

Environmental Aspects of Fusion Power

1.) Curies/unit power = C

2.) Biological Hazard Potential

$$BHP^i = \frac{C^i}{(MPC)_i}$$

where $(MPC)_i$ is the maximum permissible concentration of radioisotope i in :

- air (inhalation) mainly for accidents
- water (ingestion) mainly for leakage in waste storage facilities

MPC Example - ^{55}Fe

	Occupational		General Public	
	microcurie/ml		microcurie/ml	
Form	Air	Water	Air	Water
soluble	9×10^{-7}	2×10^{-2}	3×10^{-8}	8×10^{-8}
insoluble	1×10^{-6}	7×10^{-2}	3×10^{-8}	2×10^{-3}

$$MPC \dots \propto \frac{1}{\text{Eff. Half - Life} \dots t_{1/2}^E}$$

$$\frac{1}{t_{1/2}^E} = \frac{1}{t_{1/2}^B} + \frac{1}{t_{1/2}^P}$$

if $t_{1/2}^P \gg t_{1/2}^B$ then $MPC \propto \frac{1}{t_{1/2}^B}$

if $t_{1/2}^B \gg t_{1/2}^P$ then $MPC \propto \frac{1}{t_{1/2}^P}$

Radwaste Class	Period from Decay to Acceptable Level	Meets Minimum Waste Form Requirements	Meets Stability Requirements	Provide an Intruder Barrier	Depth of Burial
A	<<100 years	Yes	No	No	<<5 m
B	< 100 years	Yes	Yes	No	< 5 m
C	< 500 years	Yes	Yes	Yes	> 5 m
Deep Burial	> 500 years	Yes	Yes	Yes	Deep Geological Burial

Elemental Composition of Normal and Reduced Activation Steels

	<i>Concentration in Wt. %</i>			
Element	PCA	Tenelon	HT-9	MHT-9
B	0.005	0.001	0.01	0.001
C	0.005	0.15	0.2	0.15
N	0.01	0.005	0.05	0.001
O		0.007	0.01	0.007
Al	0.03	0.008	0.01	0.008
Si	0.5	0.2	0.35	0.2
P	0.01	0.13	0.02	0.013
S	0.005	0.004	0.02	0.004
Ti	0.3	0.003	0.09	0.1
V	0.1	0.002	0.3	0.3
Cr	14.0	15.0	12.0	11.0
Mn	2.0	15.0	0.55	0.53
Fe	64.88	69.4	85.0	85.2
Co	0.03	0.005	0.02	0.005
Ni	16.0	0.006	0.5	0.006
Cu	0.02	0.003	0.09	0.003
Zr	0.005	0.001	0.001	0.001
Nb	0.03	0.00011	0.0011	0.00011
Mo	2.0	0.00027	1.0	0.00027
Ag	0.0001	0.00009	0.0001	0.00009
Sn	0.005	0.003	0.003	0.003
Ta	0.01	0.0004	0.001	0.0004
W	0.05	0.01	0.5	2.50
Pb	0.001	0.0005	0.001	0.0005
Bi	0.001	0.0002	0.001	0.0002

Density of Radioactivity

Curies

cm³

Alloy	t = 0	t = 1 d	t = 1 y	t = 100 y
Nb1Zr	158	94	0.0006	0.00005
TZM	125	83	0.04	0.007
316 SS	100	68	29	0.005
2024 Al	44	8.7	0.3	0.00001
V-20Ti	27	6.6	0.31	<10 ⁻³⁷
Nat U				0.000006->

BHP- Level Figure-air,water

Alloy	<i>km³ Air</i>	<i>km³ Water</i>	
	<i>cc - metal</i>	<i>cc - metal</i>	
	t=0	t=100 Y	t=10,000
TZM	2.9	1.0	0.7
316SS	2.0	5.4	0.03
2024 Al	0.55	0.2	0.2
Nb1Zr	0.36	0.6	0.3
V-20Ti	0.2	insig.	insig
Natural U	0.001	0.2	0..2

The "Everything Goes Deep" Philosophy

One School of Thought at the IEA Workshop on Low Activation Material, Culham, UK, 8-12 April 1991

"Shallow land burial is impractical and politically unsound. This is true in many European countries at present and will probably be true in the US soon. It should be dropped from consideration in definition of criteria for low activation materials."

The "Everything Goes Deep" Philosophy

Implication

"If deep geological disposal replaces shallow land burial, then there is a greatly reduced benefit of low activation over conventional materials."

"The emphasis may shift from long lived radioactivity to short term afterheat (safety) problems. Manganese, because of the high vapor pressure is not favored in this scenario."

Another way to approach radioactivity is to calculate the total BHP over the life time of an isotope (a long lived isotope could effect many generations)

Integrated BHP = IBHP

$$\text{IBHP}(i) = (\text{BHP})_i \cdot \int_{t=0}^{\infty} \exp(-\lambda t) dt$$

$$\text{where } \lambda = \frac{0.693}{t_{1/2}^P}$$

$$\text{IBHP}(i) = \text{BHP}(i)_{t=0} \frac{t_{1/2}^P}{0.693}$$

Since we are interested in long lived isotopes(much longer than a lifetime)

$$t_{1/2}^P \gg t_{1/2}^B$$

$$\text{IBHP} \propto t_{1/2}^P \cdot t_{1/2}^B$$

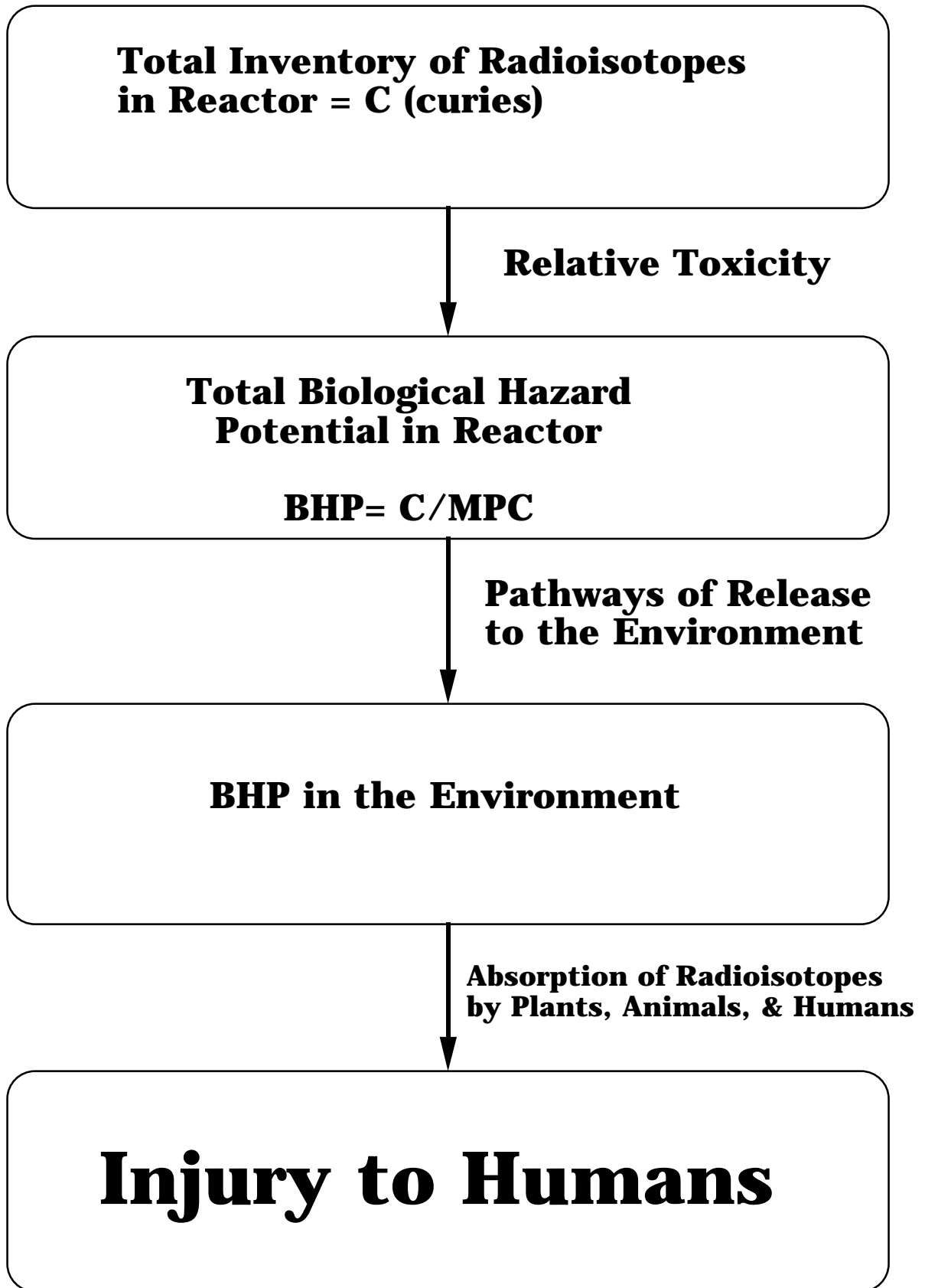
Summary of IBHP for Irradiated Fusion Materials for H₂O Diluent

Material	$\frac{10,000 \text{ km}^3 \text{ of } H_2O - s}{\text{cc of first wall}}$
2024 Al	46
TZM	24
316SS	23
Nb-1Zr	17
V-20 Ti	1.6
Natural U	0.2

Comparison of Integrated BHP For Fusion Reactor and LMFBR

	<u>IBHP</u> $\frac{\text{km}^3_{H_2O} - s}{\text{kW}_{th}} \times 10^{-5}$
Fission	60
2024 Al	10
316 SS	5
TZM	5
Nb-1Zr	4
V-20Ti	0.4

Radioactivity Concerns From Fusion



The Reasons for Developing Low Activation Stainless Steels Have Not Always Been the Same

Waste Disposal

Near Surface Burial (Class C)

Safety

**<10 Rem
Maximum Early Dose**

Maintenance

**< 1 mrem/hr
Contact Dose**

Recycling

**Contact Dose
< 1 rem/hr , t<100 Y
< 1 mrem/hr, t>100 Y**

Why Develop Low Activation Stainless Steels?

For	Against
Reduce Long Term Radiation Level to Allow Near Surface Burial	Usually Aggravates the Short Term Afterheat Problem
Reduce Long Term Waste Disposal Costs	Cost of Developing and Qualifying New Low Activation Alloy Can Be Substantial
Reduce Exposure to Workers if Alloy is Recycled	May Increase Short Term Radiation Levels and Increase Radiation Levels During Maintenance
Makes Fusion More Attractive to Environmentalists and Politicians	Time Involved in Developing and Qualifying Low Activation Materials May Delay the Implementation of Fusion