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CONF-7716171--2

POTENTIAL LITHIUM REQUIREMENTS
FOR FUSION POWER PLANTS

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Presented at the Symposium on
Lithium Needs and Resources
October 12-14, 1977
Corning, NY

Prepared for Publication
in Energy Magazine

by
J. N. Hartley
B. F. Gore
J. R. Young*

Battelle
Pacific Northwest Laboratories
Richland, Washington 99352

*Current address is WPPSS, Richland, WA

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY UNDER CONTRACT EY-76-C-06-1830

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POTENTIAL LITHIUM REQUIREMENTS FOR FUSION POWER PLANTS

J. N. Hartley, B. F. Gore, and J. R. Young†

Battelle, Pacific Northwest Laboratories, Richland, WA 99352, U.S.A.

Abstract - Because future shortages of essential materials could slow the deployment of fusion power reactors, it is important to assess the future availability of these materials. This article reviews the fuel requirements of fusion power plants in current conceptual designs with emphasis on lithium requirements.

The first generation fusion reactors using the deuterium-tritium (D-T) fuel cycle are expected to consume lithium (primarily ${}^6\text{Li}$) in nuclear reactions and in replacement of neutron-damaged blanket materials. The quantity of lithium actually consumed in nuclear reactions or blanket replacement will be a small part of the natural lithium required by fusion power plant concepts that use liquid lithium metal as a moderator, fertile material, and primary coolant.

Lithium inventories for a 10^3 -GWe generating capacity will require from 400,000 to 1,200,000 metric tons of natural lithium for different power plant designs, which is about 50 to 160 years worth of current U.S. lithium production or up to 1/3 of known U.S. lithium resources.

A discussion of lithium requirements and supply suggests that the lithium usage anticipated by the developing fusion power industry may require lithium production well beyond current production growth rates. Present U.S. lithium resources appear sufficient, however, and it is expected that the costs of increasing lithium production would be within acceptable costs for fusion power plants. Careful planning will be required to manage possible problems in obtaining adequate lithium production capacity.

†Now employed by Washington Public Power Supply System, Richland, Washington.

INTRODUCTION

Fusion is a potential energy source with a major advantage of having an almost unlimited fuel supply. Fusion is the process in which the nuclei of light elements are forced to combine and form new light elements with a net yield of energy. The development and deployment of fusion power plants will depend on the availability of large quantities of materials, some of which have never been in large supply or production. Future shortages of materials might affect the deployment of fusion power reactors.

The first generation fusion reactors will be based on the deuterium-tritium (D-T) reaction since it is the easiest fusion reaction to achieve. Lithium will be required in amounts dependent on the reactor design concept. When liquid lithium is used as a tritium breeder and a coolant, lithium inventories are large (500,000 to 1,200,000 metric tons). Concepts using solid lithium require less lithium, but the lithium must be enriched in isotope ^6Li , and a neutron multiplying agent such as beryllium must be used. High burnup rates (rates of material consumption in nuclear reactions) will affect lithium requirements in solid lithium concepts.

This paper reviews the fuel requirements of fusion power plants with emphasis on lithium requirements and lithium supply. Estimates of lithium requirements are presented for a 10^3 -GWe generating capacity (1 GWe = 1000 MWe). This is roughly twice the current total U.S. generating capacity.

Background on Fusion

Fusion reactions are nuclear reactions between light nuclei that release energy and yield product nuclei differing from the fuel nuclei. The reacting nuclei must collide hard and

often to undergo fusion. The requirements of multiple, high-energy collisions of fuel nuclei are met in a hot, dense plasma.

Such plasma must be held together by some means (e.g., magnetic confinement) long enough that more energy is released by fusion than is required to produce the plasma. Demonstration that this is possible is the near-term goal of the fusion program.

The difficulty of plasma confinement increases with plasma temperature. Consequently, it is expected that the fusion reaction to be employed in the first generation fusion reactors will be the one having the lowest plasma temperature requirements. This is the reaction between the heavy isotopes of hydrogen, deuterium (D), and tritium (T) which yields an alpha particle (^4He) and a neutron plus 17.6 MeV of energy;

The helium nucleus carries away 3.5 MeV of energy and the neutron carries away 14.1 MeV. In a magnetic fusion reactor the helium nuclei would be confined by a magnetic field while the neutrons would escape the field and enter a surrounding blanket of neutron-moderating material such as lithium. Inelastic scattering with the blanket material would convert the kinetic energy of the neutrons into thermal energy, which could be carried off by a coolant for conversion to electricity.

Although the (D-T) reaction is just one of many possible fusion reactions, it is expected to yield significant releases of fusion energy at plasma temperatures much lower than are required for the others.

Naturally occurring tritium is insufficient in quantity and concentration for use as a fuel. The entire world supply is about 10 kg distributed throughout the earth's air and water, enough to fuel one reactor about one month.¹ However, tritium can be produced from lithium via these nuclear reactions:

The neutrons produced in (D-T) fusion can cause either of these reactions with the possibility that a single fusion neutron can cause both. This happens when an energetic neutron induces the ${}^7\text{Li}$ reaction, emitting a secondary neutron that induces the ${}^6\text{Li}$ reaction. Studies indicate that (D-T) fusion reactors can be designed to breed tritium, producing more than enough tritium to fuel the fusion reaction. The (D-T) fuel cycle is shown schematically in Fig. 1. Present conceptual reactor designs include the entire fuel cycle within each power plant.

(Place Figure 1 Here)

An alternative method of achieving tritium breeding in fusion reactor designs involves the use of neutron-multiplying reactions in place of, or in addition to, the ${}^7\text{Li}$ reactions. The beryllium (Be) reaction,

is an important example. Tritium breeding reactor designs have been produced to include beryllium for its neutron multiplying effect for various reasons: to reduce space requirements; to reduce the amount of lithium required; and to make up for neutron captures by other materials.

The (D-T) fusion fuel cycle places certain basic requirements on conceptual reactor designs. The plasma must be confined and

heated to ignition conditions, a matter of fundamental importance in current research. Plasma confinement methods strongly influence the details of fusion reactor design.

All fusion reactors must have a chamber in which the reacting plasma can be isolated from surrounding structures. This plasma chamber must be surrounded by a thick material "blanket" to stop and capture the energetic neutrons liberated in the fusion reaction. Lithium must be contained in this blanket for tritium breeding. In addition, because 80% of the energy released in (D-T) fusion is carried by the neutrons (and consequently can only be recovered as heat energy) fusion reactors must incorporate a thermodynamic cycle for electric power generation. In most designs this is a steam cycle.

Lithium may be present in fusion reactor blankets as either a liquid or a solid. Liquid lithium is used in some design concepts (either as pure lithium or as a constituent of a molten salt) as both a coolant and a source of tritium. Lithium circulates through the blanket, picking up heat, and then travels to heat exchangers where the heat is transferred to other coolants. Solid lithium, usually in a ceramic form, is used only as target material for generating tritium. Ceramic lithium compounds are used because of more favorable physical characteristics for the severe operating conditions of high temperatures and intense neutron fluxes.

Operation of a power plant with the (D-T) fuel cycle requires introduction of an essentially continuous supply of deuterium and tritium into the reactor chamber. Deuterium is readily available on the open market as heavy water (D_2O). The deuterium can be separated from the oxygen by simple electrolysis. At the present market price for heavy water, the deuterium cost would be less than 0.01 mils/kWh of electricity produced by the power plant. The amount of deuterium consumed annually by a 1000-MWe power plant

would be about 50 kg. Since the earth's waters contain about 10^{13} metric tons (t) of deuterium, there is an essentially unlimited supply of deuterium available for all nations.²

Two recycle loops are required in all fusion power plant designs that incorporate the entire (D-T) fuel cycle. First, about 75% or more of the fuel will pass through the plasma without reacting and must be recovered, purified, and returned to the plasma. Second, bred tritium must be recovered from the blanket and sent to the fuel system for purification and injection into the plasma. The necessary systems, structures, and their functional relationships are diagrammed in Fig. 2. This general representation covers all existing (D-T) fusion power plant designs.

(Place Figure 2 Here)

Figure 3 presents as an example of fusion power plant concept an illustration of the University of Wisconsin Tokamak power plant, UWMAKI. The large toroidal plasma chamber and blanket enclosed by massive superconducting magnet coils typify Tokamak magnetic confinement of plasma.

(Place Figure 3 Here)

A variety of methods is being investigated to achieve the fundamental goals of fusion research: to create a plasma of thermonuclear temperature and density, and to hold it together long enough that more energy is released in fusion than is expended in creating the plasma. Plasma confinement by magnetic fields is used in tokamak, theta pinch, and mirror concepts. Plasma confinement due to the inertia of the plasma itself is used in laser-pellet concepts.

Conceptual power plant designs have been developed for each of the major confinement concepts under investigation, more than one for some of the concepts. Since it is not presently possible

to predict which of the confinement concepts may prove to be scientifically and economically feasible, and which may be developed to the point of commercial application, information for this paper has been taken from a variety of fusion reactor design studies. The designs which have been analyzed are based on different extrapolations of present technological capabilities. They are conceptual as opposed to fully engineered. They represent first attempts to develop designs that incorporate all aspects of fusion power plant performance and define systems to perform the necessary functions for power plant operation. An objective of many of the design studies was to identify, through the design attempt itself, components which cannot be realistically designed at the present time. Then technology can be developed while plasma confinement research is being carried out, to be ready when it is needed. Consequently, differing amounts and types of fuel materials are required by the various designs.

The designs upon which this paper is based were current in 1975. The originators of these designs and the study groups that prepared them are listed in Table 1.

(Place Table 1 Here)

Since that time efforts have been made to optimize fusion reactor designs. Attention has been directed toward reducing reactor size for a given power level, increasing the power density achievable in fusion reactor blankets, and increasing the lifetime of blanket materials (limited by radiation damage). Such efforts have the potential to reduce the amounts of materials required to construct fusion reactors and to replace reactor parts that exceed their useful lifetime during operation. This would lead to a reduction of lithium and beryllium inventories in fusion reactor

blankets and also to a reduction of discards of these fuel materials due to replacement (or recycle operation wastage). Consequently, the estimates of fuel requirements presented herein may be somewhat conservative.

Plasma confinement research results since compilation of the tables presented here have resulted in changes of program direction. For instance, toroidal theta pinch and classical mirror devices are no longer regarded as contenders for plasma confinement in fusion power plants. Alternative concepts under study include field reversed mirrors, a "bumpy torus" of linked mirror confinement regions, and linear systems including coupled theta pinch and laser plasma heating. Complete commercial power reactor designs either have not been produced or have not been analyzed for these concepts. Nevertheless, the designs analyzed provide a broad estimate, probably conservative, of fusion fuel requirements. It is not likely that inclusion of new confinement concepts would radically alter the conclusions drawn here.

FUSION FUEL REQUIREMENTS

The first generation fusion reactors using the deuterium-tritium fuel cycle are expected to consume lithium (primarily ${}^6\text{Li}$) through nuclear reactions and through required replacement of blanket materials damaged by neutron radiation. The amount of lithium required varies widely among the current conceptual designs for fusion power plants, depending on the extent to which beryllium is used for neutron multiplication and whether natural or enriched (${}^6\text{Li}$) lithium is used. Fusion power plant requirements for these materials depend upon several factors:

- a) consumption of materials in nuclear reactions,
- b) replacement of neutron-damaged blanket materials,
 - recycle of partially consumed materials versus disposal as waste,
 - isotopic enrichment requirements (^6Li) and disposition of enrichment tails,
- c) blanket inventory requirements.

The consumption of deuterium and tritium in nuclear reactions is primarily determined by plant power output and thermal efficiency. The corresponding consumption of lithium and beryllium are then determined by the tritium breeding ratio and by the required neutron multiplication per source neutron.

Fuel Consumption by Fusion Reactions

Normalized annual consumption rates of deuterium, tritium, ^6Li , and beryllium in fusion nuclear reactions are presented in Table 2 for conceptual fusion power plant designs.

(Place Table 2 Here)

Deuterium consumption ranges from 0.06 to 0.12 t/GW-yr. The processing of spent plasma to remove impurities will probably result in some deuterium losses. Because of the low cost and large supply of deuterium, deuterium wastage has not been carefully studied. Deuterium requirements may be 0.2 t/GWe-yr, including wastage. At this rate a generating capacity of 10^3 GWe (which is about twice the current U.S. generating capacity) would require 200 t/yr. However, because any wastage would be expected to return to the hydrosphere and be available for subsequent use, the actual reduction of the deuterium resource would be less than 0.12 t/GWe-yr.

Tritium fuel for fusion power plants will be bred from lithium in the reactor blankets and processed by plant systems. Present expectations are that fusion reactors will breed an excess of tritium with some designs doubling the initial tritium inventory in less than a year. Consequently, the tritium supply required by the entire commercial fusion power industry may be only an initial inventory for the first large reactor. Plant inventories projected for current power plant designs are listed in Table 3. Active inventories of tritium (contained in blanket, coolant, and fuel systems) range up to a maximum of 9.2 kg/GWe, and total inventories range up to 16 kg/GWe. The maximum total tritium inventory projected for a single plant is 35.8 kg. Thus, the entire commercial fusion power program may require a supply of less than 36 kg of tritium.

(Place Table 3 Here)

The maximum consumption of ${}^6\text{Li}$ by nuclear reactions is estimated to be 0.34 t/GWe-yr. Since only 7.5% of natural lithium is ${}^6\text{Li}$, this corresponds to 4.5 t/GWe-yr of natural lithium that must be produced.

Fuel Consumption Due to Blanket Replacement

In all fusion power plant designs it is necessary to replace portions of the blanket periodically because of neutron damage. During replacement operations liquid blanket constituents such as liquid lithium metal or the molten salt flibe (LiF , BeF_2 mixture) can be drained and stored for reuse. Solid fertile and neutron multiplying materials specified in some designs, however, will be replaced along with the structural material since they are also subject to radiation damage. The recycle or disposal of these materials will then be determined by economics and the

availability of materials. Differing assumptions about the need for and efficiency of recycle have been made for some designs. Estimates of annual makeup requirements for lithium and beryllium are listed in Table 4. Power plant designs not included either lack estimates or have large inventories where burnup during the plant lifetime is small. Comparison of Tables 2 and 4 shows that annual makeup requirements for lithium and beryllium range up to almost 50 times the amounts consumed by nuclear reactions. Annual makeup requirements of ^6Li range from 0.3 to 12 t/GWe capacity. The maximum consumption of ^6Li due to replacement of damaged blanket materials assuming no recycle is estimated to be 12 t/GWe-yr (160 t/GWe-yr natural lithium) which is about 50 times greater than the amount consumed by nuclear reactions. If 90% recycle were assumed, ^6Li consumption would drop to 1.2 t/GWe-yr (16 t/GWe-yr natural lithium). This would represent a maximum ^6Li consumption of 1200 t/yr (16,000 t/yr natural lithium) for a generating capacity of 10^3 GWe.

(Place Table 4 Here)

In the absence of demand for the lithium enrichment tails by other industries, the entire feedstock would be charged as a material required for fusion. However, if other industries compete for lithium supplies, the enrichment tails would be a desirable source of chemical lithium.

Annual makeup requirements of beryllium range from 0.6 to 11 t/GWe capacity. For a generating capacity of 10^3 GWe, beryllium makeup requirements would range up to 11,000 t/yr, even assuming recycle of more than 90% of the beryllium removed from reactor blankets. The makeup requirements for different power plant designs spread by a factor of 20 because of design differences and a variation of assumed recycle efficiency.

Blanket Inventory Requirements

The quantity of lithium actually consumed in nuclear reactions or blanket replacement will be a small part of the natural lithium required by fusion power plant concepts that use liquid lithium metal as a moderator, fertile material, and primary coolant. Power plant inventories of lithium and beryllium are listed in Table 5, normalized for a plant output of 1 GWe. The natural lithium inventory is expected to range between 500 and 1200 t/GWe. For a generating capacity of 1000 GWe this would represent a lithium inventory requirement of 500,000 to 1,200,000 t, which is about 160 years worth of current U.S. lithium production and $\sim 1/3$ of the total U.S. lithium resources. The bulk of the lithium inventory could be used again and again in many generations of fusion power plants, assuming continuous purification and makeup of the lithium consumed. Designs using enriched ^6Li would have a maximum inventory of about 30 t/GWe or a 30,000-t inventory for a 1000-GWe capacity. The tails from the $\sim 400,000$ t of natural uranium required to produce the enriched ^6Li could present a feedstock for chemical uses of lithium.

Inventories of enriched ^6Li in designs that use it range from 25 to 240 times its annual consumption in nuclear reactions. Annual makeup of ^6Li for these design ranges from $1/10$ to $1/2$ of the inventory and thus dominates plant requirements.

(Place Table 5 Here)

Inventories of beryllium metal in designs that use it range from 50 to 1000 times the annual consumption in nuclear reactions. Annual makeup for designs that assume recycle ranges from $1/2\%$ to 5%, thus exceeding inventory requirements over the plant lifetime in the 5% case. The beryllium inventory in the flibe molten salt blanket is 2000 times the annual consumption. No annual makeup is

required since consumption is trivial and radiation damage does not require replacement of the beryllium.

Summary of Fuel-Related Requirements

Operating fusion power plants are expected to require annual fuel-related supplies as shown in Table 6.

(Place Table 6 Here)

LITHIUM SUPPLY

Current U.S. lithium production is estimated to be approximately 4500 t/yr with a total capacity of ~5200 t/yr. The annual compounded growth rate since 1969 has been 12%. If growth continues at this rate, annual production in 1999 will be nearly 55,000 t. This is large compared to the largest lithium requirement for construction of a single fusion power plant, which is 1700 t for UWMAK-I. Cumulative production by 1999 would be 390,000 t of lithium, which is a relatively small part of total U.S. resources.

Technological developments are expected to increase the demand for lithium, and concern has been expressed over the ability of the lithium industry to meet demand toward the end of this century.¹³ The possible successful development of lithium-sulphur storage batteries (electric automobiles; utility off-peak storage) may require a ten-fold increase in lithium production and consume up to 500,000 t of lithium by the year 2000.

But significant lithium price increases could be tolerated with little effect on projected electric power costs because lithium has a high energy content as a fusion fuel. For example, at the maximum ^6Li consumption rate due to nuclear reactions of 340 kg/GWe-yr, the energy content of the lithium consumed is 20,000 KWh/g. The

cost of large-scale, commercial isotopic enrichment of lithium is not currently known, but if ^6Li is assumed to be 10 times the present cost of natural lithium, 15/lb, consumption by nuclear reactions would yield a lithium fuel cost of 0.02 mills/kWh. Increasing this by a factor of 40 to include required makeup of ^6Li due to blanket replacement would still yield a lithium fuel cost of less than one mill/kWh. This would allow fusion reactors to compete favorably for supplies, and would also allow the exploitation of lower-grade resources.

Lithium Reserves and Resources

U.S. lithium reserves and identified resources are estimated to be about 373,000 t and 3,200,000 t, respectively.¹⁴⁻¹⁶ Large lithium resources, such as Chile's 1.5 million t, are also found elsewhere in the world.

The ocean is an additional resource of lithium, although recovery would probably be very expensive compared to present sources. The ocean contains about 0.17 g/m³ or about 2.5×10^{13} t of lithium.

The identified U.S. resources of 3.2 million t is roughly 1000 times the feedstock required to supply the ^6Li annually consumed by nuclear reactions with a 10^3 GWe generating capacity. Makeup requirements rather than consumption by nuclear reactions limit the time it would take to consume identified U.S. resources of lithium.

The 3.2 million t of U.S. lithium resources are only 25 times the feedstock required to supply the maximum ^6Li makeup for a generating capacity of 10^3 GWe, assuming no recycle. If enriched ^6Li in the solid blanket concepts can be removed with 90%-efficient recycle, lithium resources appear sufficient to support more than a century of makeup requirements for a 10^3 -GWe generating capacity. Since the production of enriched ^6Li rejects more than 90% of the

feedstock materials for possible use by other industries, greatly expanded chemical use of lithium should not impede production of ^6Li for the fusion program.

Present plant designs using natural lithium coolant material require 500,000 to 1,200,000 t of inventory for 10^3 GWe of generating capacity. Because insignificant burnup of lithium is expected in these plants over the entire assumed 30-yr plant life, this inventory could be recycled through successive generations of plants. Only makeup of ^6Li consumed in nuclear reactions would be required (along with the makeup due to planned continuous in-plant removal of impurities). Consequently, U.S. lithium resources appear sufficient to support more than a century of 10^3 -GWe generation by plants using natural lithium coolant/fertile material.

SUMMARY AND CONCLUSIONS

Present U.S. lithium resources appear sufficient to support more than a century of fusion power plant operation with first-generation conceptual power plant designs at a generating capacity of 10^3 GWe. U.S. lithium production at its present compounded annual growth rate of 12% will not be sufficient to supply the needs of a fusion generating capacity that large by the time the power plants are expected to be built. Furthermore, it is possible that new technologies (e.g., lithium-sulfur storage batteries) will use significant quantities of lithium in the future. This scenario would require a large increase in production capacity to meet the increased demand for lithium.

Because of lithium's high energy contribution as a fusion fuel increased costs to increase the production of lithium would have little effect on projected electric power costs. Fusion power plants would complete favorably for lithium supplies, and even the added cost of exploiting lower-grade resources would yield acceptable lithium fuel costs. If future fusion power plants use

inventories of ${}^6\text{Li}$, tailings from the isotopic enrichment process would make good feedstock for other lithium industries.

The lithium usage anticipated for the developing fusion power industry may meet problems in obtaining adequate lithium supplies. Careful planning will be required to make these problems manageable.

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TABLES

1. Originators of Conceptual Fusion Power Plant Designs
2. Normalized Annual Consumption of Fuel Materials by Nuclear Reactions
3. Normalized Power Plant Tritium Inventories
4. Normalized Annual Makeup Requirements of Lithium and Beryllium
5. Normalized Initial Power Plant Inventories of Lithium and Beryllium
6. Annual Fuel-Related Requirements of a Fusion Reactor

Magnetic
Confinement DesignsDesign Originators

Tokamak

{ University of Wisconsin (UWMAK)
Brookhaven National Laboratory (BNL)
Princeton Plasma Physics Laboratory (PPPL)
Oak Ridge National Laboratory (ORNL)

Theta Pinch

Los Alamos Scientific Laboratory (LASL)

Mirror

Lawrence Livermore Laboratory (LLL)

Inertial
Confinement Designs

Wetted Wall

LASL

Suppressed Ablation

LLL

Table 2

Power Plant Design	Net Plant Thermal Efficiency (%)	Consumption by Nuclear Reactions (metric tons/GWe-year)			
		Deuterium	Tritium	⁶ Li†	Beryllium‡
UWMAK-I Tokamak ³	32	0.11	0.17	0.33	--
BNL Blanket for UWMAK-I ⁴	32	0.11	0.16	0.32	0.24
UWMAK-II Tokamak ⁵	36	0.09	0.13	0.26	0.26
PPPL Tokamak ⁶	38	0.07	0.10	0.20	0.07
ORNL Tokamak ⁷	52	0.06	0.09	0.17	--
Theta Pinch ⁸	34	0.09	0.13	0.30	0.15
Mirror ⁹	27	0.12	0.17	0.34	--
Wetted Wall Laser ¹⁰	27	0.11	0.16	0.31	--
Suppressed Ablation Laser ¹¹	36	0.10	0.15	0.29	--
UWMAK-III Tokamak ¹²	42	0.08	0.11	0.22	--
Range		0.06-0.12	0.09-0.17	0.17-0.34	0.07-0.26

† Estimated assuming consumption of one atom of ⁶Li per fusion neutron.

‡ Estimated using specific Be reaction rate per fusion neutron for each reactor.

Table 3

Power Plant Design	Tritium Inventory, kg/GWe		
	Active	Storage	Total
UWMAK-I Tokamak ³	9.2	6.8	16.0
BNL Blanket for UWMAK-I ⁴	0.1	6.2	6.3
UWMAK-II Tokamak ⁵	3.0	3.6	6.6
PPPL Tokamak ⁶	0.3	1.0	1.3
ORNL Tokamak ⁷	0.8	10.8	11.6
Theta Pinch ⁸	0.6	0.4	1.0
UWMAK-III Tokamak ¹²	8.5	9.3	17.8
<hr/>			
Range	0.1-9.2	0.4-10.8	1.0-17.8

Power Plant Design	Annual Makeup Requirement, metric tons/GWe	
	<u>⁶Li†</u>	<u>Beryllium</u>
BNL Blanket for UMAK-I ³		
Tokamak	0.3§†	0.6
UWMAK-II Tokamak ⁵	12.2†	10.7*
Theta Pinch ⁸	0.3‡	2.4
<hr/>		
Range	0.3-12	0.6-11

†Natural lithium required for enrichment feed is
12 to 15 times this amount

§70% recycle assumed.

†Solid lithium compound blanket

||98% recycle assumed

*90% recycle assumed

‡Liquid lithium blanket

Table 5

Power Plant Design	Inventory, metric tons/GWe		
	Lithium		Beryllium
	Natural	⁶ Li†	
UWMAK-I Tokamak ¹	1,200	---	---
BNL Blanket ² for UWMAK-I§	---	3	120
UWMAK-II ³ Tokamaks	175	29	250
PPPL ⁴ Tokamak¶	290	---	430
ORNL Tokamak ⁵	890	---	---
Theta Pinch ⁶	220	12	12
Mirror ⁷	490	---	---
UWMAK-III Tokamak ¹⁰	240	---	---

† Natural lithium required for enrichment feed is 12 to 15 times this amount.

§ Solid lithium compound blanket

¶ Flibe blanket (LiF, BeF₂ mixture)

<u>Materials</u>	<u>Annual Fuel-Related Requirements, metric tons/GWe</u>
Deuterium	0.06 to 0.2
Tritium	None after initial inventory is supplied
^6Li	0.3 to 12 (if used)
Beryllium	0.6 to 11 (if used)

FIGURES

1. Deuterium-tritium fuel cycle.
2. Functional relationships of fusion power plant systems.
3. Wisconsin Tokamak fusion reactor, UWMAK-I.

Table 6. Annual fuel-related requirements
of a fusion reactor

FIGURES

1. Deuterium-tritium fuel cycle.
2. Functional relationships of fusion power plant systems.
3. Wisconsin Tokamak fusion reactor, UWMAK-I.

DEUTERIUM-TRITIUM FUEL CYCLE

WISCONSIN TOKAMAK FUSION REACTOR, UWMAK-I

1. PLASMA
2. TOROIDAL FIELD COIL (12)
3. RETRACTABLE DIVERTOR COIL (8)
4. TRANSFORMER COIL (10)
5. EVACUATED PRIMARY CONTAINMENT BUILDING

6. Li PRIMARY SYSTEM (ONE FOR EACH OF 12 MODULES)
7. Na SECONDARY SYSTEM (ONE FOR EACH OF 12 MODULES)
8. DIVERTOR Li PRIMARY SYSTEM
9. DIVERTOR Na SECONDARY SYSTEM
10. TURBINE-GENERATOR BUILDING

11. HOT CELL REPAIR AREA
12. MAGNET SHIELD
13. BLANKET
14. DIVERTOR COLLECTION AREA
15. MOTORIZED MODULE SUPPORT VEHICLE
16. AUXILIARY EQUIPMENT AREA

1. PLASMA
2. TOROIDAL FIELD COIL (12)
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