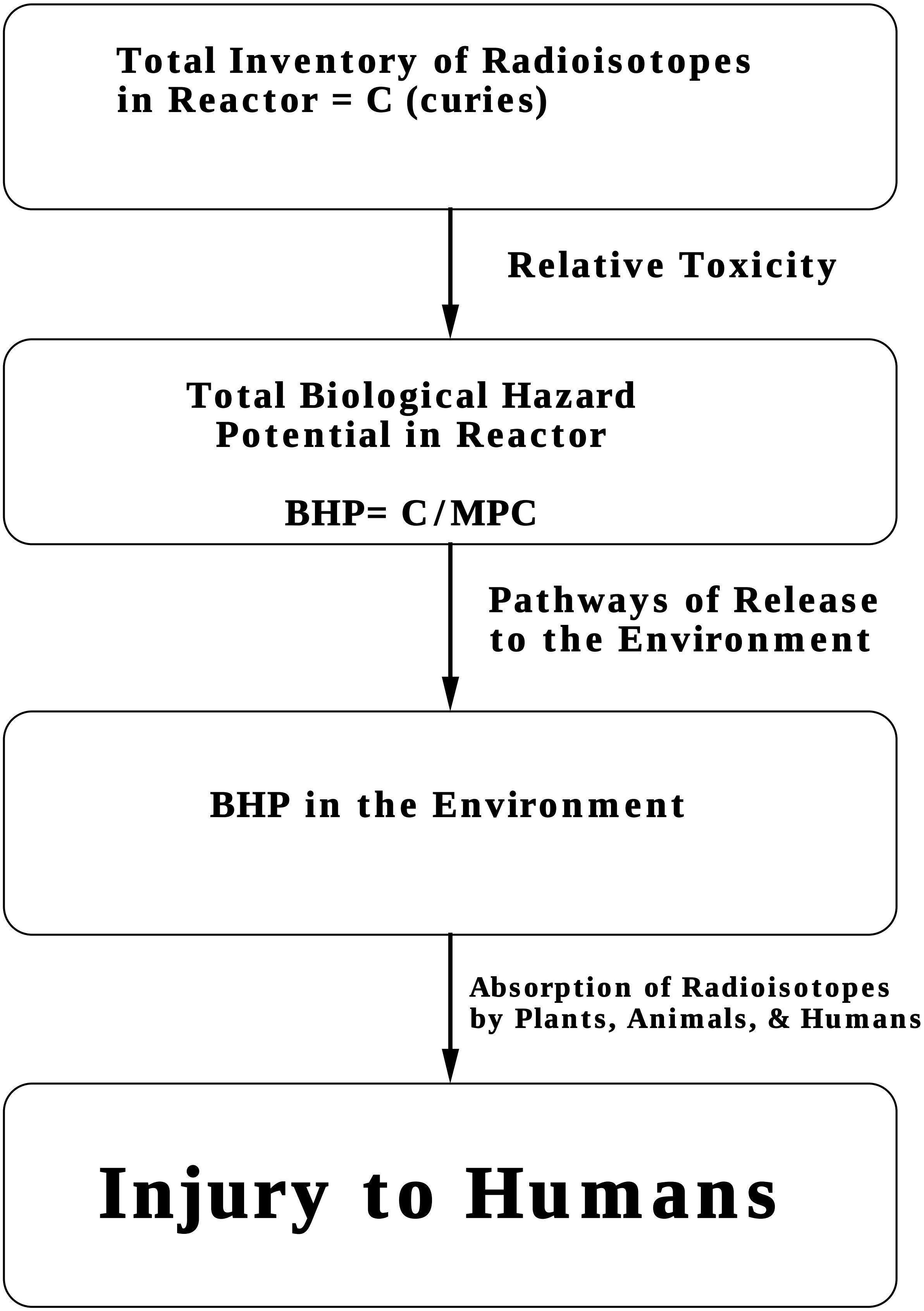
Radioactivity Concerns From Fusion



Total Inventory of Radioisotopes in Reactor = C (curies)

Relative Toxicity

Total Biological Hazard Potential in Reactor

BHP= C/MPC

Pathways of Release to the Environment

BHP in the Environment

Absorption of Radioisotopes by Plants, Animals, & Humans

Injury to Humans

Neutron Induced Activity in Fusion Structural Materials

- Associated with DT, DD, and even D^3He

- Very material dependent

- Design dependent (% structure, etc.)

Example

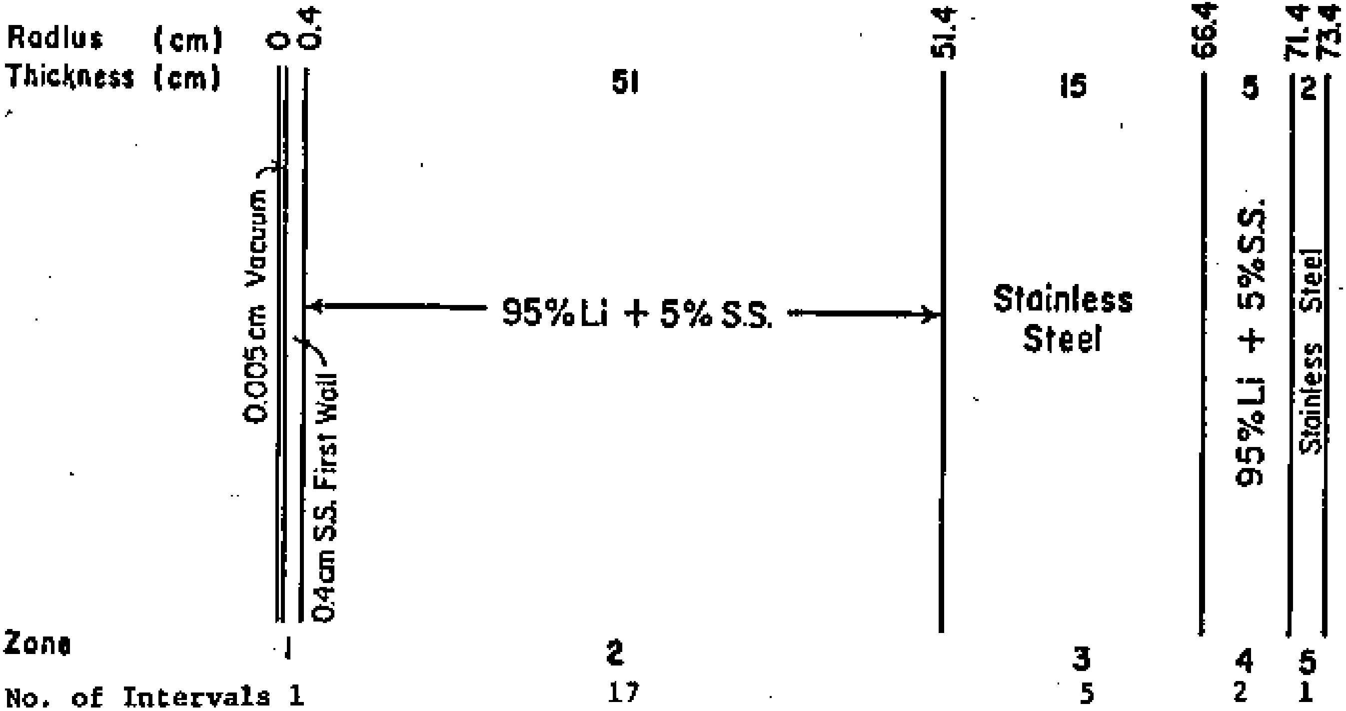
- DT
- 316 SS
- 2024 Al
- TZM
- V-20Ti
- Fixed Blanket Structure (see figure)

Use Calculational Procedure Developed by Sung-Vogelsang

"DKR-A Radioactivity Calculational Code for Fusion Reactors", UWFDM-170

"Decay Chain Data Library for Radioactivity Calculations", UWFDM-171

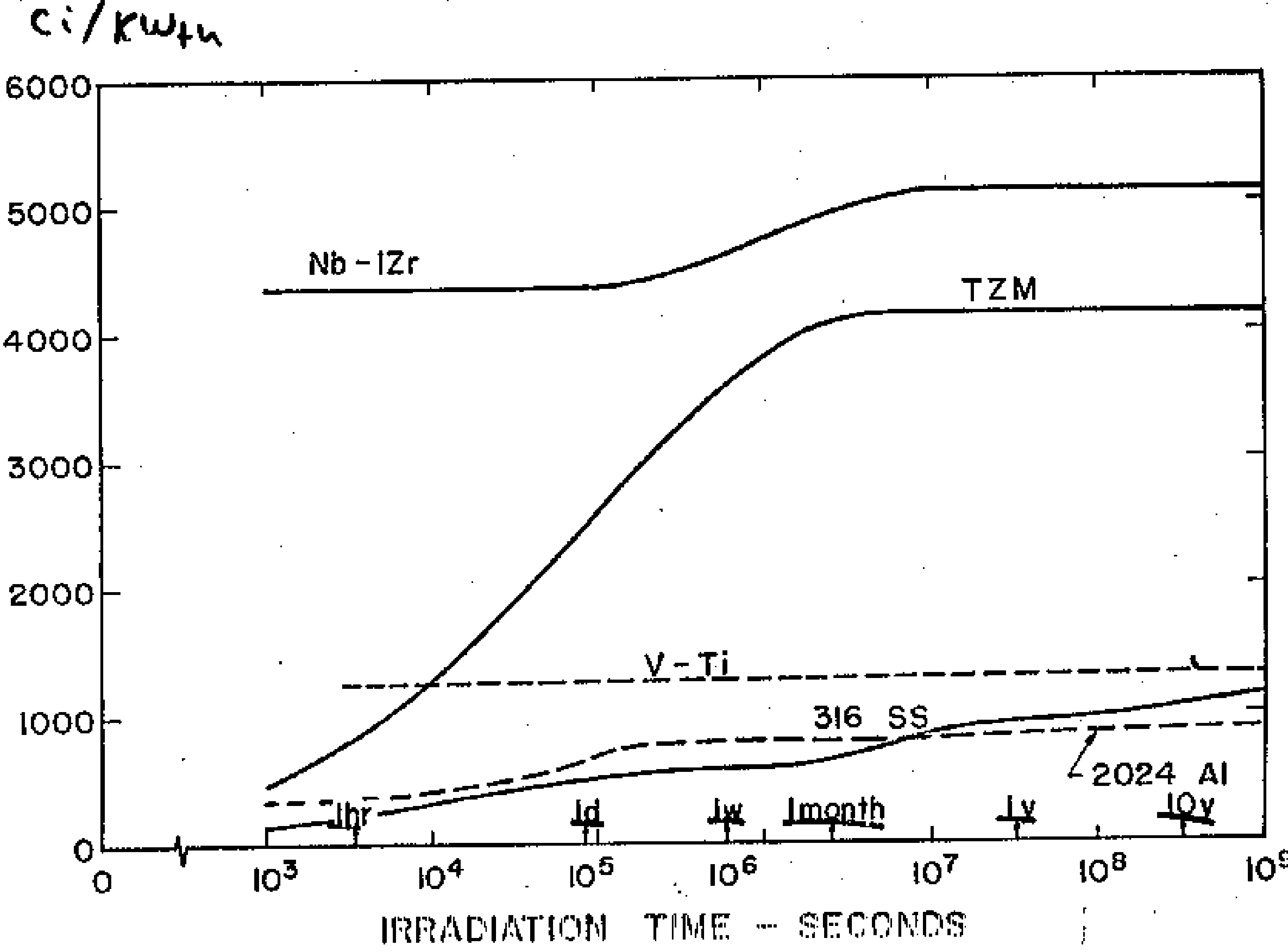
Tak Sung, PhD Thesis-Oct. 1976
"Radioactivity Calculations in Fusion Reactors"

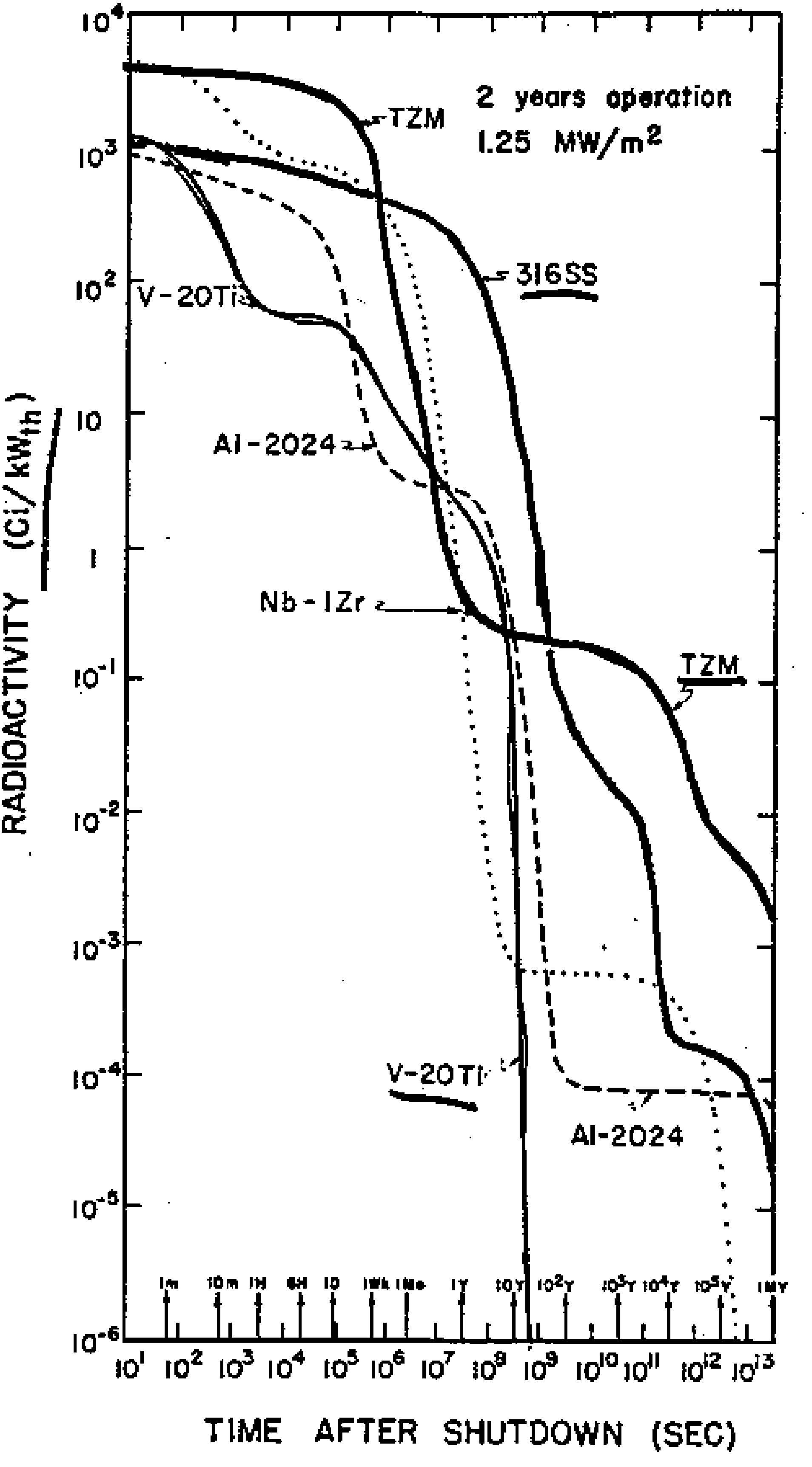


University of Wisconsin CTR Blanket Structure

UWMAK-I

Effect of Reactor Operation Time on Induced Activity in CTR Structural Materials



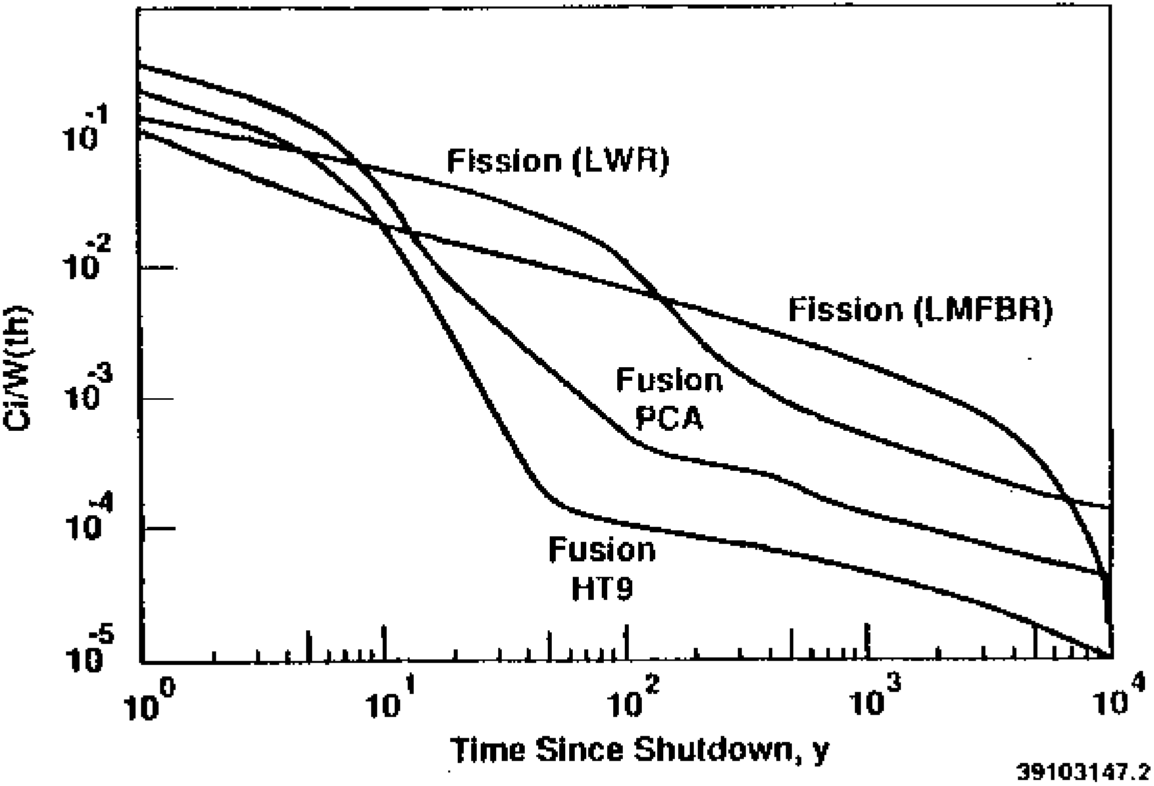

2 years operation
1.25 MW/m²
TZM
316SS
V-20Ti
Al-2024
Nb-1Zr
TZM
V-20Ti
Al-2024
RADIOACTIVITY (Ci/kWth)
10⁴
10³
10²
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
1m
10m
1H
6H
1D
1Wk
1Mo
1Y
10Y
10²Y
10³Y
10⁴Y
10⁵Y
1MY
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹
10¹⁰
10¹¹
10¹²
10¹³
TIME AFTER SHUTDOWN (SEC)

Time to Decay to Specific Levels of Radioactivity in Various CTR Designs

Level-Ci/kW	316 SS	TZM	Nb-1Zr	V-20 Ti	2024 Al
Initial	*1,060*	*4,120*	*5,150*	*1,260*	*8.80*
1,000	100 s	3 d	1 h	1 min	-
100	3 y	2 wks	1 mon	30 min	1 d
10	15 y	40 d	6 mon	2 wks	3 d
1	30 y	6 mon	1 y	3 y	4 y
0.1	60 y	3,000 y	1.5 y	10 y	20 y
0.01	2,000 y	40,000 y	2 y	15 y	30 y
0.001	5,000 y	1,000,000 y	5 y	20 y	40 y

Radioactivity in Fission and Fusion Reactors

Total for 30 yr Reactor Lifetime

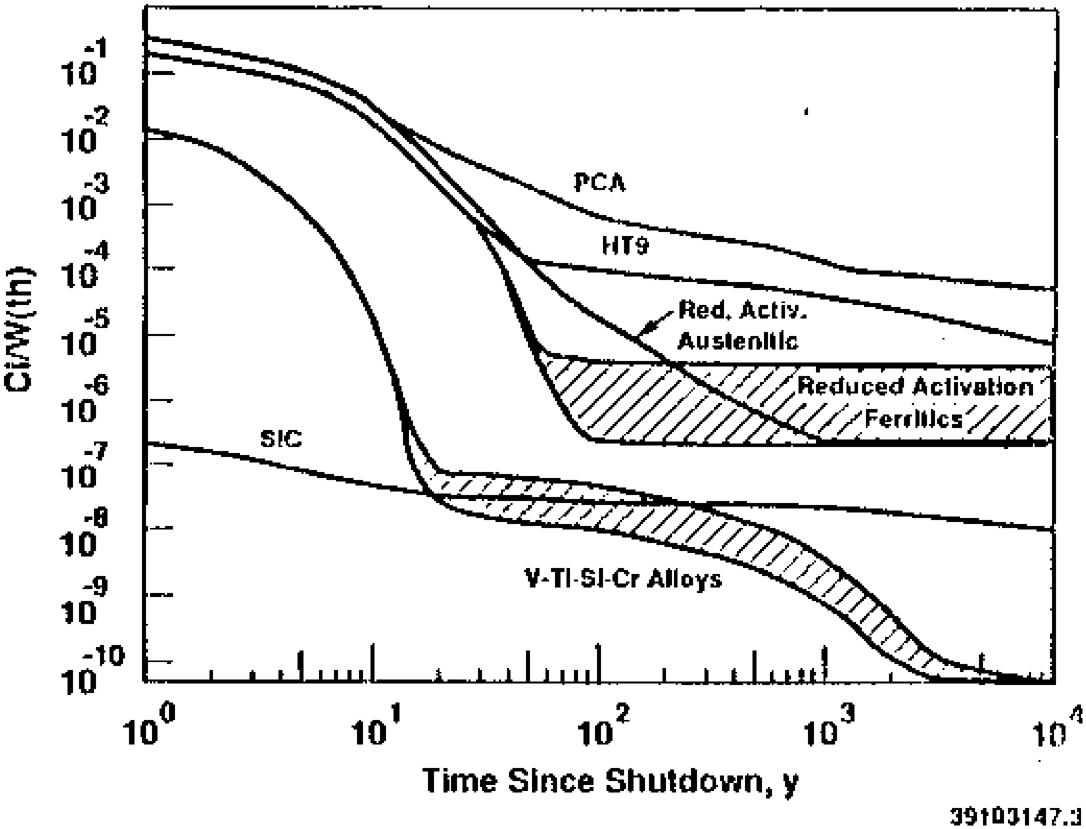


F. W. Wiffen

IEA Low Activation Materials Workshop
Culham, England April 8-12, 1991

Inventory of Radioactivity in a Fusion Reactor

STARFIRE, Total for 30 yr Reactor Lifetime



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Elemental Composition of Normal and Reduced Activation Steels

	Concentration in Wt. %			
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

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	<u>Contact Dose</u> < 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 Aggrevates the Short Term Afterheat Problem
Reduce Long Term Waste Disposal Costs	Cost of Developing and Qualifying New Low Activation Alloy Can Be Substantual
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

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**

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."

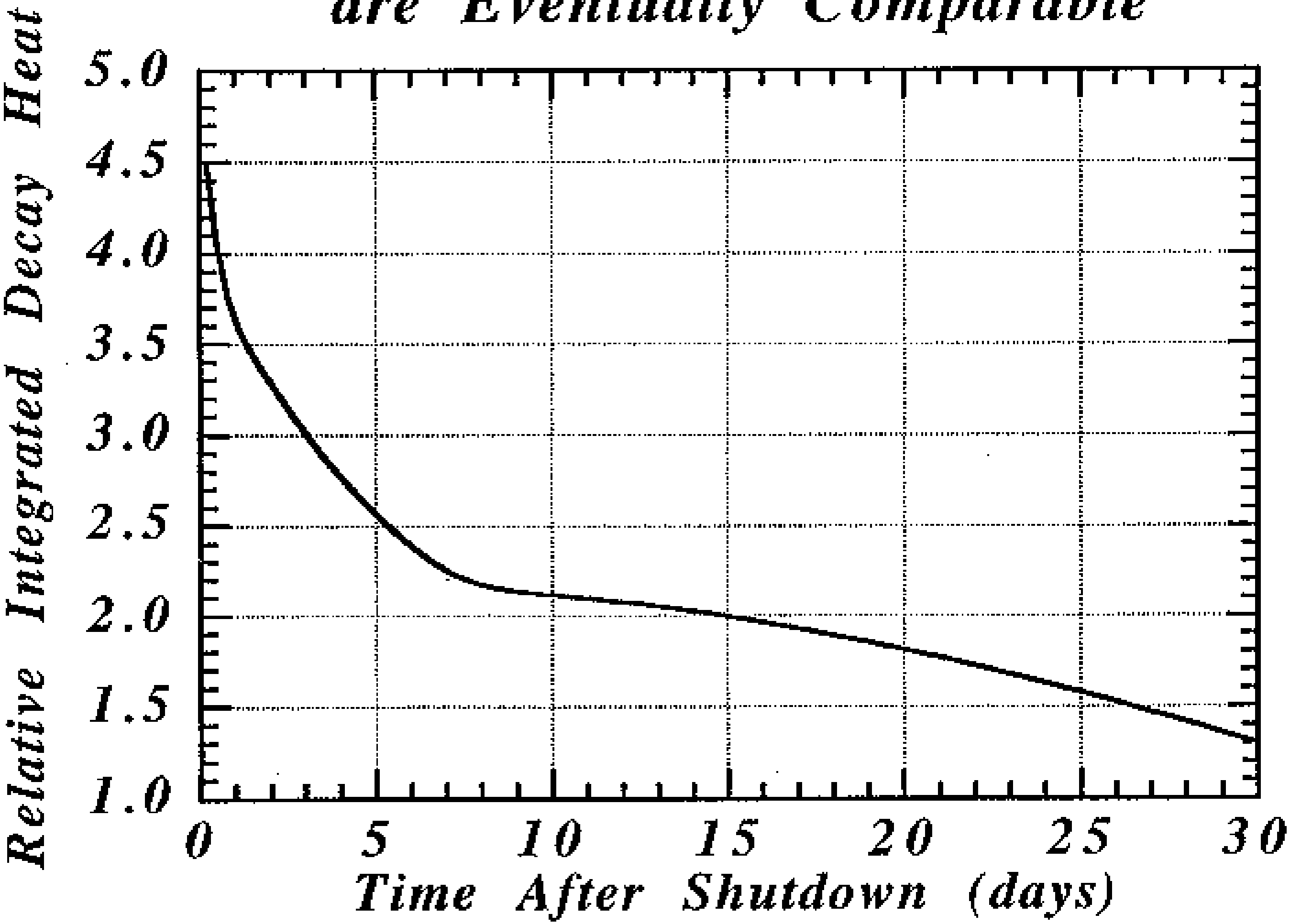
The "Everything Goes Deep" Philosophy

Implication

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

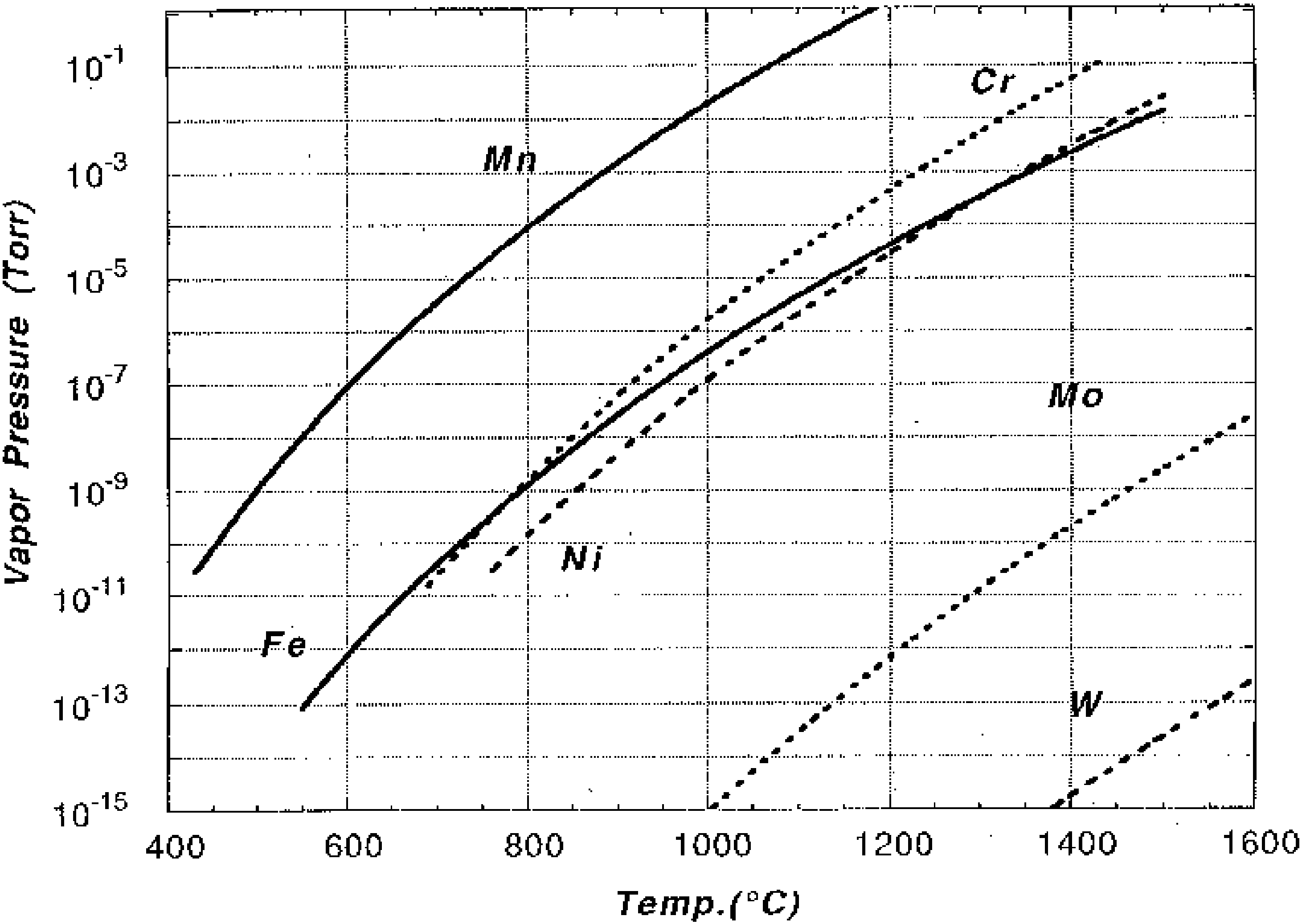
"The emphasis may shift from long lived radioactivity to short term afterheat (safety) problems. Manganese, because of the high vapor pressure is not favored in this scenario."

In Spite of High Short Term Afterheat From Mn steels, Total Energy Released by Mn-SS and 316 SS are Eventually Comparable



University of Wisconsin

Manganese is the Most Volatile Radioactive Alloy Element in Stainless Steels



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}

$$MPC..\alpha \frac{1}{Eff.Half-Life..t^{E}_{1/2}}$$

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

if $t^{P}_{1/2} >> t^{B}_{1/2}$ **then MPC** $\alpha \frac{1}{t^{B}_{1/2}}$

if $t^{B}_{1/2} >> t^{P}_{1/2}$ **then MPC** $\alpha \frac{1}{t^{P}_{1/2}}$

Density of Radioactivity

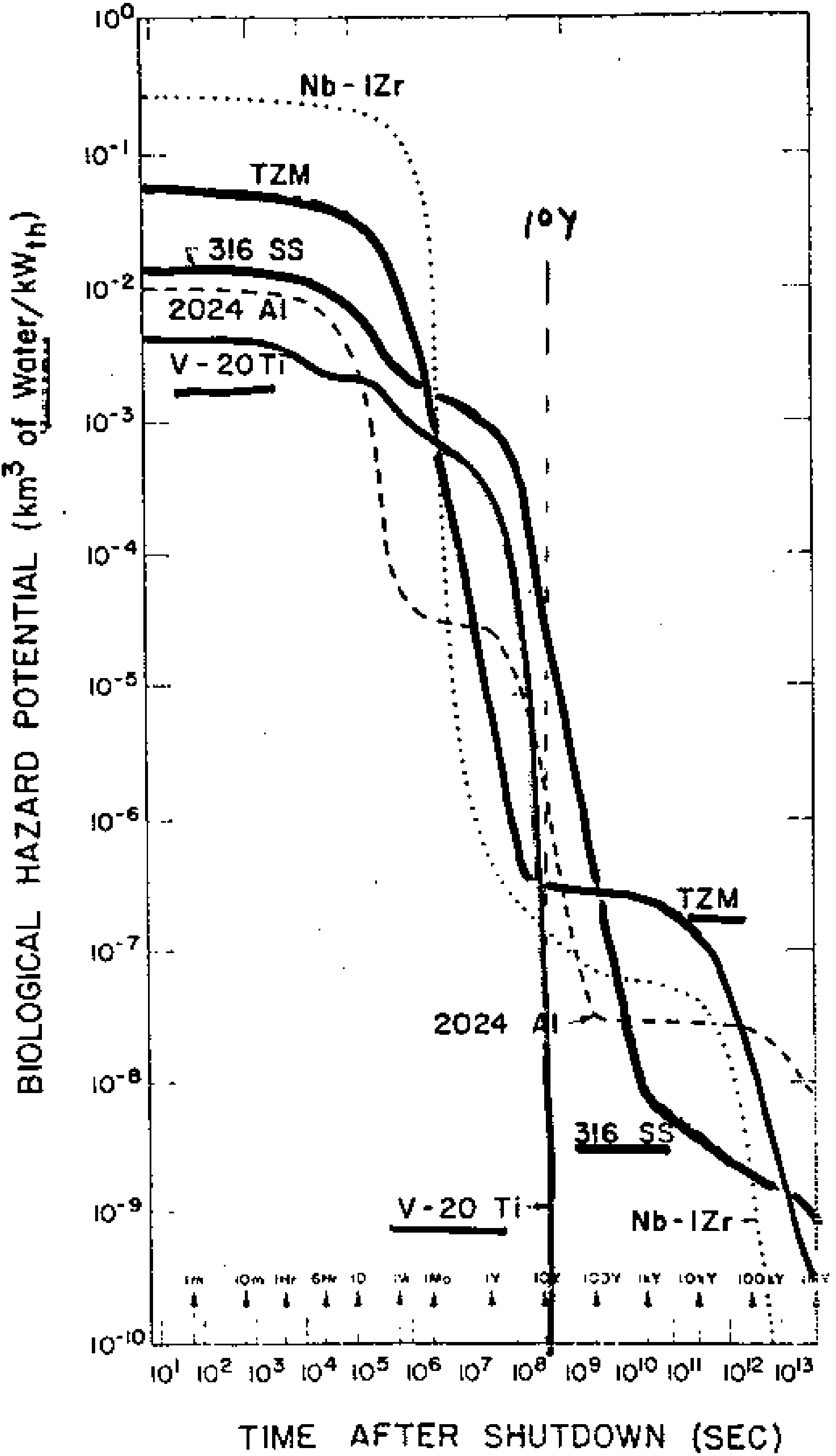
$$\frac{Curies}{cm^3}$$

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->

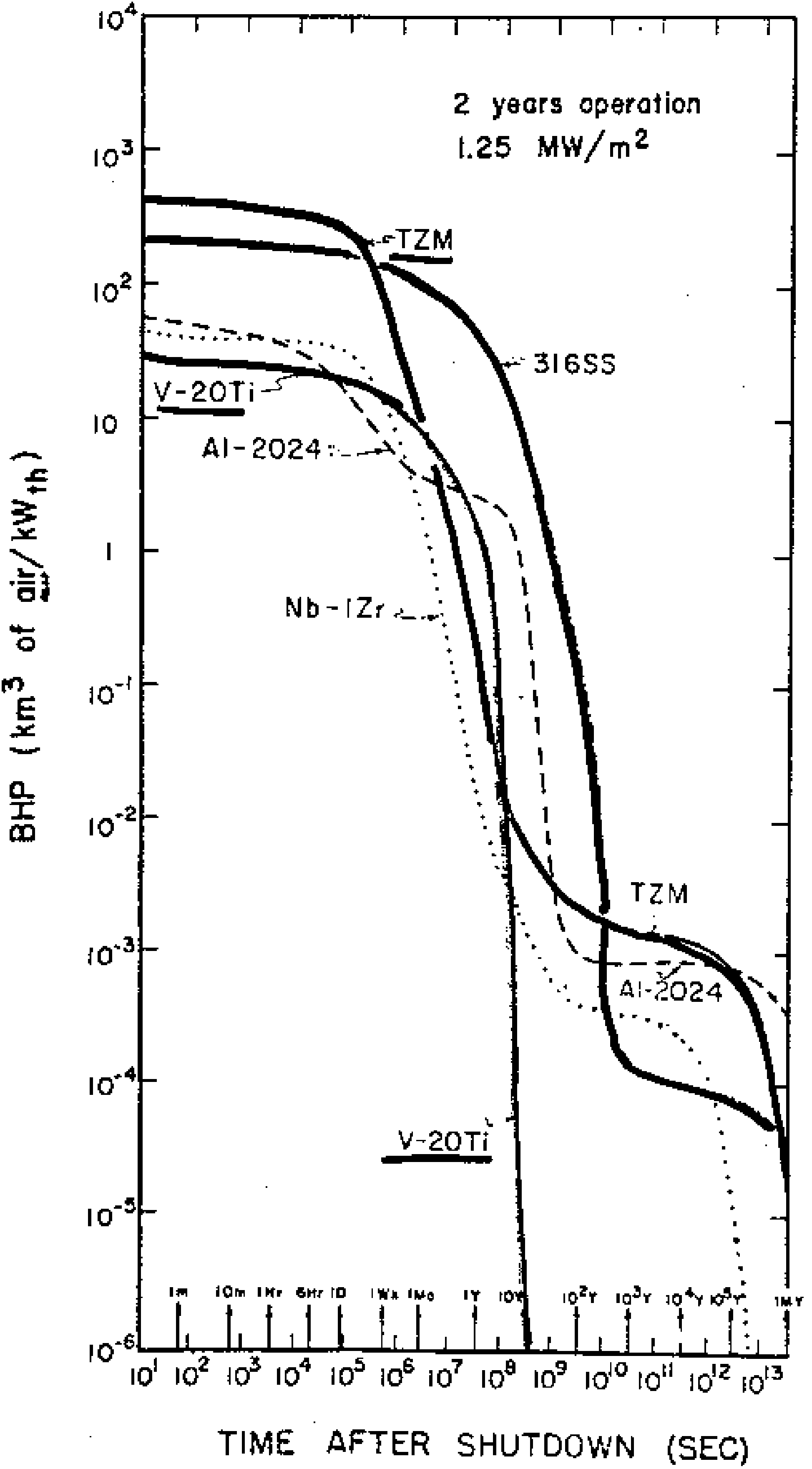
BHP- Level Figure-air,water

Alloy	$\frac{km^3 Air}{cc-metal}$	$\frac{km^3 Water}{cc-metal}$	
	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

CTR Blankets After Shutdown - H_2O Diluent



Biological Hazard Potential (BHP) of CTR Blankets After Shutdown



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

$$\mathrm{IBHP}^{(i)} = (\mathrm{BHP})^{i} \bullet {}_{t=0} \int \exp(-\lambda t)\, dt$$

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

$$\mathrm{IBHP}^{(i)} = \mathrm{BHP}^{(i)}_{t=0} \; \frac{t_{\frac{1}{2}}^{P_i}}{0.693}$$

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

$$t^{p}_{1/2} >> t^{B}_{1/2}$$

$$\mathrm{IBHP} \;\; \alpha \;\; t^{p}_{1/2} \cdot t^{B}_{1/2}$$

Summary of IBHP for Irradiated Fusion Materials for H_2O Dilutent

Material	$\frac{10,000\ km^3 of\ H_2O - s}{cc\ of\ \ first\ wall}$
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

	IBHP $\frac{km^3_{H_2O} - s}{kW_{th}}\ \ x\ 10^{-5}$
Fission	60
2024 Al	10
316 SS	5
TZM	5
Nb-1Zr	4
V-20Ti	0.4