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FUSION REACTOR RADIOACTIVE WASTE MANAGEMENT

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MASTER

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Quantities and compositions of non-tritium radioactive waste are estimated for some current conceptual fusion reactor designs, and disposal of large amounts of radioactive waste appears necessary. Although the initial radioactivity of fusion reactor and fission reactor wastes are comparable, the radionuclides in fusion reactor wastes are less hazardous and have shorter half-lives. Areas requiring further research are discussed.

INTRODUCTION

The large neutron fluxes in the first generation fusion reactors will activate the reactor structural materials, coolants, and impurities in the coolants and fuel materials. Although many of the radioisotopes will remain in the structures and process streams until they decay to stable isotopes, others will be removed from the process streams by purification equipment, or will escape from the process equipment as a result of leakage.

This report analyzes several fusion reactor design concepts to determine the types and quantities of radionuclides that must be handled as radioactive waste, the quantities that must be stored as solid waste, and the quantities released as liquid or gaseous effluents.

Tritium is included in the analysis of this section only in those cases where tritium accompanies other radionuclides in solid waste.

This report is divided into four sections. The first section describes the sources of radioactive waste for five fusion reactor design concepts:

- Tokamak University of Wisconsin (UWMAK-I)
Brookhaven National Laboratory (BNL)
Princeton Plasma Physics Laboratory (PPPL)
Oak Ridge National Laboratory (ORNL)
- Theta Pinch Los Alamos Scientific Laboratory (LASL)

The second section summarizes the amounts of waste created. The third section describes inner wall disposal, and the final section identifies additional research needs.

Conceptual plant designs have been developed for several approaches to fusion energy production. These conceptual designs provide a framework for identifying the range of radioactive waste sources and treatment schemes that must be reevaluated for the first commercial fusion reactor. Changes in reactor design may significantly change the radioactive waste system. Therefore, the radwaste system designs and projected waste volumes described here apply only to existing specific fusion concept designs. The amounts of waste and the

environmental effects described should be interpreted as a worst case based on current technology. Advances in technology before commercial fusion reactors are operated could reduce the amount of radwaste.

1.0 GENERAL SOURCES OF RADIOACTIVE WASTE

Each conceptual power plant design was analyzed to determine the plant systems that would be expected to create radioactive waste. This section identifies these systems.

1.1 WASTE SOURCE TERMS FOR UWMAK-I

In the conceptual design for UWMAK-I⁽¹⁾, reactor systems and operations expected to yield significant quantities of radioactive waste were identified.

Solid Waste Sources. Solid waste contaminated with radioactive materials will be produced in the following systems:

- . Lithium Cleanup System (Diverter and Blanket)
- . Sodium Cleanup System (Diverter and Blanket)
- . Vacuum System
- . Facility and Equipment Decontamination Processes
- . Equipment Replacement and Repair
- . Shield Cooling System

Liquid Waste Sources. Liquid waste will be generated primarily as a result of decontamination operations. Mercury used in vacuum pumps will become contaminated, but will be disposed of as a solid sludge or amalgam rather than as a liquid. Lubricating oil used in the vacuum pumps may be a source of liquid waste, but will be combined with absorbents to produce a solid waste. Liquid waste will come from equipment decontamination solutions and laundry waste water.

Gaseous Waste Sources. Gaseous waste will be generated in inleakage of air into the plasma region, and by production of helium from fusion. The gases will have

to be removed from the vacuum system and the lithium cleanup system.

1.2 WASTE SOURCE TERMS FOR PPPL TOKAMAK

The PPPL Tokamak design⁽²⁾ has materials and coolants that may produce waste different from UWMAK-I wastes.

Solid Waste Sources. Solid waste contaminated with radioactive materials will be produced by the following systems in the PPPL Tokamak.

- . Flibe Cleanup System
- . Vacuum System
- . Helium Coolant Cleanup System
- . Facility and Equipment Decontamination
- . Equipment Replacement and Repair

Liquid Waste Sources. Liquid waste will be generated primarily as a result of decontamination operations. Mercury used in vacuum pumps will become contaminated, but will be disposed of as a solid waste. Liquid will come from equipment decontamination solutions and laundry waste water.

Gaseous Waste Sources. Gaseous waste will be generated by inleakage of air into the plasma region, and by production of helium from fusion. These gases will have to be extracted from the vacuum system and from the flibe cleanup system.

1.3 WASTE SOURCE TERMS FOR ORNL TOKAMAK

Several distinguishing features of the ORNL Tokamak⁽³⁾ are: 1) inner wall blanket support material made from Nb-1%Zr, 2) no diverter protecting the inner wall, 3) plant sized to produce 1000 megawatts-thermal (Mwt) power, and 4) heat removed from the lithium metal blanket by heat exchangers cooled by liquid potassium. To simplify comparison of waste from the various reactor designs, the waste quantities were scaled to those expected for a 5000 Mwt plant.

Solid Waste Sources. Solid waste is expected to be generated by the following systems in the ORNL Tokamak:

- . Lithium Cleanup System
- . Potassium Cleanup System
- . Vacuum System
- . Shield Cooling System
- . Facility and Equipment Decontamination
- . Equipment Replacement and Repair

Liquid Waste Sources. Liquid waste sources are equipment decontamination solutions and laundry waste water.

Gaseous Waste Sources. There will be no air inleakage to the plasma chamber because of the vacuum building surrounding the reactor. Pressure in the vacuum building will be kept below 10^{-3} torr, hence air inleakage will be reduced to negligible levels.

1.4 WASTE SOURCE TERMS FOR THE THETA PINCH DESIGN⁽⁴⁾

Although the method for producing plasma and thermonuclear burn is unique, the inner wall hardware and the auxiliary systems resemble those of the tokamak designs. Niobium is used as the first wall material and lithium is used as the primary coolant and breeding material.

Solid Waste Sources. Solid waste is expected to be generated by the following systems in the reference theta pinch reactor:

- . Lithium Processing System
- . Fuel-ash Processing System
- . Vacuum System
- . Shield Cooling System
- . Facility and Equipment Decontamination
- . Equipment Replacement and Repair

Liquid Waste Sources. The liquid waste sources are the same as the liquid waste sources for the tokamak designs, that is, equipment decontamination solutions and laundry waste water.

Gaseous Waste Sources. The reference theta pinch design has a secondary vacuum chamber surrounding the plasma chamber to prevent inleakage of air which might become activated.

1.5 WASTE SOURCE TERMS FOR THE MINIMUM ACTIVATION BLANKET DESIGN⁽⁵⁾

In this concept the blanket uses an Al-Mg-Si alloy as the structural material. The blanket is designed to fit the UWMMAK-I reactor and to operate at the same first wall load, total thermal power, and plasma conditions.

This blanket design has two temperature zones. The cool zone is the aluminum structure bordering the plasma space cooling by a circulating water system designed for zero blowdown. The hotter zone inside the aluminum shells includes graphite, beryllium and solid lithium compounds and is cooled by recirculating helium.

Since the water and helium coolants are noncorrosive and because the water system is designed for zero blowdown, routine removal of activation products from the coolants will probably not be necessary. As a result, there should be a very small amount of nontritium radioactive waste from the coolant streams during routine operation.

Activation Products from Inleaking Air.

Since the plasma chamber is surrounded by a vacuum, there should be no air leaking into the plasma chamber. As a result, there should be no activation products from inleaking air.

2.0 SUMMARY OF RADIOACTIVE WASTE VOLUMES

This section summarizes the estimated amounts of waste resulting from normal fusion reactor operation. In addition, the number of 55 gallon drums of solid waste was estimated, allowing for void spaces, inert binders and shielding.

2.1 UWMMAK-I

The sources and quantities of solid and gaseous waste produced by operation of a UWMMAK-I reactor are summarized in Table 1, 2 and 3.

2.2 PPPL TOKAMAK

The sources and quantities of solid, liquid and gaseous waste produced by operation of a PPPL reactor are summarized in Table 4, 5 and 6.

2.3 ORNL TOKAMAK

The sources and quantities of solid and liquid waste produced by operation of a ORNL reactor are summarized in Table 7 and 8. No appreciable source of gaseous waste other than tritium has been

identified in the ORNL plant. Air inleakage, the gaseous waste source in the UWMAK-I and PPPL plants, is expected to be negligible because the reactor is located within a vacuum building.

2.4 THETA PINCH

A summary of waste from the reference Theta Pinch reactor is given in Table 9.

2.5 MINIMUM ACTIVATION BLANKET

A summary of waste from the Minimum Activation Blanket design is given in Table 10.

TABLE I Summary of Solid Waste From UWMAK-I

Waste Description	Source	Quantity/Year	Curies/Year	No. of 55 ga. Drums
Zirconium Foil	Impurity Traps	1.1×10^5 kg/yr	5×10^6	80
Li ₂ O	Li Cold Traps	800 kg/yr	1.1×10^5	2
Yttrium Foil	T Gettering	1870 kg/yr	1100	2
Na ₂ O	Na Cold Traps	80 kg/yr	1	(combine with Li ₂ O)
Charcoal	Cryopumps	4×10^4 kg/yr	5×10^5	110
Equipment	Various	70 M ³ /yr	27	340
Concrete and Bitumen	Liquid Waste Immobilization	330 M ³ /yr	80 ci/yr	1580
Other Solids	Hg Purification	1.6×10^3 kg/yr	5×10^5	2
			Total	2116

TABLE 2 Summary of Liquid Waste From UWMAK-I

Disposition	Waste Description	Source	Quantity/Year	Curies/Year
Released to Environment	Laundry Waste Water	Clothing Laundry	100,000 gal/yr	<1

TABLE 3 Gaseous Waste Produced by UWMAK-I

Waste Description	Source	Curies/Year
⁴¹ Ar	Activation of leaked air	~0
¹³ N	Activation of leaked air	~0
¹⁴ C(CO ₂)	Activation of leaked air	30

TABLE 4 Summary of Solid Waste From PPPL Tokamak

<u>Waste Description</u>	<u>Source</u>	<u>Quantity Year</u>	<u>Curies Year</u>	<u>Number of 55 gal. Drums</u>
Flibe + Corrosion Products	Salt Cleanup System	33 M ³	3.6 x 10 ⁷	145
Contaminated KF Salt	TF Decomposition	1 MT	4	13
Hg Amalgam	Vacuum System	2 M ³	7 x 10 ⁶	3
Solidified Oil	Vacuum System	2 M ³	<1	10
Yttrium	He and Gas Septn.	8 M ³	40	38
Bitumen	Decon. Processes	30 M ³	160	145
Concrete	Decon. Processes	300 M ³	160	1440
Equipment	Various	66 M ³	62	317
			Total	2111

TABLE 5 Summary of Liquid Waste From PPPL Tokamak

<u>Waste Description</u>	<u>Source</u>	<u>Quantity/Year</u>	<u>Curies/Year</u>
Laundry Waste Water	Clothing Laundry	100,000 gal	<1

The dilute aqueous waste would be released to the environment by mixing it with cooling tower blowdown water.

TABLE 6 Nontritium Gaseous Waste Released from PPPL Tokamak

<u>Waste Description</u>	<u>Source</u>	<u>Curies/Year</u>
⁴¹ Ar	Activation of leaked air	~0
¹³ N	Activation of leaked air	~0
¹⁴ C(CO ₂)	Activation of leaked air	30

TABLE 7 Summary of Solid Waste From ORNL Tokamak

<u>Waste Description</u>	<u>Source</u>	<u>Quantity (Year)</u>	<u>Curies (Year)</u>	<u>Number of 55 gal. Drums</u>
Zr Foil + Corrosion Products	Li and K Cleanup Systems	90 MT	2 x 10 ⁷	200
Li ₂ O + K ₂ O	Li and K Cleanup Systems	160 kg	5 x 10 ⁴	1
Spent Yttrium	Tritium Extraction	1.6 kg	5 x 10 ³	<1
Hg Amalgam	Vacuum System	3 MT	7 x 10 ⁶	3
Solidified Oil	Vacuum System	2 M ³	<1	10
Bitumen	Decon. Processes	30 M ³	160	144
Concrete	Decon. Processes	300 M ³	160	1441
Equipment	Various	67 M ³	71	322
			Total	2121

TABLE 8 Summary of Liquid Waste From ORNL Tokamak

<u>Waste Description</u>	<u>Source</u>	<u>Quantity/Year</u>	<u>Curies/Year</u>
Laundry waste Water	Clothing Laundry	100,000 gal	<1

TABLE 9 Summary of Waste From the Reference Theta Pinch Reactor

<u>Waste Description</u>	<u>Source</u>	<u>Quantity/Year</u>	<u>Curies/Year</u>	<u>Number of 55 gal. Drums</u>
Lithium and Corrosion Products	Lithium System	1700 kg	6×10^6	12
Failed Equipment	Lithium System	1 M ³	1	5
Failed Equipment	Fuel-ash System	1 M ³	1	5
Mercury Sludge	Vacuum System	0.7 M ³	1.6×10^7	3
Solidified Pump Oil	Vacuum System	5 M ³	<2	25
Failed Equipment	Vacuum System	70 M ³	90	24
Spent Yttrium	Shield Cooling System	1200 kg	600	25
Failed Equipment	Shield Cooling System	1 M ³	12	5
Organic Residues in Bitumen	Decontamination	30 M ³	380	144
Inorganic Residues in Concrete	Decontamination	300 M ³	380	1441
Laundry Water	Laundering Protective Clothing	100,000 gal.	<1	
Misc. Failed Equipment	Varied	30 M ³	120	144
			Total	1833

TABLE 10 Summary of Waste From Minimum Activation Blanket Design

<u>Waste Description</u>	<u>Source</u>	<u>Quantity/Year</u>	<u>Curies/Year</u>	<u>Number of 55 gal. Drums</u>
Mercury Sludge	Vacuum System	1.6 M ³	6	8
Charcoal and Solidified Oil	Vacuum System	40 M ³	6	192
Failed Equipment	Vacuum System	30 M ³	10^{-4}	144
Organic Residues in Bitumen	Decontamination	30 M ³	0.4	144
Inorganic residues in Concrete	Decontamination	300 M ³	10	1441
Laundry Water	Laundering Protective Clothing	100,000 gal.	<1	
			Total	1929

TABLE 1. Summary of Projected Radwaste Generation From Various CTR Designs (Tritium Excluded)

Key	UWMAK-I	BNL Blanket	UWMAK-II	PPPL	ORNL	Theta Pinch
Waste Source	Blanket; inner 20 cm (2 yr life)	Blanket; full depth (3 yr life)	Blanket; inner 20 cm (2 yr life)	Blanket; full depth (5 yr life)	Blanket; full depth (10 yr life)	Blanket; full depth (5 yr life)
Average Waste Per Yr; Mate- rial (10 ³ kg)	SS/250	Al/230, C/180, Al ₂ O ₃ /43, LiAlO ₂ /4	SS/285, LiAlO ₂ /220, Be/215	Pe-16/220	Nb/14, C/110	Nb/770, C/140, Be/10
Waste Source	Blanket; outer 53 cm (10 yr life)		Blanket; outer 69 cm (10 yr life)			
Average Waste Per Yr, Mate- rial/(10 ³ kg)	SS/620		C/43			
Total Average Waste Per Yr Per GWe, Material/	SS/543, Corr./1.8	Al/150, C/118, Al ₂ O ₃ /27, LiAlO ₂ /2.4	SS/167, LiAlO ₂ /129, Be/126, C/25	Pe-16/100	Nb/27, C/212	Nb/188, C/34, Be/2.4
Thermal Power Net Electrical Power	4.7 1.5	5.0 1.6	5.0 1.7	5.3 2.0	1.0 0.5	12.0 4.1
Activity/Afterheat Of Annual Waste Quantity; (MCI)/ (MW):			Similar to UWMAK-I			
At Shutdown	1000/10	700/		4000/	700/2.5	12000/180
After Brief Decay		7/		2000/7		
After 1 Yr	350/1			300/0.6		200/0.2
After N Yrs; N: (MCI)/(MW)	20: 5/0.01	10: 0.0003/		20: 10/		20: 50/
Major sources of Long-Lived Radioactivity:						
Material	SS structure	Structural impurities & Al		P3-16 structure	Nb structure	Nb structure Cu coils
Isotopes/ T 1/2 (Yr)	⁵⁵ Fe/2.7 ⁵⁴ Mn/0.9 ⁵⁷ Co/0.7 ⁶⁰ Co/5.3 ⁴⁹ V/0.9 ⁶³ Ni/100	⁵⁴ Mn/0.9 ^{119m} Sn/0.7 ⁵⁵ Fe/2.7 ⁶⁵ Zn/0.7 ²⁶ Al/7x10 ⁵		⁵⁷ Co/0.7 ⁵⁵ Fe/2.7 ⁶⁰ Co/5.3 ⁵⁴ Mn/0.9 ⁴⁹ Ni/100 ⁴⁹ V/0.9	^{93m} Nb/14 ⁹⁴ Nb/2x10 ⁴	^{93m} Nb/14 ⁶⁰ Co/5.3 ⁶³ Ni/100 ⁹⁴ Nb/2.10 ⁴

3.0 INNER WALL DISPOSAL EFFECTS

The replacement of fusion reactor structures damaged by neutron irradiation is expected to be an important source of radioactive waste arising from fusion power plant operation. Fortunately, most of the radioactivity is bound up on the structure as activation products which minimizes the likelihood of release. On the other hand, many of the activation products are isotopes of the structural material elements so that separation or removal of the radioactivity is impractical, making prompt reuse of highly activated materials difficult, if not impossible.

One scheme that now appears to be feasible for managing this waste would include the following steps: 1) removal of unbound tritium, 2) removal of smearable activated material from the structure surfaces, 3) size reduction (to reduce packaging, shipping and storage costs), 4) packaging, and 5) shipping and storage. The decision whether to store the waste at the reactor site or to ship the waste to a central repository would depend both on safety and economic consideration which, in turn, depend on the radioisotopes involved.

While there may be some improvement possible in the waste management scheme described here, the greatest opportunities for minimizing the radioactive waste problem appear to lie in reducing the production of long lived radionuclides through careful selection of materials of construction and the design of the reactor. Certainly the management cost and hazard of the radioactive waste should be considered in optimizing fusion reactor designs.

3.1 QUANTITY AND COMPOSITION OF ACTIVATED STRUCTURE

The amount of activated waste material projected for the various hypothetical fusion reactor design is estimated from the size of the structures and their expected service lifetimes. Table 11 summarizes these estimates as compiled from various fusion reactor design documents. The information in this table provides the main basis for this study of the inner wall disposal problem. This table shows how the amount of solid radwaste and the distribution of radionuclides strongly depends on the wall material selected.

3.2 REQUIRED STORAGE TIME FOR ACTIVATED MATERIALS

The activated wall material must be stored in some controlled manner until the radioactivity decays to a level which permits unrestricted use, or else to a level where the material may be economically reused. To estimate the limits of the storage time, the time was calculated for the radioactivity to decay to concentrations in the metal equal to the maximum permissible concentration in air as defined in 10 CFR 20. The results for proposed inner wall materials are summarized in Table 12. These times represent the outer limits for required safe storage time. In some cases, the material may be safely and economically reclaimed and reused for a nuclear application long before the radioactivity has reached these low levels. Nevertheless, these limiting storage times provide a comparative measure of the radioactive waste management problem associated with the various materials of construction.

TABLE 12 Maximum Storage Time for Wall Materials

Material	Maximum Storage Time (Yr)	Limiting Radionuclide	MPC Ci/ml	t 1/2, Yr
V-20 Ti	23	^{45}Ca	9.6×10^{-10}	0.45
316 SS	3300	^{63}Ni	1.9×10^{-9}	92
Nb-1%Zr	$10^7 - 10^8$	^{93}Zr	4×10^{-9}	10^7
		^{92}Nb	1×10^{-10}	1.5×10^6
PE 16	10^5 Yr	^{93}Mo	2.5×10^{-8}	$\sim 10^4$
Al-Mg-Si	10^7 Yr	^{26}Al	3×10^{-8}	7.3×10^5

TABLE 13 Time Required for Activation Products in V-20 Ti to Decay to MPC Levels

Isotope	Initial Activity Ci/cc	MPC Ci/cc	t 1/2	Decay Time to MPC, Yr
^{45}Ca	1.14	9.6×10^{-16}	165d	22.6
^{46}Sc	0.945	8×10^{-16}	83.9d	11.5
^{47}Sc	0.7	2×10^{-14}	3.43d	0.4
^{48}Sc	5.38	4.9×10^{-5}	1.83d	--
^{49}Sc	0.172	3×10^{-14}	57.5m	--
^{50}Sc	0.252	3×10^{-14}	1.72m	--
^{45}Ti	0.051	1×10^{-16}	3.09h	--
^{51}Ti	7.03	3×10^{-13}	5.79m	--
^{52}V	9.16	2.3×10^{-13}	3.75m	--

TABLE 14 Time required for Longer Lived Activation Products in 316 SS to Decay to MPC Levels

Isotope	Initial Activity Ci/cc	MPC Ci/cc	t 1/2	Decay Time to MPC, Yr
^{49}V	3×10^{-5}	1×10^{-16}	333d	34.4
^{51}Cr	11.3	8×10^{-14}	27.8d	3.57
^{54}Mn	10.8	1×10^{-15}	303d	44.2
^{55}Fe	62.2	3×10^{-14}	2.6y	132
^{59}Fe	2.2×10^{-2}	2×10^{-15}	45.6d	5.4
^{57}Co	4.59	5.9×10^{-15}	270d	36.5
^{58}Co	12.7	2×10^{-15}	71.3d	10.2
^{60}Co	2.08	3×10^{-16}	5.26y	277
^{63}Ni	1.3×10^{-4}	1.9×10^{-15}	92y	3300y

From reference 1.

TABLE 15 Time Required for Longer Lived Activation Products in NB-1%Zr to Decay to MPC Levels

Isotope	Initial Activity Ci/cc	MPC Ci/cc	t 1/2	Decay Time to MPC, Yr
^{92}Nb	3.5×10^{-2}	1×10^{-16}	$\sim 2 \times 10^7 \text{ y}$	$\sim 10^8$
$^{92\text{m}}\text{Nb}$	684	1×10^{-16}	10.16d	1.74
$^{93\text{m}}\text{Nb}$	1.35	1×10^{-15}	13.6y	656
$^{95\text{m}}\text{Nb}$	8.46	1×10^{-16}	90h	4.7
^{95}Nb	1.84	3.1×10^{-15}	35d	4.7
^{89}Zr	0.45	1×10^{-16}	78.4h	0.5
^{93}Zr	2.67×10^{-3}	4×10^{-15}	$1.5 \times 10^6 \text{ y}$	5.9×10^7
^{91}Y	5.11×10^{-3}	1×10^{-19}	58.8d	8.9
^{89}Sr	16.8	3×10^{-16}	52.7d	10

From reference 1.

TABLE 16 Time Required for Longer Lived Activation Products in Al-Mg-Si to Decay to MPC Levels

Isotope	Initial Activity Ci/cc	MPC Ci/cc	t 1/2	Decay Time to MPC, Yr
^{54}Mn	5.8×10^{-6}	1×10^{-15}	303d	27
^{119}Sn	3.9×10^{-6}	4×10^{-10}	245d	8.9
^{55}Fe	2.7×10^{-6}	3×10^{-14}	2.6y	69
^{58}Co	1.4×10^{-6}	2×10^{-15}	71.3d	5.7
^{95}Zr	7.6×10^{-7}	1×10^{-15}	65.5d	5.3
^{26}Al	6.4×10^{-7}	$3 \times 10^{-14} \text{ (b)}$	$7.3 \times 10^5 \text{ y}$	1.8×10^7

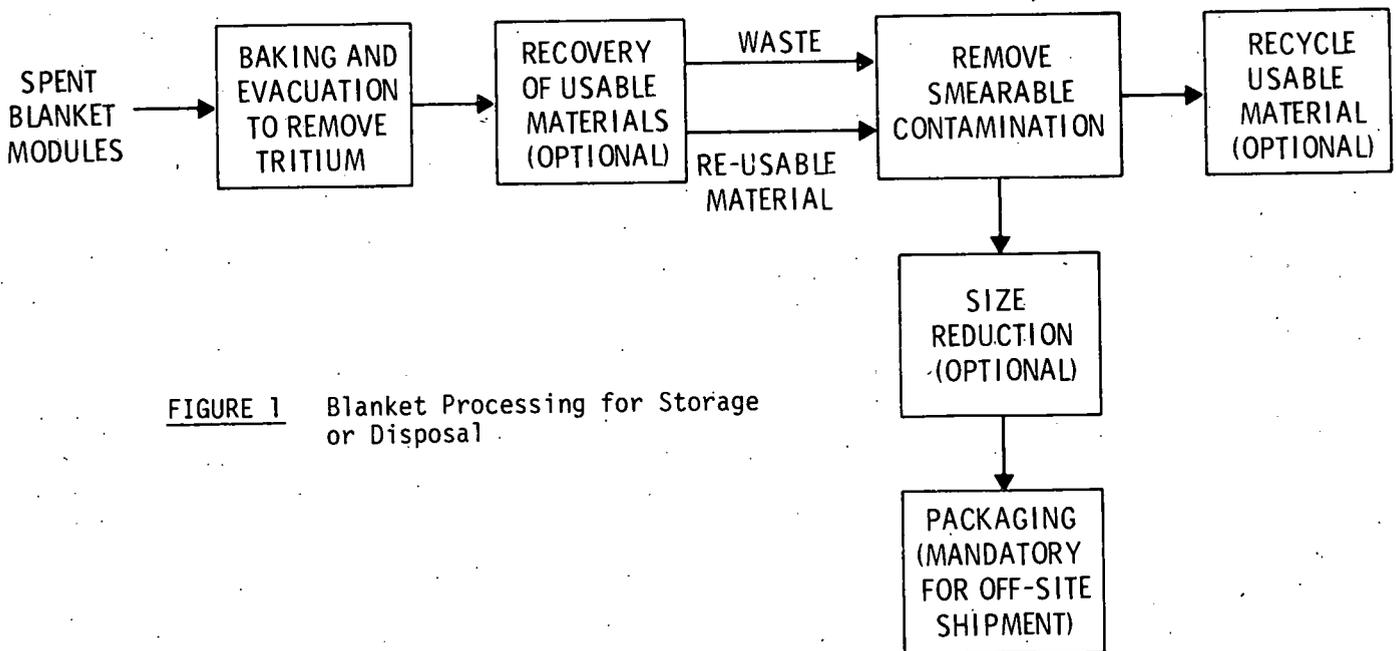


FIGURE 1 Blanket Processing for Storage or Disposal

Of the materials shown in Table 12, the vanadium-titanium alloy has the shortest storage time and, therefore, appears to be the most recycleable material. The short storage time required should result in a relatively inexpensive storage facility at the reactor site. The vanadium-titanium alloy must not contain impurities producing appreciable amounts of long-lived and hazardous activation products. Therefore, the purity requirements may make this alloy relatively expensive.

The niobium-zirconium alloy requires very long storage times reminiscent of fission reactor waste. The long (10^5 yr) storage time for PE-16 is due to activation of molybdenum which is a minor constituent of the alloy. If the molybdenum were absent, the storage time for PE-16 would be about 4000 years which is comparable to the storage time for 316 stainless steel.

Tables 13, 14, 15 and 16 give a detailed breakdown of decay times for the individual activation products formed in four of these alloys. The high levels of activation mean that an uncertainty in the initial activity has a minor effect on the time estimate for decay for MPC levels. This means that activation product inventories calculated by different investigators are comparable in spite of variation in operation time, neutron fluence, and cross sections.

3.3 TREATMENT OF INNER WALL PRIOR TO STORAGE

The spent blanket materials will have to be processed before storage or disposal. The final waste package must be of manageable size, the activity must be nondispersible, and an economic recovery of usable blanket materials should be made. In order to accomplish these, a blanket processing scheme to accomplish these things might be

as depicted in Figure 1.

The decontamination steps shown will probably be necessary in any case to minimize the hazard from tritium and finely divided or soluble activation products. Deciding to recover usable blanket materials immediately depends on the value of the materials involved and waste storage cost saved versus the increased cost of recovering highly activated materials.

The size reduction step is intended to save money by reducing the amount of storage volume and packaging.

Packaging may not be necessary if the smearable contamination can be removed and if the materials are stored on site. For shipment of the waste off-site, packaging will be mandatory. Size reduction may also be required so that the waste materials will fit into acceptable containers.

Tritium Removal. Tritium absorbed or dissolved in the blanket materials would be a hazard if it desorbed or outgassed during waste processing and storage. To avoid this problem, it has been proposed by Powell and coworkers⁽⁵⁾ that the blanket modules be heated in a high vacuum to a suitable temperature which may be 600 to 800°F (300 to 400°C). The outgassed tritium would be trapped in titanium beds for recovery. The optimum temperature for outgassing the tritium would depend on the blanket material. Without specific information about the solubility of tritium in the blanket materials, it would seem reasonable to outgas at temperatures exceeding the maximum temperature expected during subsequent waste storage. This outgassing would be a batchwise operation with excavation time on the order of one day. For blankets containing lithium and flibe, some of the lithium or flibe will melt and drain

away from the blanket structure at high temperatures.

Removal of Smearable and Soluble Materials with Decontaminating Solutions. There are two approaches possible for managing the spent inner wall and blanket structures after removing the uncombined tritium: 1) to place the structures within high integrity containers which provide the primary protection against dispersal, and 2) to first remove all smearable and soluble material such as corrosion products, flibe and lithium from the structures before packaging blanket material. However, complete removal of lithium or flibe from the blanket structure may require other systems. Dissolving these substances in water would be the most obvious method of removal. When lithium is dissolved in water, decomposition of LiT would result in the evolution of HT gas which probably would have to be trapped, oxidized and fixed. Some of the tritium would also combine with the water solvent perhaps making the water too radioactive to release. Water that is already contaminated with tritium from other plant operations could be used as the solvent to avoid creating additional tritiated waste.

Size Reduction. The reason for size or volume reduction is to save cost of packaging and shipping. Therefore, the cost of size reduction and compaction should be balanced against the savings in anticipated shipping, storage costs and reclaimed material. Because of the radiation hazard, the size reduction operation would have to be carried out remotely in a shielded cell. Any size reduction would probably involve cutting metal. Available metal cutting techniques that might be applicable are: cutting torches, saws or abrasive wheels, shears and, in some special instances,

shaped explosive charges. Compaction could be carried out by hydraulic presses or melting. Melting would probably be quite expensive because of the high melting point of most of the metals proposed for the blanket structures. However, melting may advantageously fix smearable radioactivity.

Packaging. The primary purpose for packaging contaminated equipment is to prevent dispersal of radioactivity during handling and shipping to a final storage site. If offsite shipping is not required, elaborate packaging may not be necessary. At ERDA's Hanford plant, contaminated equipment is packaged in wooden or concrete boxes for local storage or disposal (Committee, 1969). Wooden boxes, lined with plastic are inexpensive and suitable for nonretrievable disposal or for retrievable storage under conditions where wood and plastic would not decompose. Concrete boxes will not rot and cost less than metal containers. The concrete containers are especially suited for retrievable burial because of their high strength under compressive loads, but they are heavy which is a disadvantage if the waste must be shipped a long distance. The kind of packaging chosen then depends on the specific disposal method.

5.4 STORAGE OF ACTIVATED INNER WALL STRUCTURES

The choice of storage method will depend on 1) where the material is to be stored, 2) whether the material is to be retrieved, and 3) the length of time the material remains hazardous.

The decision to store onsite or at a federal repository should logically account for the relative hazards and costs of either alternative. Even though the waste is shipped offsite, some onsite storage

will be necessary while scheduling shipments or to allow time for reducing the radiation level and heat generation rate before shipping.

For retrievable storage of large, heavy contaminated items, the shielded tunnel used at Hanford (WASH-1538) should be suitable. As shown in Figure 2, the tunnel is made of reinforced concrete and is lined with galvanized steel. The tunnel is covered with soil for shielding. Large pieces of contaminated equipment are packaged and placed on railroad flat cars which can be remotely moved into the tunnel. The tunnel may be filled with soil after it is no longer used. A tunnel with openings at both ends should be useful when temporary storage is required to provide decay or cooling time. The oldest material

can be removed at the outlet without excessive handling or reshuffling. Radiogenic heat may be removed by ventilating the tunnel.

In the storage of cylindrical blanket modules, Powell and coworkers (5) have suggested dropping the modules into cased holes in the ground. The casing would be closed at the bottom, water tight and anchored so that it cannot float upward due to ground water pressure. Figure 3 shows a typical storage well. There are many other methods available for onsite storage ranging from simple burial trenches useful for long-term non-retrievable storage, to water basins suited for temporary storage of blanket structures with very high radiogenic heating rates.

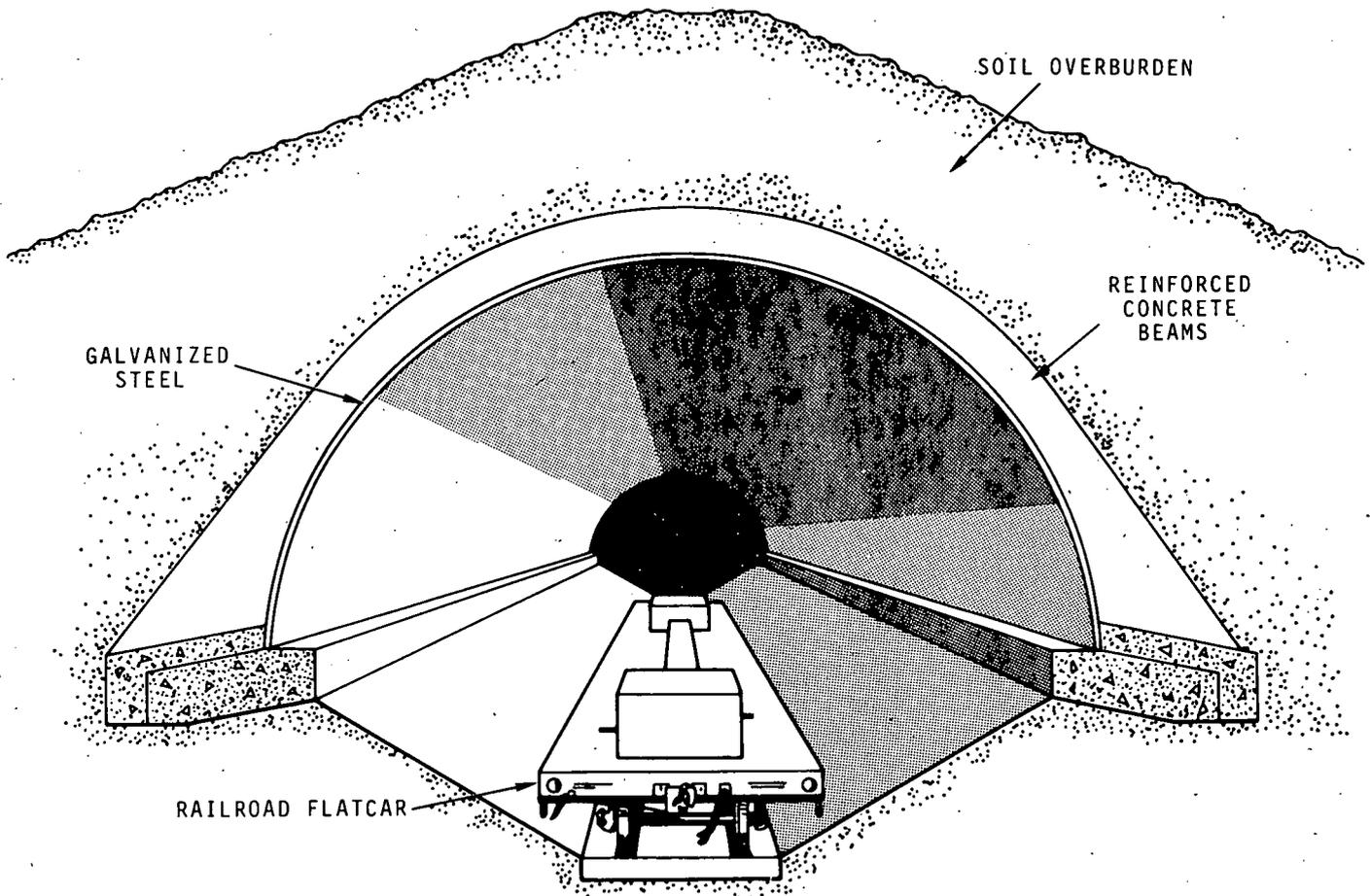


FIGURE 2 Tunnel for Storage of Radioactive Equipment

Some of the concepts for the design of federal repositories that have been described recently (WASH-1297) for the disposal of high-level radioactive waste resulting from the reprocessing of fission reactor fuels should generally be suitable for off-site storage of activated inner wall structures.

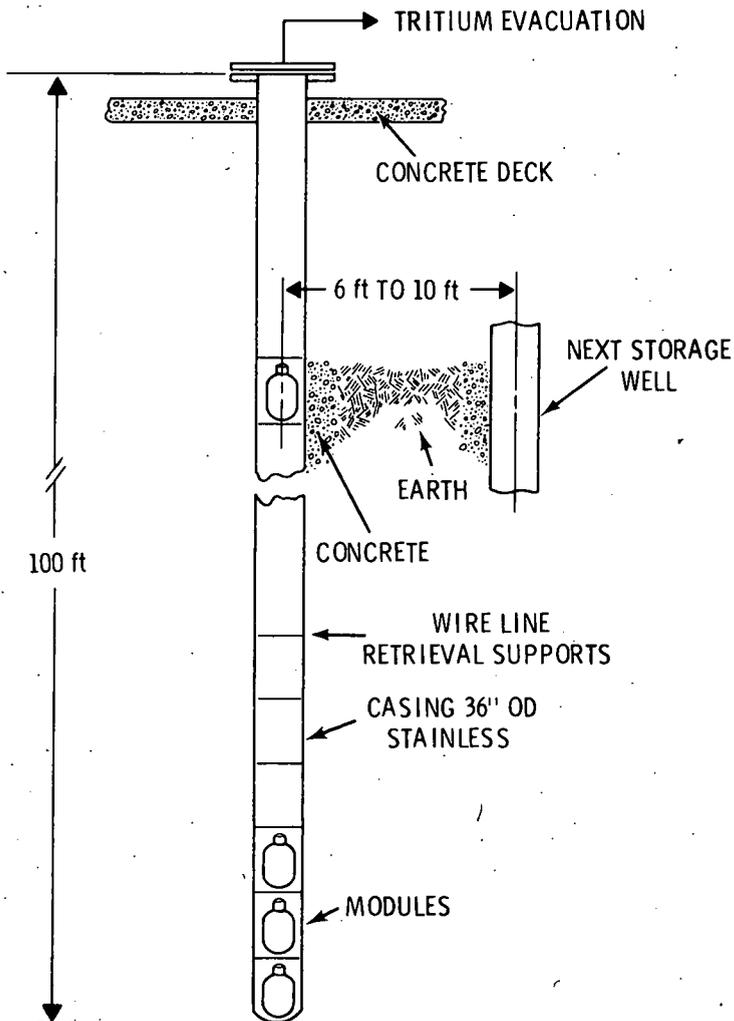


FIGURE 3 Typical Module Storage Well (25 Modules per Well)

A retrievable surface storage concept should be particularly useful for spent inner walls because the recovery value of this waste is high and the hazard is low compared to fission reactor waste. Some of the possible onsite storage schemes such as tunnels and wells described previously

can be used for retrievable surface at a federal repository.

Storage in cavities mined in geologic formations should reduce the likelihood of release of radioactivity. However, the size of waste packages would be limited by the size of the mined cavity which in turn depends on the depth of the cavity and the structural strength of the formation. Another disadvantage is that retrieval may be more difficult and expensive. Sea bed disposal may be used but would probably make retrieval still more uncertain and expensive compared to storage in a geologic formation.

4.5 RADIOACTIVE EFFLUENTS FROM PROCESSING SPENT INNER WALL STRUCTURES

A result of processing the inner wall structures for storage will be radioactive wastes such as spent decontamination solutions, floor drain liquids, ventilation filters, and cold traps. The contribution of the radioactivity in these wastes to the total amount of radioactive effluents resulting from routine reactor operation should be negligible because: 1) It has been assumed that the coolant purification systems are effective. As a result, the inventory of mobile activation products remaining in the coolant is much smaller than the amount removed per year by the purification systems. 2) The processing of the inner wall structure essentially removes only the mobile or smearable activation products from these structures. 3) The lifetime of the inner wall is greater than one year, so that a relatively small amount of waste would be generated relative to the waste generated directly by reactor operations. From these assumptions it follows that, except for the inner walls themselves, the radioactive effluents resulting from processing the

inner wall for disposal will contain much less radioactivity than the active effluents resulting from routine reactor operation. The radioactive waste side streams from inner wall disposal can be combined and treated with the radioactive waste from reactor operation without appreciably increased environmental consequences.

3.0 POTENTIAL STUDY AREAS

In preparing this review of radioactive waste treatment for fusion power reactors, it has become apparent that many assumptions were required to determine the sources and disposition of wastes. Most of the uncertainties derive from the sketchy design of the plant systems, rather than unique problems associated with the waste disposal. This is expected because the conceptual designs focus primarily on the reactor problems rather than on the auxiliary systems.

The quantities and activity levels of some waste depends on the specific design of the fusion power plant. For example, large quantities of zirconium foil waste appears in the plant designs showing Zr getting beds used to remove corrosion products from lithium metal coolant. If other techniques for cleaning the coolant are used, this waste source could disappear. As another example, if a carbon liner were used to protect the inner metal wall, the level of neutron activation products might be appreciably reduced, but there could be an offsetting production of ^{14}C .

Several aspects of waste treatment which represent fairly typical problems that will require additional resolution have been identified and are briefly noted in the following sections.

Disposal of Corrosion Products. Reactors which use cooling fluid other than helium will generate corrosion products that will

be largely removed in cold traps. Additional studies are needed to determine whether to dispose of this material as is, or to convert it to a more inert form such as glass. A glass formulation would be relatively easy to develop for metal oxides, but a glass formulation may be a problem if corrosion products were present as fluorides (as in the PPPL flibe coolant).

Recycling of Yttrium and Zirconium.

Yttrium is comparatively expensive (\$500.00/kg) and reprocessing might be chosen rather than storage as a radioactive waste. Additional studies would be worthwhile to determine the cost-benefit for recycling this material. Similar effort might be considered for less costly zirconium.

Reclaiming Contaminated Mercury. Reclaiming contaminated mercury by distillation is a common procedure today. Additional study would be worthwhile to determine what would result from cleanup where alkali metals are present in the mercury, and what should be the final form for this waste.

Solidification of Detergent Wastes. A major source of radioactive nuclides released to the environment is the laundry effluent water. While the activity levels are very low, they could be greatly reduced if a method were developed to solidify detergent waste. The spent detergent and contaminants could then be retained and stored as solids rather than being discharged to the environment as a liquid waste. This problem is not unique to fusion reactors but also exists for present fission reactors.

Disposition of Contaminated Vacuum Pump Oil. It was assumed that contaminated pump oil derived from the vacuum pumps would be mixed with a solid sorbent or immobilization. Such a process needs more study to show that the mixture can be considered a solid,

and to show the degree to which tritium is immobilized by such a procedure.

Transport and Deposition of Wall Erosion Material. Due to neutron and photon bombardment, erosion of the inner wall is expected. The eroded wall material is assumed to enter the plasma as an ionic species that is removed along with other plasma particles by the vacuum and diverter systems. Additional study should be directed at determining to what extent these erosion products cool, condense, or plate out in the various chambers and flow passages. Knowledge of the transport characteristics would aid in determining activity levels in waste originating from the vacuum system and the diverter circuit.

Activation of Inleaked Air. It was assumed that air would leak into the vacuum plasma chamber at a rate of 0.1% per day based on the volume of the plasma chamber. This leak rate was taken from experience in low leakage containment vessels used to house fission reactors. This quantity of inleaked air results in a modest source term for gaseous radioactive waste because of neutron activation of nitrogen and argon. Additional study to more thoroughly evaluate the rate of air leakage would show whether this source term has been realistically assessed, particularly for designs with secondary vacuum chambers.

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