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Processing and Waste Disposal Representative for
Fusion Breeder Blanket Systems

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Abstract

This study is an evaluation of the waste handling concepts applicable to fusion breeder systems. Its goal is to determine if breeder blanket waste can be disposed of in shallow land burial, the least restrictive method under U. S. Nuclear Regulatory regulations. The radionuclides expected in the materials used in fusion reactor blankets are described, as are plans for reprocessing and disposal of the components of different breeder blankets. An estimate of the operating costs involved in waste disposal is made.

1. Introduction

The breeder blanket is a major component of a commercial fusion reactor which is fueled with deuterium and tritium. The breeder blanket is composed of a lithium containing breeder compound, structural material, and a heat transfer medium. Within the breeder blanket, neutrons react with the lithium to produce tritium needed for fuel. Neutrons also react with other elements in the breeder blanket to produce radionuclides. Neutron damage from these interactions limits the lifetime of a fusion breeder blanket to 6-8 years. Five to six blankets are needed over one fusion reactor's 30-40 year life. The number of blankets needed is about 5000 in a 1000 GWe fusion economy, i.e., one with >800 fusion reactors. The number of blankets needed is

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replacement gives rise to several questions. First, must the unreacted lithium in the blanket be recovered and reused? Second, can the radionuclides produced in the blanket be disposed of in shallow land burial? Third, are the operating costs for waste disposal prohibitive?

The purpose of this study is to determine the waste handling concepts that are applicable to fusion breeder systems. Its goal is to determine if the waste can be disposed of in shallow land burial, the least restrictive method under U. S. Nuclear Regulatory regulations.

In the study we will first describe the radionuclides expected in the materials used in fusion reactor blankets. Second, we will describe plans for reprocessing and disposal of the components of different breeder blankets. Next, we will make an estimate of the operating costs involved in breeder blanket waste disposal. Last, we will ascertain if the goal of shallow land burial is attainable for breeder blanket waste.

2. Background

Blanket Prototypes-The blankets in two commercial fusion reactor designs are used as prototypes to estimate the waste disposal requirements for breeder blankets. For solid breeders, the blanket in STARFIRE[1], a 1200 MWe tokamak power plant is used as a prototype. Its breeder blanket is designed as 24 identical sectors, which together form the reactor torus. In STARFIRE, lithium aluminate is the breeding material; a stainless steel labeled PCA is the structural material; water is the heat transfer medium. Each year four of

the sectors are completely replaced. The four sectors contain 75 Mg of stainless steel, and 100 Mg of lithium aluminate. This blanket prototype sets an upper limit on the problems associated with fusion waste handling.

For the three liquids, the blanket in TPSS[2], a 873 MWe tokamak power plant is used as a prototype. The TPSS breeder blanket is designed as 8 identical sectors, which together form the torus. In TPSS, liquid lithium is the breeding material and the heat transfer medium; a vanadium alloy is the structural material. Every two years, two of the sectors are replaced. The two sectors are drained of lithium (11.7 Mg) before being replaced. Since the lithium is reused, there is no lithium waste. Part of the vanadium structure of each sector is replaced; part is reused. The weight of the replaced structural material in two sectors is 9.9 Mg. This blanket prototype sets a lower limit on the problems associated with fusion waste handling.

Lithium supply - Evans[3] estimated the lithium reserves and the lithium resources in the U. S. as 4.2×10^5 Mg and 3.1×10^6 Mg, respectively. His estimates did not include undeveloped or unproven sources of lithium. A 1000 GWe fusion economy, requires 1.6×10^5 Mg of lithium to provide the 1.1×10^4 lithium-6 needed by a STARFIRE reactor to produce the tritium used for power generation. Figure 1 is a plot of the lithium supply in the U. S. and of the U. S. needs.

If lithium in the blanket sectors is not recycled, then 2.8×10^6 Mg of lithium would be required to build the replaced STARFIRE blanket sectors. This amount of lithium is greater than the U. S. reserves and close to the

U. S. resources. Thus lithium must be recycled for a solid oxide breeder blanket.

An isotope enrichment plant would be needed to provide the needed lithium-6 content in a replacement breeder sector. The cost of enriching lithium will probably be dependent on the type of enrichment route chosen. The cost quoted for the classical route was \$1.25/g[4]. In this route, an aqueous solution of LiOH and a lithium amalgam are equilibrated. Another route using solvent extraction techniques quotes the cost at \$0.50/g at a plant with a 100 Mg annual capacity.[4]

The cost to enrich lithium can be the dominant cost in the total cost of lithium for a reactor. Reactors which do not require lithium enrichment to achieve tritium breeding will have a lower lithium cost. However, most reactors require Li-6 enrichment.

3. Waste Disposal Regulations

Regulations for disposal of radionuclides in the United States are established by the Nuclear Regulatory Commission (NRC). These regulations are codified in 10CFR61[5] and 10CFR60[6]. Three classes of material are defined in 10CFR61 for shallow land burial. They are labeled A, B, and C. Packaging requirements for B and C waste are more stringent than those for A waste. Materials are consigned to geological disposal if their radioactivity exceeds the limits of 10CFR61. Geological disposal is not preferred since it is more costly than shallow land burial.

Table 1 lists the criteria for land disposal. These criteria were established assuming fission radioactive wastes. Therefore, several radionuclides produced from fusion reactions are not included. Since the NRC regulations treat all unmentioned radionuclides in 10CFR61 as Class A waste, we will judge the classification of radionuclides in fusion waste by comparing them to similar fission radionuclides.

Table 2 lists the concentration limits for long-lived radionuclides. Alpha emitting transuranic nuclides with a half life greater than five years are considered. In the fusion breeder material, lithium-lead, there are two alpha emitting radionuclides, Bi-210 and Po-210.

Table 3 [7] lists the assumed or estimated concentration limits for long-lived gamma emitters. The bismuth radionuclides might be derived from impurities in lithium-lead.

4. Materials

Structure-Structural metallic materials for fusion reactors are of two general types as shown in a recent survey[7]. First, there are materials like stainless steel(PCA) and ferritic steel(HT-9) which are unacceptable for shallow land burial. Other materials like vanadium alloys , are representative of a class of "low activation" materials which can be disposed of in shallow land burial sites 10 years after removal from the reactor.

The radionuclides most responsible for requiring geological disposal of PCA and HT-9 are Nb-94(source Mo and Nb), Ni-63(source Ni) and Ag-108m(source

Zr). Both molybdenum and nickel are basic constituents of stainless steel (PCA). Molybdenum is a significant component in ferritic steel (HT-9). One or two molybdenum isotopes form deleterious radionuclides; Mo-97 seems the best isotope to use to limit the formation of radionuclides. Using isotopic separation, one can prepare materials free of the undesired isotope(s). Removal of all molybdenum isotopes but Mo-97 from a ferritic steel results in a material which is not precluded from shallow land burial for disposal. For stainless steels, isotopic tailoring of molybdenum to obtain Mo-97 and of nickel to obtain Ni-61 produces a stainless steel acceptable for shallow land burial. The separated product cost for molybdenum ranges from \$6000/kg (1982\$) at a production rate of 0.25 MT/yr to \$1000/kg at a production rate >4 MT/yr [8].

Breeders—There are two general types of breeder materials: those that are solid at breeder blanket operating temperatures and those that are liquid at breeder blanket operating temperatures. Both lithium oxide (Li_2O) and the ternary oxide, lithium aluminate (LiAlO_2) are examples of the first type. Liquid lithium (Li), lithium-lead ($^{17}\text{Li}^{83}\text{Pb}$) and flibe (Li_2BeF_4) are examples of the second type. For the latter type, the breeding material can be drained from the blanket if recycling of the lithium is needed.

Impurities in the breeder material are a major contributor to the amount of radionuclides formed during irradiation. Rigid control must be exercised in limiting the impurity content to prevent formation of deleterious radionuclides. Also important to consider, especially for the liquid breeders, are the amounts and types of corrosion products which are dissolved in the breeder material or on structural walls during the lifetime of a blanket.

LiAlO₂ - In Fig. 2, the elemental contributions to LiAlO₂'s activation are shown. These results were obtained assuming the following weight % impurity content (K-0.05, Ni-0.002, Mo-0.003). After 50 years, the radioactivity in LiAlO₂ is dominated by Ar-39 (source K), Al-26 (source Al), Ni-63 (source Ni), Nb-93m (source Mo), Mo-93 (source Mo), and Nb-94 (source Mo and Nb). These results in Fig. 2 show that none of the radionuclides present in LiAlO₂ would exceed the requirements for disposal in a shallow land burial site. The radioactivity may be low enough that direct contact during reprocessing may be possible.

Li₂O - In Li₂O, there are fewer impurities than in LiAlO₂. The potassium impurity provides the largest amount of radionuclides. In Fig. 3, the data show that after 50 years, the dominant radionuclides are Ar-39 (source K) and Ni-63 (source Ni); these two nuclides are comparable in concentration to that in LiAlO₂.

Lithium - The impurity content in lithium is about the same as that for Li₂O. (4,7)

Lithium-lead - The anticipated impurities found in lithium-lead should be comparable to the induced radioactivity in the solid oxides with the addition of polonium-210. The polonium is derived from three sources. The first source is by reaction and decay from Pb-208. The second source is by reaction and decay from Pb-209. The third is by reaction and decay of the impurity Bi-209 in the lithium-lead. The second route is responsible for only a small fraction of the Po-210. [9]

For the first decade after removal of the lithium-lead, the Po-210 half-life of 138 days dominates the decrease in its radioactivity; the radioactivity falls four orders of magnitude in 5 years. After the bulk of the Po-210 has decayed, the further decay is controlled by the decay of Pb-210 which has a half-life of 22 years.

Flibe - The impurity content in flibe is about the same as in Li_2O with the absence of potassium. The absence of potassium eliminates the formation of Ar-39 and Cl-36. Corrosion products from the structural material used may be the dominant source of radionuclides in the flibe.

If a vanadium alloy V-Cr-Ti[10] is used as the structural material with flibe, the activated corrosion products in the flibe are mainly Mn-56, Mn-54, Sc-48, Sc-46, Co-58, and Fe-59. The dose 21 days after removal of the flibe from the reactor is dominated by Mn-54(70%). The other radionuclides still present are Sc-46, Co-58 and Fe-59.

To reduce corrosion of structural material by flibe, molybdenum[11] has been suggested as a coating on all structural materials in contact with flibe. If the molybdenum coating becomes the reference design, then isotopic separation of the molybdenum would be required to minimize the amounts of Mo-93, Nb-93m and Nb-94 present as corrosion products in the flibe or as a coating on the structural material used.

Data in Table 4[7] show that one day after either the solid or liquid breeders are removed from the neutron environment, the three liquid breeders

have the lowest radioactivity. Although all of the liquid breeders have to be handled by remote contact, their liquid nature makes movement readily easy.

5. Reprocessing

LiAlO_2 - There are two procedures that can be used to reprocess the LiAlO_2 to recover the lithium. One is a solid-state reaction in which fresh lithium carbonate enriched in Li-6 is reacted with the lithium depleted breeder. The reaction desired is one between the Li_2CO_3 and the lithium depleted compound LiAl_5O_8 . A disadvantage of the solid-state reaction is that the Al-26 induced radioactivity is not eliminated. This reaction route requires that the breeder material in four sectors (100 Mg) be reduced to a fine powder. The breeder material and the required Li_2CO_3 to convert LiAl_5O_8 to LiAlO_2 are then ball-milled together. The resulting mixture is sintered in air at 923K.

The solid state reaction described will be carried out remotely. New blanket sectors would be loaded with the regenerated LiAlO_2 remotely. Using this process no waste is produced.

The second procedure used to regenerate LiAlO_2 can not only recover the lithium but it can also eliminate the Al-26 from the regenerated product. This second procedure is based on the reaction reported by Lejus[12]. He found that gamma- LiAlO_2 reacts with water via a two step process. The product is a lithium solution and a precipitate of $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$. The lithium solution is separated from the precipitate and the lithium is precipitated as the

carbonate. The precipitate of $Al_2O_3 \cdot 3H_2O$ and the waste solution are immobilized in concrete for disposal in a shallow land burial. An additional waste product that may occur using this technique, is the $LiAl_5O_8$ present in the $LiAlO_2$. The $LiAl_5O_8$ may precipitate with the $Al_2O_3 \cdot 3H_2O$ since it may not be soluble in water. It would be processed in the same manner as described for $Al_2O_3 \cdot 3H_2O$.

If reprocessing of $LiAlO_2$ were carried out using the aqueous technique, 121 Mg ($\sim 50 \text{ m}^3$) of $Al_2O_3 \cdot 3H_2O$ is produced annually. In addition, 0.8 Mg of $LiAl_5O_8$ is produced annually. This is a wastage of 0.08 Mg of lithium annually.

Li_2O - The Li_2O blanket material is regenerated by dissolving the oxide in water. The requisite Li-6 is added to the water solution after which the lithium is precipitated as the carbonate. The precipitated carbonate is filtered, dried, and then ignited to yield the Li_2O . Required fabrication is then done.

Soluble impurities that do not precipitate with the carbonate remain in solution and can be discarded. The solution can be distilled to concentrate the waste solution. The waste solution would be immobilized in concrete for disposal in a shallow land burial waste site.

Liquid breeders - The liquid breeders are used continuously throughout a reactor's lifetime. Periodically Li-6 is added to the liquid breeder to maintain the lithium concentration needed for adequate tritium breeding. Each

type of liquid breeder would have a special purification system to remove corrosion products. A small slip-stream from the breeder would be routed to the purification system and then back to the breeder. The major waste generated from liquid breeders would come from these purification systems.

At reactor end-of-life, an assessment would be made for each liquid breeder whether reuse of the breeder in another reactor was feasible. If it was feasible, the liquid breeder material would be transported to the site of the next reactor. If reuse was not feasible, each of the liquid breeders would be processed for shallow waste burial.

The lithium might be stored as solid lithium or be converted to the oxide and then stored as the oxide in 55 gal(0.2 m³) drums. The lithium-lead waste would be packaged as solid lithium-lead in 55 gal drums. The drums would be stored on site for ten years before final disposal. The flibe would also be packaged in 55 gal drums if there were no excess molybdenum decay products present.

6. Costs of Reprocessing and Waste Disposal

Disposal of High Level Radioactivity-The cost of high level radioactivity disposal is composed of three elements, the cost of packaging, the cost of transportation to the disposal site and the cost of emplacing the waste in a geological depository. High level waste in a breeder blanket comes from unmodified PCA or unmodified HT-9 structural material. The waste is generated annually when four sectors are replaced and at the reactor's end-of-life.

The maximum high level structural waste generated annually is the 75 Mg of unmodified stainless steel from four sectors of a STARFIRE reactor. The steps taken to handle this waste are the following. The steel would be packaged in 44 canisters assuming a packing fraction of 25%. Each canister is 0.6 m diameter x 3.05 m long; the 0.6 m diameter allows larger waste pieces to be accommodated and makes disassembly of reactor sectors simpler. The canister is of simple design; each should cost \$7500(1982\$) to fabricate.[13] The total cost for 44 canisters is \$330,000(1982\$).

The canisters would be transported by rail to the geological storage site. The cost for a round-trip of 4828 km (3000 miles) is \$37,500(1982\$) for a rail car carrying three canisters in shielded shipping containers[13]. The total cost for 15 round-trips is \$568,000.(1982\$)

The emplacement cost for a canister of this size is estimated at \$90,000(1982\$). The emplacement cost is based on the costs estimated by Clark for disposal of nuclear waste [14]. The canister used for fusion waste has twice the volume assumed by Clark. A direct cost scaling with volume was assumed in order to use Clark's costs. The total cost for emplacement of 44 canisters is \$ 3.96 Million(1982\$).

The total annual disposal cost is \$ 4.9 million/yr(1982\$) for 44 canisters of high level waste. The costs for emplacement are 80% of the total.

At reactor end-of-life there would be 264 canisters of high level waste produced from the stainless steel structural material in the breeder blanket

of a STARFIRE type reactor. The total disposal cost for this material is \$29 million(1982\$).

Disposal of low level radioactivity - There are four sources of low level radioactivity waste in breeder blankets. These sources are: the structural material in a reactor like TPSS, the radionuclide waste from regenerated solid breeders, the corrosion impurities in liquid breeders, and the final disposal of breeder material from a reactor.

The low level radioactivity vanadium structural material from TPSS would be packaged in 55 gal drums for placement in shallow land burial. Each drum will contain 0.05 m^3 of material, assuming a packing fraction of 25%. Each drum will emit a maximum of 0.25 kW/drum. Storage for a year would be required to permit the radioactive heat to decrease to the manageable level, 5 kW/m³. Storage for ten years may be desirable to reduce the disposal costs.

The vanadium waste (9.9 Mg) handled semiannually from two TPSS sectors is 1.67 m^3 . To dispose of this waste 34 drums are required. By blending all the vanadium, each of the drums will contain 2.2×10^4 Ci/drum after a year of cooling. After five years, each drum will contain 10^3 Ci. To ship these wastes even after five years, a shielded container is necessary. Each shielded container could contain fourteen 55 gal drums. Assuming a 1600 km (1000 mi) trip from reactor to disposal site, an oversized load and two drivers, the cost per shipment[13] would be \$3916(1982\$). The total cost for 3 shipments is \$11,700(1982\$). The cost would be doubled for a trip to a burial site which was twice as distant.

The costs for disposal in shallow land burial are based on the volume of waste buried and its activity level.[15] For a 55 gal drum with an activity level of 2.2×10^4 Ci, the cost would be \$5830/yr(1982\$). The total cost for 34 drums is \$198,200(1982\$). If disposal were delayed until five years after removal from the reactor, the cost would be \$622/drum or \$21,200 annually. If disposal were delayed for ten years, the activity would be 35 Ci/drum and all Curie surcharges would be dropped. The basic shallow land burial rate would then apply; \$90/drum. The total burial cost for the vanadium waste is \$3,100/yr(1982\$).

The minimum total cost for disposal of the vanadium alloy is \$15,000/2yr (1982\$); this assumes that shallow burial is delayed for ten years.

The volume of aluminum waste($Al_2O_3 \cdot 3H_2O$) generated from the aqueous regeneration of the $LiAlO_2$ in four sectors of a STARFIRE reactor is $50 \text{ m}^3/\text{yr}$. If we assume a packing fraction of 90%, 265-55 gallon drums are needed to handle the waste. To ship the aluminum wastes, a shielded container is necessary. Each shielded container contains fourteen 55 gal drums. Assuming a 1600 km (1000 mi) trip from reactor to disposal site, the cost per shipment is \$3916(1982\$). The total cost for 19 shipments/yr is \$74,400(1982\$). The cost would be doubled for a trip twice as distant.

The Al-26 radioactivity content in the aluminum waste is 1.46 Ci/m^3 . At this radioactivity level, no disposal surcharges are incurred. The basic shallow land burial rate applies; \$90/drum. The total burial cost is \$23,900.

The total annual cost for disposal of the aluminum waste from the aqueous regeneration of LiAlO_2 is \$98,000(1982\$).

At reactor end-of-life, the LiAlO_2 in the solid oxide breeder blanket may have to be disposed of in shallow land burial. The volume of LiAlO_2 waste would be 178.2 m^3 . Assuming a 90% packing fraction, the waste LiAlO_2 would be packaged in 945 drums. The drums would be sent to the disposal site in 68 shipments. The cost for transportation is \$266,300(1982\$). The cost for shallow land disposal of the 945 drums is \$85,100(1982\$). The total cost for disposal of the waste is \$351,400(1982\$).

The volume of waste generated per year from purification of the liquid breeders is estimated to be 0.1% of the liquid breeder volume in the TPSS reactor. This is a volume of 0.18 m^3 so one 55 gallon drum is needed. Due to the low volume of these wastes, the total cost for shallow burial would be included in other waste costs.

The volume of blanket waste handled at end of life of a TPSS fusion reactor consists of 187 m^3 of breeder and 18 m^3 of vanadium structure. To dispose of the waste, the breeder will be loaded into 991 drums and the vanadium structure will be loaded into 360 drums. The transportation cost to move the 1351 drums in 97 trips to the disposal site is \$380,000(1982\$). The burial cost if there are no excess Curie charges is \$122,000(1982\$).

The total cost to dispose of one of the liquid breeder blankets is \$520,000(1982\$).

Table 5 is a list of the relative costs of waste disposal of breeder components, of lithium enrichment, and of isotope tailoring. The cost advantage for shallow land burial can accommodate the cost of isotope tailoring for materials like stainless steel or ferritic steel. In addition, actual costs for geological disposal are escalating by 30% each year, whereas enrichment or isotope tailoring costs are decreasing as technology improves.

7. Conclusions

Our goal of shallow land burial appears attainable for the components of a fusion breeder blanket. Structural materials like the vanadium alloys are easily disposed of in shallow land burial. Materials with potentially high activation like stainless steel (PCA) can be modified by isotope tailoring so that they too can be disposed of by shallow land burial. The breeder materials, both solid oxides and liquid breeders, can be disposed of by shallow land burial if impurities in these materials are carefully controlled.

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Table 1. Waste Classification: Limit on Concentration of Short-Lived Radionuclides

Radionuclide	Concentration (Ci/m ³)		
	Column 1 ^a	Column 2 ^a	Column 3 ^a
Total for all nuclides with less than 5 year half-life	700	b	b
H-3	40	b	b
Co-60	700	b	b
Ni-63	3.5	70	700
Ni-63 in activated metal	35	700	7000
Sr-90	0.04	150	7000
Cs-137	1	44	4600

^a Class A waste, if nuclide concentration in Column 1 is not exceeded.
 Class B waste, if nuclide concentration is greater than value in Column 1, but less than that in Column 2.
 Class C waste, if nuclide concentration is greater than value in Column 2, but less than that in Column 3.

^b There are no limits established for these radionuclides in Class B or C wastes. Practical considerations such as the effects of external radiation and internal heat generation on transportation, handling, and disposal will limit the concentrations for these wastes. These wastes shall be Class B unless the concentrations of other nuclides determine the waste to be Class C independent of these nuclides.

Table 2. Waste Classification: Limits on Concentration^a of Long-Lived Radionuclides

Radionuclides	Concentration Ci/m ³
C-14	8
C-14 in activated metal	80
Ni-59 in activated metal	220
Nb-94 in activated metal	0.2
Tc-99	3
I-129	0.06
Alpha emitting transuranic nuclides with half life >5 yr	100 ^b
Pu-241	3,500 ^b
Cm-242	20,000 ^b

^a If the waste contains <0.1, the indicated concentration, the material is Class A. If the concentration is >0.1, the indicated concentration, the material is Class C.

^b Units are nano Ci/g.

Table 3. Waste Classification: Estimated Limit for Class C Long Half-Life Gamma Emitters not Listed in 10CFR61

Radionuclide	Concentration Limit (Ci/m ³)
Al-26	0.1
Nb-92	0.3
Ag-108m	3
Bi-207	17000
Bi-208	0.1
Bi-210m	2

Table 4. Relative Rankings of Materials by RMR.

Time after shutdown							
1 Hour		1 Day		10 Years		100 Years	
Material	RMR(mrem/hr)	Material	RMR(mrem/hr)	Material	RMR(mrem/hr)	Material	RMR(mrem/hr)
TENELON	9.14×10^{10}	LiAlO ₂	2.83×10^{10}	PCA	2.30×10^8	LiAlO ₂	2.09×10^4
LiAlO ₂	8.17×10^{10}	VCrTi	1.36×10^{10}	Nitrate salt	4.61×10^7	HT9	2.07×10^4
PCA	3.69×10^{10}	TENELON	1.33×10^{10}	HT9	4.41×10^7	PCA	9.44×10^3
ModHT9	2.93×10^{10}	PCA	1.16×10^{10}	TENELON	1.39×10^7	LiPb	9.24×10^3
HT9	2.89×10^{10}	ModHT9	4.24×10^9	ModHT9	1.11×10^7	ModHT9	4.26×10^2
VCrTi	1.93×10^{10}	HT9	4.17×10^9	LiAlO ₂	5.36×10^5	TENELON	4.22×10^2
Nitrate salt	8.55×10^9	Nitrate salt	3.25×10^9	LiPb	4.16×10^6	VCrTi	1.83×10^2
Be	4.92×10^8	Be	1.67×10^8	Be	1.26×10^6	Be	4.99×10^1
LiPb	1.42×10^8	LiPb	8.85×10^7	Lithium	9.13×10^4	Nitrate salt	2.33×10^1
Li ₂ O	2.17×10^7	Lithium	5.86×10^6	Li ₂ O	4.44×10^4	Li ₂ O	1.72×10^0
Lithium	1.48×10^7	Li ₂ O	5.53×10^6	FLIBE	2.79×10^4	FLIBE	2.02×10^{-1}
FLIBE	6.06×10^6	FLIBE	1.73×10^6	VCrTi	6.53×10^3	Lithium	1.87×10^{-2}

Table 5. Relative Operating Costs for Waste Disposal, for Lithium Enrichment, and for Isotope Tailoring for a Fusion Breeder Blanket (1982\$)

Material (\$M)	Annual Cost (\$M)	One-Time
PCA	4.9	29
V alloy	<0.015	---a
LiAlO ₂	0.098	0.351
Li ₂ O	---b	0.351 ^c
Liquid Breeders	---b	0.520 ^a
Lithium Enrichment ^d	---	45
Isotope Tailoring ^e		
-Molybdenum(2%)	---	9
-Nickel(20%)	---	90

a This cost is included in the liquid breeder end cost.

b The costs are expected to be low so are not included.

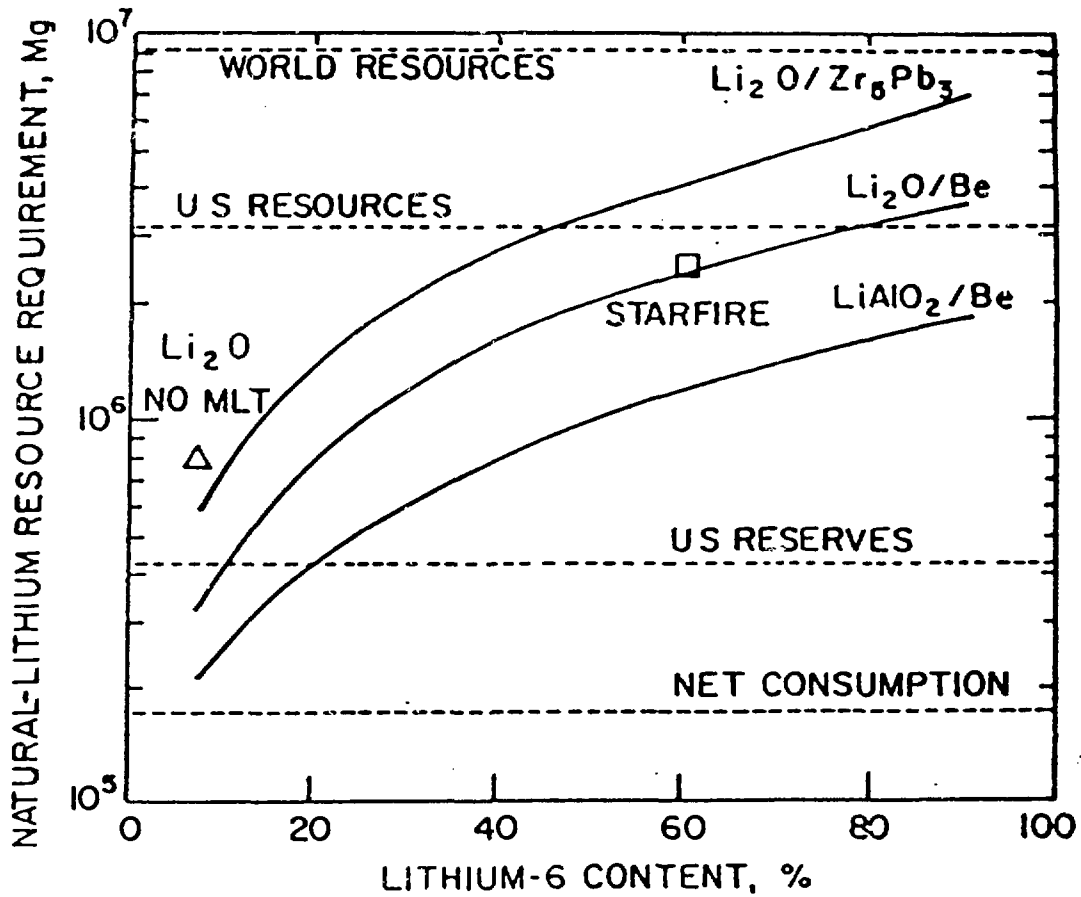
c It is assumed that the volume of material will be similar to that for LiAlO₂.

d This is the cost for 60% enrichment for STARFIRE at \$0.5/g. The annual cost was not computed, since this depends on the reactor design.

e A cost of \$1000/kg is assumed.

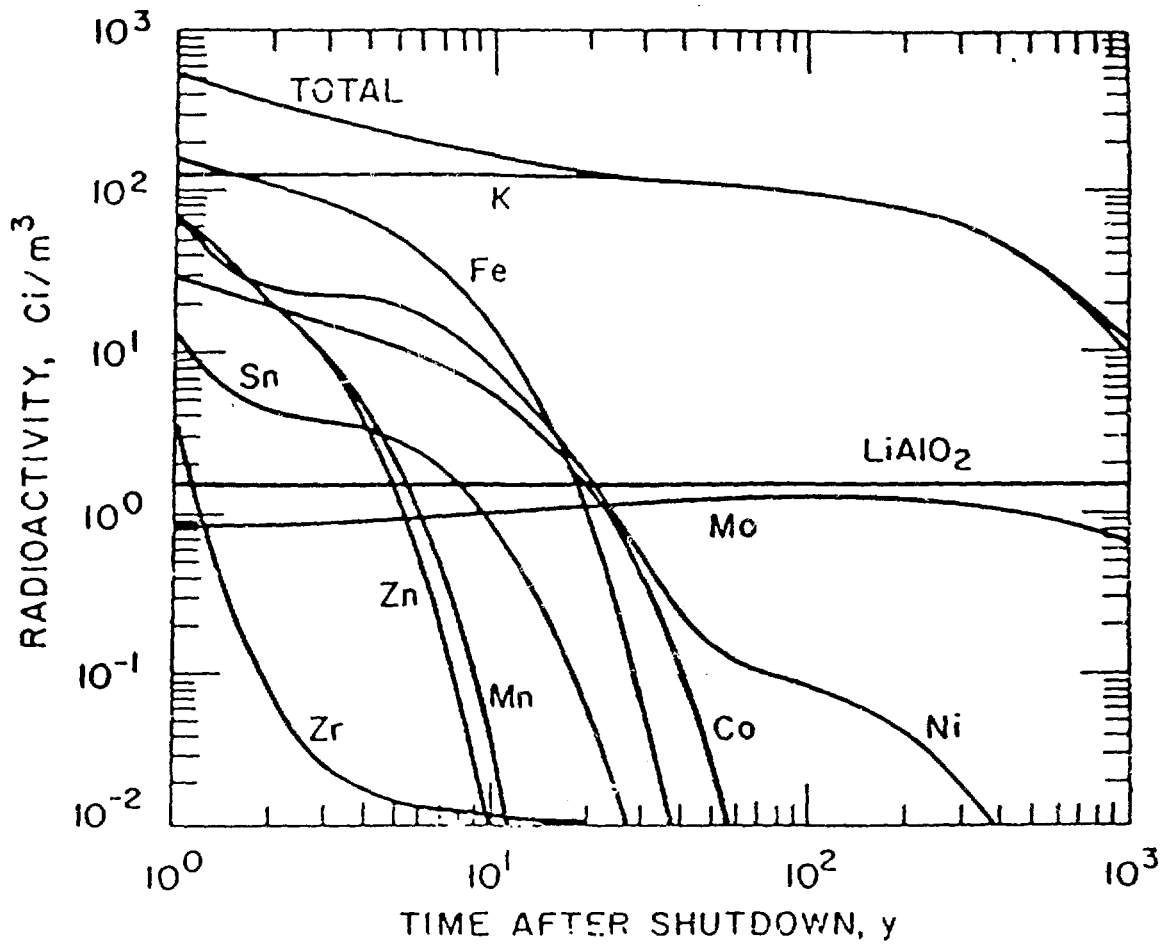
Figure Captions

- Fig. 1. Impact on lithium resource requirement from selection of a solid breeder and its ${}^6\text{Li}$ enrichment.
- Fig. 2. The elemental impurity contribution to the LiAlO_2 activation.
- Fig. 3. The elemental impurity contribution to the Li_2O activation.

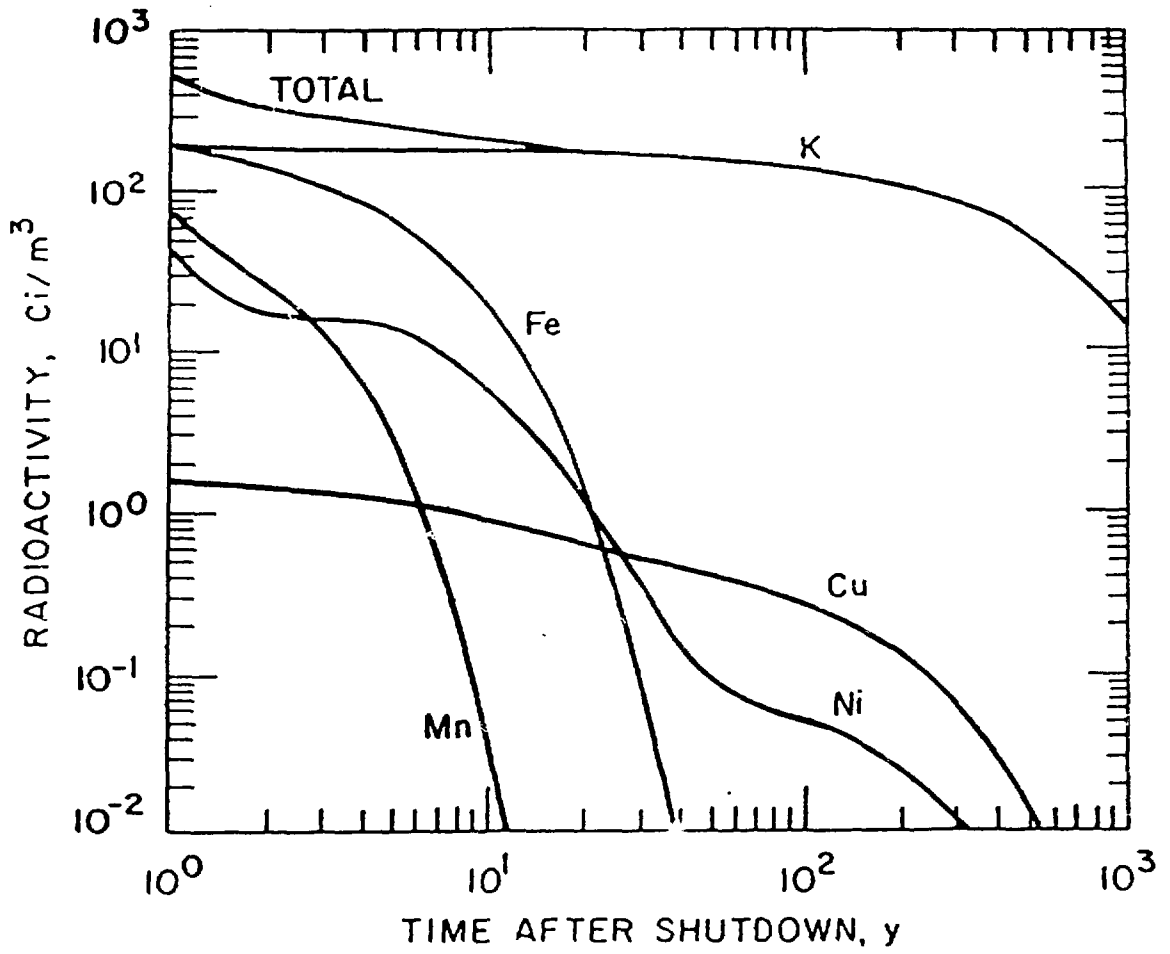


IMPACT ON LITHIUM RESOURCE REQUIREMENT FROM TYPE OF SOLID BREEDER AND ITS LI-6 ENRICHMENT

1
C
1



ELEMENTAL IMPURITY CONTRIBUTION TO LIALO₂ ACTIVATION



ELEMENTAL IMPURITY CONTRIBUTION TO LI20 ACTIVATION

Fig 3
D
Kumar

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