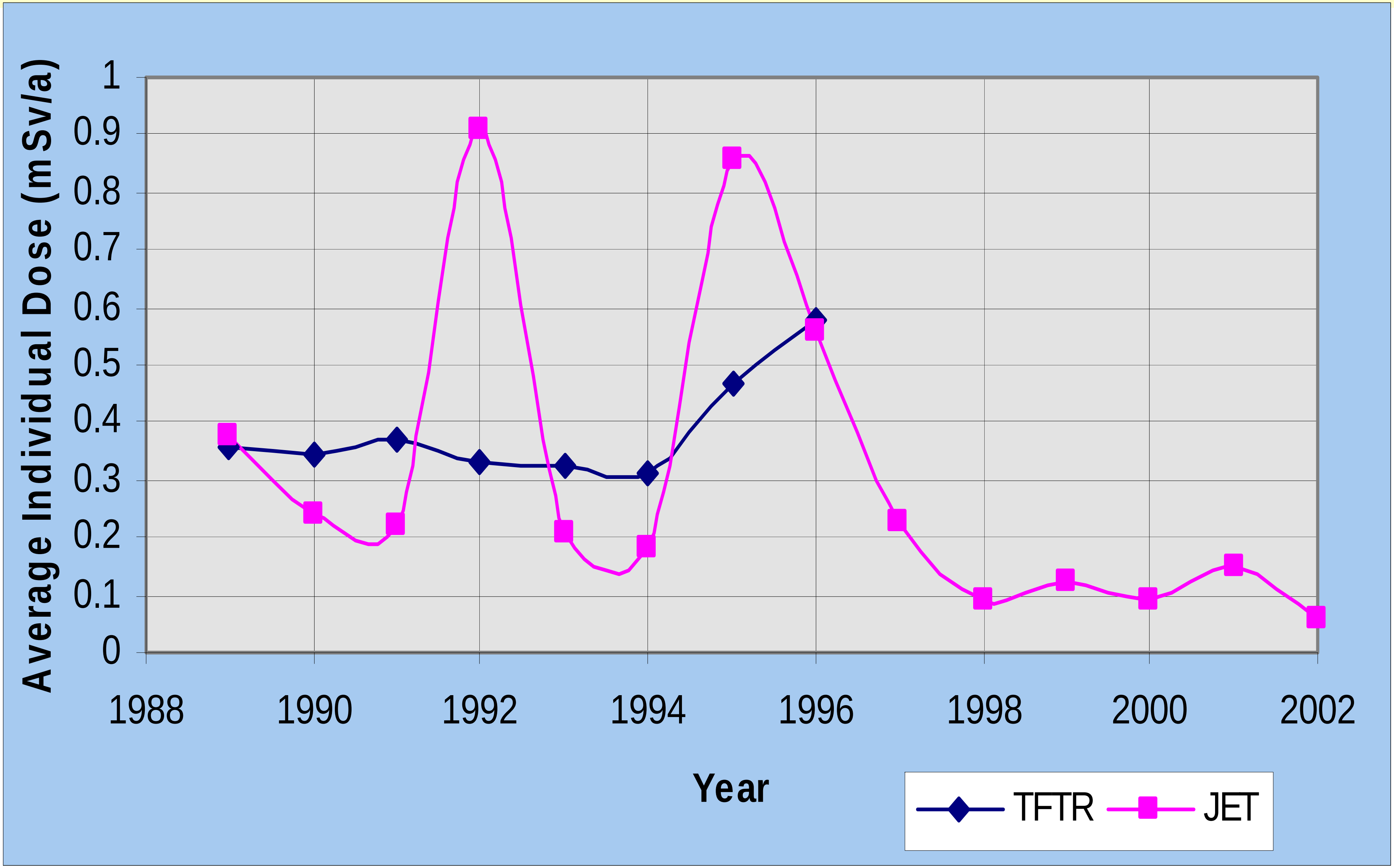
The ICRP has also recommended that all doses be maintained ALARA.

Compliance with Worker Health Requirement

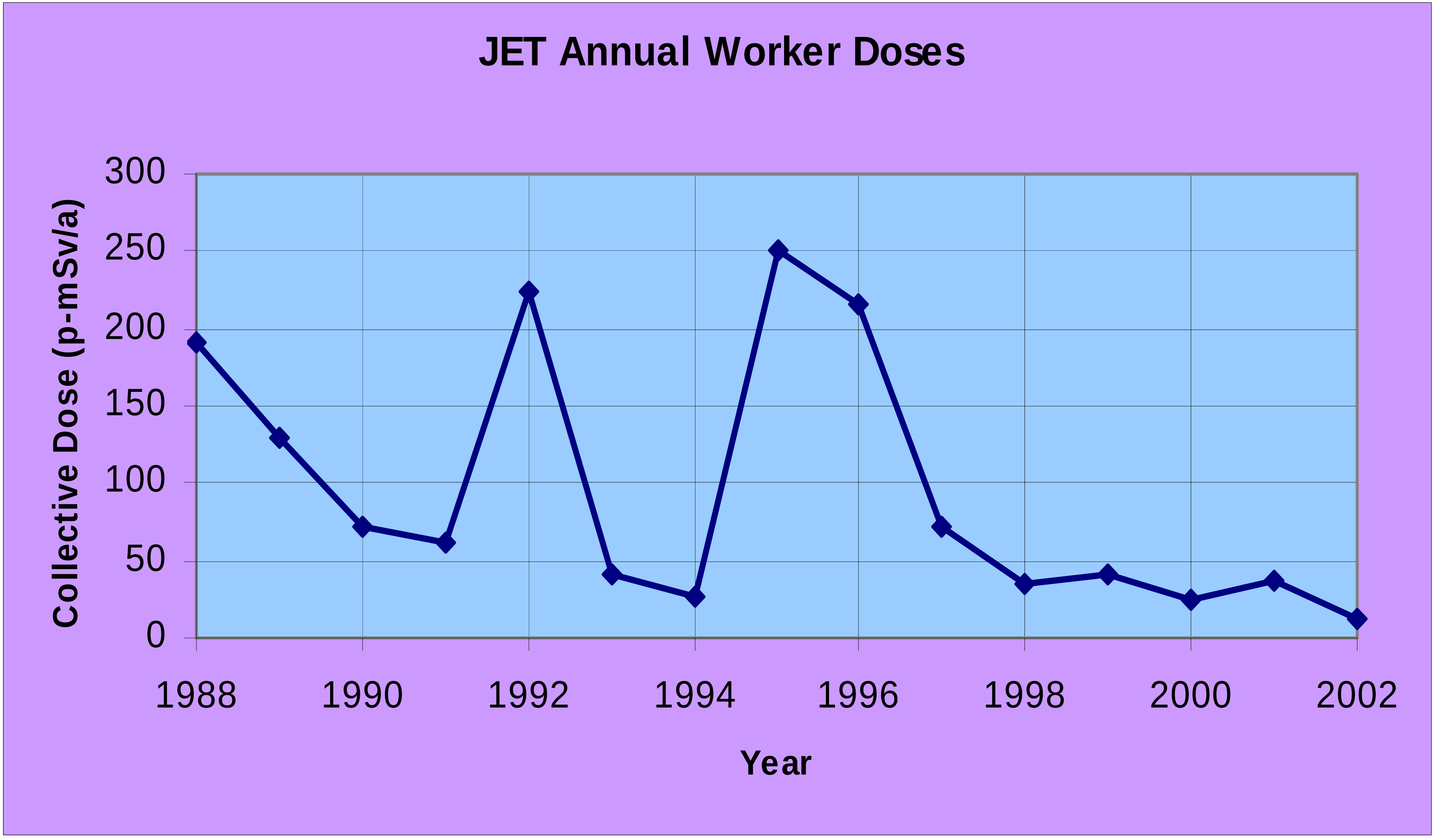
Table 3
Occupational radiation exposures

Source / practice	*Number of monitored workers (thousands)*	*Average annual effective dose (mSv)*
Man-made sources		
Nuclear fuel cycle (including uranium mining)	800	1.8
Industrial uses of radiation	700	0.5
Defence activities	420	0.2
Medical uses of radiation	2 320	0.3
Education/veterinary	360	0.1
Total from man-made sources	4 600	0.6
Enhanced natural sources		
Air travel (crew)	250	3.0
Mining (other than coal)	760	2.7
Coal mining	3 910	0.7
Mineral processing	300	1.0
Above ground workplaces (radon)	1 250	4.8
Total from natural sources	6 500	1.8

Compliance with Worker Health Requirement



Compliance with ALARA (ALARP)



Compliance with ALARA

Satisfying the ALARA requirement could be the most difficult licensing issue with respect to the health regulations.

Worker Safety Requirements

There are no specific radiation protection requirements for workers under postulated accident conditions.

Public Safety Requirements

Design using Defence-in-Depth

focus on accident prevention

high standards of design, manufacturing, construction and installation

Assess design using Accident Analysis

focus on accident mitigation and containment

Public Safety Requirements

Design Basis Accident

assess public consequences

Public Dose Limit

250 mSv

yard-stick for assessing acceptability of DBA consequences

Probabilistic Safety Assessment

Uses event trees to generate all possible plant-damage-states, from single initiating event

hundreds of initiating events analyzed in typical PSA

Uses fault trees to estimate each plant-damage-state frequency

hundreds of fault trees needed in a typical PSA

Sample Worst-Case Accident

Tritium release directly to environment

- 1 kg of tritium in HTO form
- ground-level release
- stable atmospheric conditions
- no mitigation

Worst-Case Accident Consequence

Estimated Public Dose ~ 1 Sv

1 Sv ~ threshold for radiation sickness

Health Effects (UNSCEAR 2000)

Table 11
Emergency workers with acute radiation sickness following the accident
[I5]

Degree of acute radiation sickness	*Range of dose (Gy)*	*Number of patients treated* [a]		*Number of deaths* [b]	*Number of survivors*
		Moscow	*Kiev*		
Mild (I)	0.8–2.1	23	18	0 (0%)	41
Moderate (II)	2.2–4.1	44	6	1 (2%)	49
Severe (III)	4.2–6.4	21	1	7 (32%)	15
Very severe (IV)	6.5–16	20	1	20 (95%)	1
Total	0.8–16	108	26	28	106

a Acute radiation sickness was not confirmed in a further 103 treated workers.
b Percentage of treated patients in parentheses.

Possible Worst-Case Accident Consequence Mitigation

Sheltering

Normal weather instead of worst-case

HT release instead of HTO

Elevated release instead of ground-level

Worst-Case Accident with Minimal Mitigation

Minimum dose reduction from

1 Sv to 0.1 Sv

Comparison between Fusion & Fission Worst-Case Accident

Fusion has significantly lower consequences provided:

- mobilizable tritium inventory < 1 kg
- no significant quantities of mobilizable tokamak dust << 10 kg

Tokamak Dust – Potential Issue

The release of 10 kg of tokamak dust would have about the same dose consequence as the release of 1 kg of tritium (HTO).

Ground deposition would be problematic, however

Summary & Conclusions

Worst-case accident consequences have been problematic for fission reactor licensing

The same should not be true for fusion reactor licensing, however

Tokamak dust is only potential licensing issue

Summary & Conclusions

General public has witnessed broken promises wrt fuel waste disposal in fission industry

Therefore, public will be skeptical about similar promises from fusion industry.
Two factors favour fusion, however:

- established disposal solution in time for fusion
- low radio-toxicity index