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The NUWMAK design is a second generation reactor design study. It utilizes the experiences we obtained from UWMAK series designs, combined with recent development in plasma physics and aimed toward a more optimized reactor design. The blanket for NUWMAK is designed to minimize thermal cycling, provide internal thermal energy storage, eliminate the need for an intermediate loop, minimize tritium inventory, facilitate tritium recovery, reduce the possibility of violent chemical reaction, and minimize long term radioactivity. These requirements are satisfied in the NUWMAK blanket design.

INTRODUCTION

The overriding figure of merit which will determine the acceptability of fusion power plants by the utilities will be the competitiveness of the net cost of electrical energy produced. During the past few years, increasing attention has been directed to preliminary engineering studies of possible fusion reactor power plants. These, however, were point studies, and were far from being optimized. They served the purpose as problem-finders rather than problem-solvers. The accompanying cost analysis indicated that tokamak fusion reactors would be expensive.

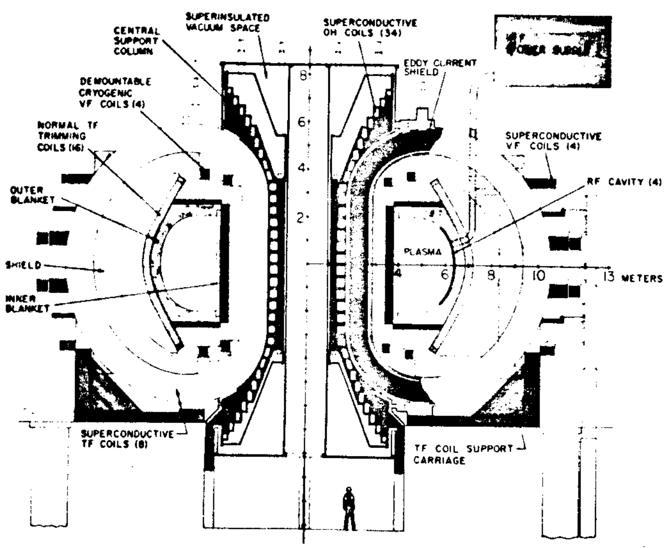
The University of Wisconsin Fusion Research Program has been involved in conceptual design studies for the past five years. Our series of tokamak reactor power plants, designated UWMAK-I[1], II[2], and III[3] were point design studies based on different philosophies and assumptions. From this experience, we carried out a second generation design study, designated NUWMAK.[4] The purpose of this study is to incorporate our experience and the recent development in plasma physics toward a more optimized reactor design. In particular, we tried to design a tokamak reactor which is compact, has a high β, high wall loading, and is accessible and maintainable. This paper discusses the blanket design for NUWMAK. The general introduction,[4] plasma considerations,[5] magnet design,[6] structural material selection,[4] and maintenance procedures[7] are discussed in other reports.

The blanket for NUWMAK is designed to minimize thermal cycling, provides internal thermal storage, eliminates the need for an intermediate loop, minimizes tritium inventory, facilitates tritium recovery, reduces the possibility of violent chemical reaction, and minimizes long term radioactivity. These requirements are satisfied by using a titanium alloy as the structural material and boiling water as the coolant. The eutectic $Li_{62}Pb_{38}$ compound is used both as the breeding and energy storage material. To provide redundancy and reduce tritium leakage into the coolant, a multi-layered coolant tube is used throughout the blanket. The steam conditions of such a system will be similar to that of a BWR. The blanket is operated as a latent heat thermal storage unit. A steam drum is used to further smooth out the power output fluctuations caused by the plasma cycle. The boiling water cooling scheme, the latent heat energy storage system and the turbine-generator systems for such a reactor are all within the present state-of-the-art, and should be simple, reliable and easy to maintain.

REACTOR DESCRIPTION

NUWMAK is a new conceptual design of a moderately sized tokamak fusion reactor of medium toroidal field, high power density and high neutron wall loading. A cross-sectional view of NUWMAK is shown on Fig. 1. The major characteristics of the

FIGURE 1 CROSS-SECTIONAL VIEW OF NUWMAK



design are summarized in Table 1. Some of the important parameters are as follows: the time average thermal power is 2097 MW, the electrical output is 660 MW, the major radius is 5.13 m, the plasma half width is 1.13 m, and the plasma height to width ratio is 1.65, the on-axis magnetic field is 6.05 T and the maximum field at the superconducting TF coil is 11.5 T, the plasma power density is 10.5 MW/m^3 and the surface average neutron wall loading is 4.0 MW/m^2. The power density and electrical power output chosen for this unit represent a typical full scale power reactor operating in a base-loaded mode at the turn of the century.

The plasma is not designed with a divertor but rather fueling and plasma cleansing are affected by periodic gas puffing. DT gas is puffed for 50 msec to invert the density profile at the edge and then allowed to relax over about 300 msec. The plasma burn time is 225 sec and the time between burns is about 20 sec. Plasma heating is with RF

TABLE 1. Parameters of NUWMAK

Thermal Power	2097 MW
Electric Power (Net)	660 MW
Neutron Wall Load	4.0 MW/m^2
Major Radius	5.13 m
Plasma Half Width	1.13 m
Height to Width Ratio	1.64
Plasma Current	7.2 MA
Toroidal Beta	6%
Aspect Ratio	4.54
Plasma Shape	"D"
Heating Method	RF at 92 MHz ($2\omega_{ci}$)
RF Heating Power	80 MW
RF Power Duration	3 sec
Axial Toroidal Field	6.05 T
Maximum Toroidal Field	11.5 T
Number of S/C Coils	8
Field Ripple Correction	Cu Saddle Coils
Number of Saddle Coils	16
Outer Blanket Structure	Ti Alloy
Breeding Material	$Li_{62}Pb_{38}$
Blanket Coolant	Boiling H_2O
Structure	Ti-Alloy
Shielding	W-B_4C
Breeding Ratio	1.54

at 92 MHz ($2\omega_{ci}$). A heating power of 80 MW is sufficient to ignite the plasma in 3.0 sec.

The toroidal field magnet set is unique in NUWMAK. There are just 8 main superconducting TF coils located symmetrically about the machine leaving large areas between coils for access. High purity Al is the stabilizer for NbTi superconductor maintained at 1.8^{o}K by superfluid helium. The maximum field at the conductor is 11.5 T. The large TF ripple produced by the 8 coils is corrected to less than 1% by saddle shaped normal copper trimming coils located behind the outer blanket close to the plasma. These saddle coils are easily removable. This approach has potential for both near term experiments and power reactors.

The blanket of NUWMAK is designed to minimize thermal cycling, to provide internal thermal storage, to eliminate the need for an intermediate loop in the power cycle, and to minimize long term radioactivity. These requirements are satisfied by using a titanium alloy as the structural material and boiling water as the coolant. A lithium-lead compound, $Li_{62}Pb_{38}$ eutectic operated at its melting point is used as both the tritium breeding and thermal energy storage material. The steam conditions of such a system are almost identical to BWR's (300^{o}C, 1250 psi).

MATERIAL SELECTION

The structural material for NUWMAK is Ti-alloy. Ti-alloy is used due to its high strength-to-weight ratio, good fatigue resistance, high resistance to crack growth, fabricability, and low long term residual activity. A detailed discussion of the applicability of titanium alloys for fusion reactors is given in Reference (8). Ti-6Aℓ-4V was chosen for the first wall and coolant tube material because of its weldability, while Ti-6242 was chosen for the internal blanket structure and tube support because of its high temperature stability. Some of the physical and mechanical properties of Ti-6-4 are summarized in Table 2.

TABLE 2. Physical Properties of Ti-6-4 (at 400°C)

Atomic Weight	45.9
Melting Point	1668°C
Mass Density	4.4 g/cm^3
Yield Strength	530 MPa
Modulus of Elasticity	85 GPa
Yield-to-Weight Ratio	120 N•m/g
Thermal Conductivity	.12 W/cm•k
Coefficient of Thermal Expansion	10 x 10^{-6}/°C
Heat Capacity	668.8 J/kg•k

The advantages and problem areas of using Ti alloys are listed in Table 3. Two unique properties of Ti-alloys, especially Ti-6-4, have to be pointed out. The first is the very low thermal conductivity, which is about half that of 316 SS. The low thermal conductivity produces a large temperature difference across the coolant tube wall. The second, which compounds the problem even further, is that titanium alloys, Ti-6-4 in particular, have a very narrow range of operating temperatures. The minimum operating temperature, which is determined by the solubility of hydrogen isotopes in titanium, is 300°C. The maximum operating temperature is determined by phase stability and for Ti-6-4 is probably limited to 430°C. In order to include a safety factor and account for the uncertainties encountered in a fusion environment, we chose a maximum design temperature of 400°C. The maximum allowable temperature for Ti-6242 is 500°C. The poor thermal conductivity and the narrow operating temperature range are important considerations in this blanket design. Thus, for example, helium cooling can be essentially ruled out for a blanket with Ti structure.

TABLE 3. Advantages and Problems Associated With Ti Structure

Advantages (Relative to Stainless Steel)

1. Higher Strength
2. High Strength to Weight Ratio
3. Better Fatigue Life
4. Better Corrosion Resistance - Li
5. Lower He Production
6. No Void Swelling (Yet)
7. *Inherently Non-Magnetic
8. *Fairly Well Established Industry
9. *Abundant Resources

*Not Relative to Stainless Steel

Problems

1. Very Limited Operating Temperature Range
2. Very Low Thermal Conductivity
3. More Costly
4. Lack of High Flux n Data
5. Hydriding < 300°C

The eutectic $Li_{62}Pb_{38}$ mixture is used as the breeding material. This compound is chosen for its high breeding potential, suitable melting temperature, low lithium chemical activity, and its relative inertness with respect to water. It was reported[9] that "LiPb resembles Pb in every rspect except density. LiPb would not ignite even when exposed to the flame of a gas-air torch." During operation, the LiPb will be in a molten state in the blanket such that the latent heat of fusion will provide the energy storage needed in the blanket during down time. The uncertainties in using the LiPb eutectic as the breeding and energy storage material at this time lies in the unavailability of physical properties data. Table 4 lists some of the properties used. They are mostly educated guesses at best and should not be taken as correct data.

TABLE 4. Physical Properties (Used)* of $Li_{62}Pb_{38}$

Solid Density	6.5 g/cm^3
Liquid Density	5.0 g/cm^3
Thermal Conductivity	.35 W/cm-°C
Latent Heat of Fusion	140 kJ/kg
Heat Capacity	174 J/kg-k
Melting Temperature	464°C

*The numbers listed on this table, with the exception of melting temperature, are educated guesses at best and should not be referred to as exact figures. The melting temperature is experimentally verified.

The very high first wall thermal loading, combined with the low thermal conductivity and the narrow operating temperature ranges for titanium alloys impose stringent conditions on the coolant requirement for NUWMAK. A very high heat transfer coefficient and a small coolant temperature rise are required. The candidate which best fulfills both requirements is boiling heat transfer. The operating temperature of Ti-alloy further restricts the coolant choice to only one, namely, boiling water. The possibilities of a violent chemical reaction between water and the lithium compound, and the difficulty of tritium recovery from water have restrained designers from using such a cooling scheme. However, the less activity of the lithium in Li_{62} Pb_{38} make the use of water acceptable from a safety standpoint. To minimize tritium diffusion into the cooling water we have proposed to use tubes of multi-layer design. Such tubes while inhibiting tritium diffusion also provide redundancy against leaks. The use of a low chemical activity breeding material combined with a multi-layer tube design gives as the confidence that boiling water cooling can be both safe and environmentally acceptable.

BLANKET DESIGN

The design philosophy for NUWMAK, based on our experience obtained from the UWMAK series, is to design a tokamak reactor which will avoid or alleviate as many problems as possible. Thus, NUWMAK is not an optimized design. Rather, it is a second generation design study leading toward a more optimized, more economically attractive design. The NUWMAK blanket design philosophy is consistent with the reactor design philosophy.

In order to avoid or alleviate as many problems as possible in the blanket design, it is useful to list the problems. Table 5 tabulates those problems and their causes. It also briefly summarizes the solutions we have provided in the NUWMAK design. It is clear that most of the problems are caused by:

1. The cyclic behavior of the plasma
2. The requirement for tritium breeding in the blanket.

The cyclic behavior of the plasma results in thermal cycling and fatigue of the structural material. To provide a constant thermal input to the power conversion system, a thermal storage unit is usually included for load leveling. The tritium breeding requirement of the blanket imposes the need for an intermediate loop to reduce tritium diffusion to the power conversion system and in the case of a steam cycle, to avoid the possibility of a water-lithium compound reaction. The effects of these problems are to reduce the reliability of the blanket structure, to increase the complexity and cost of the power cycle and to increase the difference between the blanket operating temperature and the steam temperature. The NUWMAK blanket design is aimed at reducing the severity of these problems.

TABLE 5. Problems, Causes and Possible Solutions for a Tokamak Blanket

Problems	Caused By	NUWMAK Solution
Thermal Fatigue	Cyclic Plasma	Ti Structure, Boiling Water Cooling
Thermal Storage	Cyclic Plasma	Phase Change (of Breeding Material) Thermal Storage
Intermediate Loop	H_2O-Li Compound Reaction Possibility	Li_{62} Pb_{38} Breeding, Redundant Structure
T-Diffusion	Toward Cooling Water	Multiple Layer Coolant Tube Design
High 1st Wall Thermal Load	High Wall Loading, No Divertor	Ti Structure, Boiling Water Cooling
Coolant Tube Maintenance	Tube Leak	Double Wall Tubes (Redundancy)
Waste Disposal, Reprocessing	Radioactivity	Ti Structure
Blanket Life	Radiation Damage	Low Operating Temperature

The cross-sectional view of the blanket is shown in Fig. 2. Saturated water is fed through a tube between the TF magnets, connected to a set of toroidal headers. The toroidal headers supply the coolant tubes in the blanket. A continuous bank of tubes form the first wall of the blanket. The coolant tubes within the blanket are on a

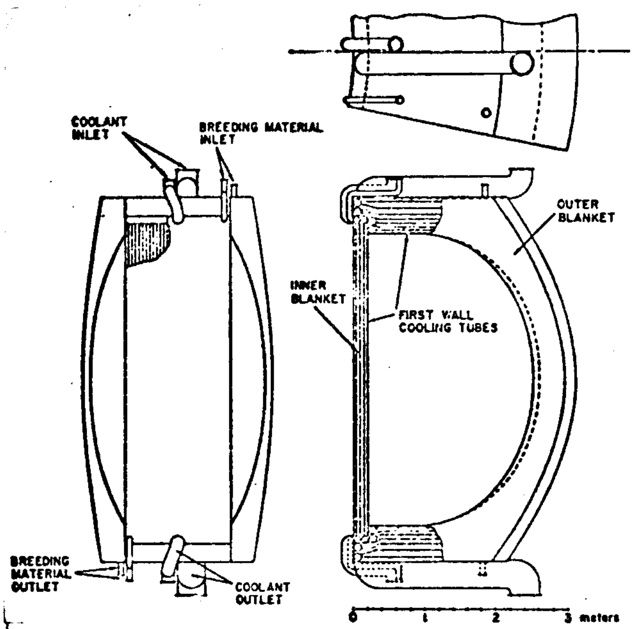


FIGURE 2. Cross-Sectional View of Blanket

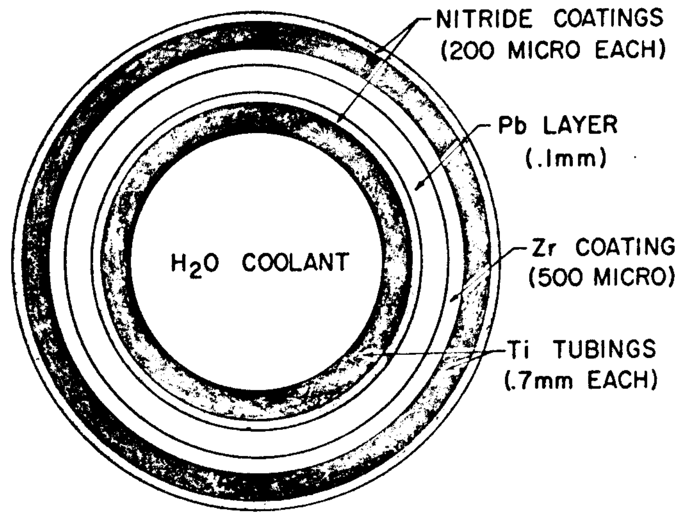


FIGURE 3 CROSS-SECTIONAL VIEW OF A COOLANT TUBE

triangular pitch, with the distance between two tubes inversely proportional to the nuclear heating rate. The inner blanket and outer blanket are completely separated and can be removed independently when maintenance is required. Breeding material inlets and outlets are also provided for each blanket module, both for tritium recovery and for dumping procedures.

A cross-sectional view of a coolant tube is shown on Fig. 3. The coolant tube is designed for maximizing blanket reliability. Double walled tubes are used throughout the blanket for redundancy. A layer of lead fills the gap between the two concentric tubes to increase the thermal conductance across the composite tube wall. Outside surfaces of both tubes are coated with a nitride coating to reduce the tritium diffusion into the coolant. The inner surface of the outer tube is coated with Zr which acts as a getter to absorb the tritium diffusing through the outer wall. Such a double walled tube will minimize tritium loss to the water while providing a reliable blanket. The cost of fabricating such tubes is undoubtedly high, but can be justified in view of the advantages gained.

The blanket is filled with $Li_{62}Pb_{38}$ among the coolant tubes, acting as both the breeding and energy storage material. The maximum temperature in the blanket is 500°C, which governs the distance between adjacent cooling tubes. The breeding material around each coolant tube is always solid, while between coolant tubes it is always molten. There is an intermediate zone which will change phase during the plasma cycle and the latent heat of the breeding material in this zone provides the energy storage during down time.

The blanket design described above has a major impact on the power cycle. A conventional power cycle[2] and the one proposed for NUWMAK are shown in Fig. 4 for comparison. The conventional power cycle is not only much more complicated, and therefore, much more expensive, it also reduces the steam temperature from the primary coolant temperature by ~ 100°C. Use of a multi-layered coolant tube, a breeding material with a low lithium chemical activity and latent heat energy storage in the blanket makes a BWR type power cycle possible. The cost saving should be significant and will be estimated in a future report.

NEUTRONIC CALCULATIONS

The neutronics analysis makes use of a two-

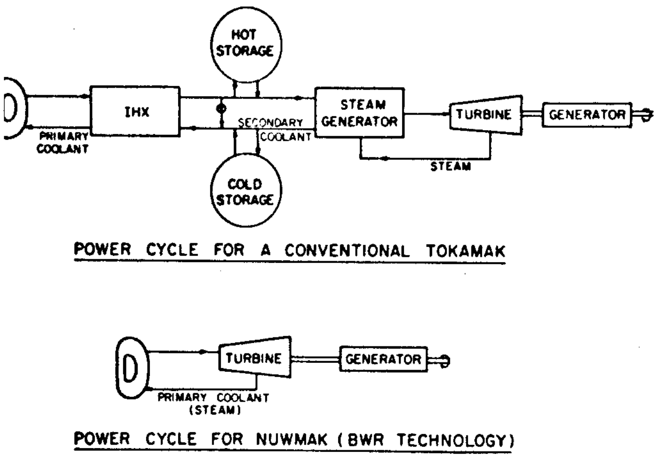


FIGURE 4 COMPARISON OF POWER CYCLE OF NUWMAK TO A CONVENTIONAL TOKAMAK REACTOR

TABLE 6. Summary of Neutronics Calculations

Tritium Production (T/D-T Neutron)	INNER	OUTER	TOTAL
$^6Li(n,\alpha)T$ (T_6)	0.2604	1.1249	1.3853
$^7Li(n,n'\alpha)T$ (T_7)	0.0375	0.1192	0.1567
$T_6 + T_7$	0.2979	1.2441	1.5420
Nuclear Heating (MeV/D-T Neutron)	**INNER**	**OUTER**	**TOTAL**
Neutron	2.2665	8.9298	11.1963
Gamma-Ray	2.4143	3.5422	5.9565
Neutron + Gamma-Ray Total	4.6808	12.4720	17.1528
Neutron Multiplication (Reaction/D-T Neutron)	**INNER**	**OUTER**	**TOTAL**
Pb(n,2n)	0.1339	0.4181	0.5520
W(n,2n)	0.0137	------	0.0137
Total	0.1476	0.4181	0.5657
Maximum Atomic Displacement Rate in the Superconducting Magnet Aluminum Stabilizer (dpa/year)	2×10^{-6}		

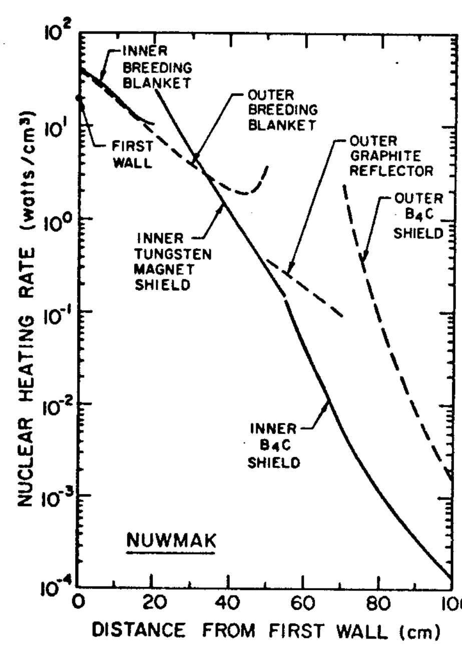


FIGURE 5 SPATIAL NUCLEAR HEATING RATE

dimensional discrete ordinate transport code DOT.[10] The calculation was performed with P_3S_4 approximation in r-z geometry. The nuclear cross section library used is the same as described elsewhere[11] and is collapsed into coupled 25 neutron and 21 gamma-ray groups. The neutronics model, which is essential in order to provide the more detailed spatial neutron/gamma-ray fluxes and nuclear responses, consists of important components in fusion reactors, namely, the magnet, the shield, the blanket and the plasma core. At the midplane, the inner blanket/shield region consists of a 10 cm lead shield, a 40 cm boron carbide shield, a 35 cm tungsten and a 20 cm $Li_{62}Pb_{38}$ eutectic blanket. In the outer blanket/shield region, it consists of a 50 cm lithium lead eutectic blanket, a 20 cm graphite reflector and a boron carbide shield. Note that the blanket regions are divided into five zones to account for various amounts of structure/piping and coolant water inferred from nuclear heating distributions (two and three for inner and outer blankets, respectively).

The neutronics results are summarized in Table 6. The spatial nuclear heating rate is shown in Fig. 5. The tritium breeding ratio is 1.54, which 90% is contributed from $^6Li(n,\alpha)$ reactions. This is due to the large Pb(n,2n) and W(n,2n) reaction rate, ~ 0.57 per source neutron and the sufficient amount of ^6Li in natural lithium within the lithium lead eutectic ($Li_{62}Pb_{38}$). However, the tritium breeding ratio is not very sensitive to the enrichment of ^6Li of the total lithium inventory. It shows a maximum value of 1.64 at ~ 30% ^6Li and a value of 1.51 at 90% ^6Li enrichment with most of the contribution (~ 99%) coming from ^6Li (n,α) reactions. The total nuclear heating in this sytem is 17.15 MeV/D-T neutron with ~ 35% contributed from gamma-ray heating. Most of the gamma-rays come from the neutron inelastic scattering and (n,γ) reactions with high Z elements such as lead and tungsten. The presence of such elements also enhances the radiation shielding capability. This table also shows that the maximum atomic displacement rate in the superconducting magnet aluminum stabilizer is 2 x 10^{-6} dpa/year. This dpa rate will increase the resistivity of the aluminum by 20% after one year of operation, and will necessitate periodic annealing.

HEAT TRANSFER CALCULATIONS

The most important consideration is to verify the concept of latent heat thermal storage. A two dimensional, transient, with phase change computer program was written in the course of the study. The program calculates the temperature change in the blanket as a function of time during a burn cycle as well as the location of the solid-liquid interface between two coolant tubes. Many important conclusions can be drawn from the results. The summary of the heat transfer calculations are listed in Table 7.

Figure 6 shows the temperature response of the NUWMAK first wall during a burn cycle, and compares it with a gas cooled first wall. Boiling water is a very good coolant and the first wall is kept within a reasonable temperature limit. However, there is little thermal inertia in the first wall and consequently its temperature drops to the coolant temperature within ~ 0.1 second of plasma shutdown. The stress associated with such a thermal shock is yet to be calculated but a first order estimate indicates it is acceptable. Notice the large temperature gradient across the first wall. This is due to the high thermal loading on the first wall and the poor thermal conductivity of the Ti-alloy. The total stress in the first wall is estimated to be 103 MPa and is

TABLE 7. Summary of Heat Transfer Calculations

Power Output (During Burn)	2283 MW
Neutron Wall Loading	4.34 MW/m^2
First Wall Area	360 m^2
Total Thermal Wall Loading	6.34 MW/m^2
First Wall Thermal Loading	1.08 MW/m^2
Plasma Burn Time	225 Second
Plasma Down Time	20 Second
Structure	Ti Alloy
Breeding Material	Li_{62} Pb_{38} Eutectic
Energy Storage Material	Li_{62} Pb_{38} Eutectic
Coolant	Boiling H_2O
Coolant Temperature	300°C
Coolant Pressure	8.6 MPa
Maximum Coolant Wall Temperature	400°C
Maximum Coolant Wall Stress	103 MPa
Maximum Blanket Temperature	500°C
Average Coolant Tube Thermal Load	44 W/cm^2
Total Coolant Tube Surface Area	4350 m^2
Net Power Output (Continues)	660 MW(e)
Net Thermal Efficiency	31.5%

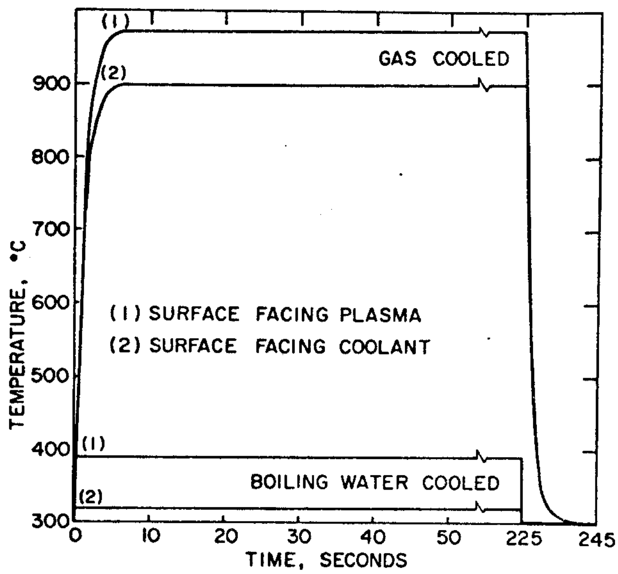


FIGURE 6 TEMPERATURE RESPONSE OF THE FIRST WALL DURING A BURN CYCLE, He VERSUS BOILING WATER COOLING

acceptable. It is worth noting that if the first wall is helium cooled, both the high temperature and the large temperature drop at the end of a burn cycle would result in an unacceptable design.

Figure 7 shows the temperature of the $Li_{62}Pb_{38}$ between a coolant tube wall and midway between two coolant tubes at three different times during a

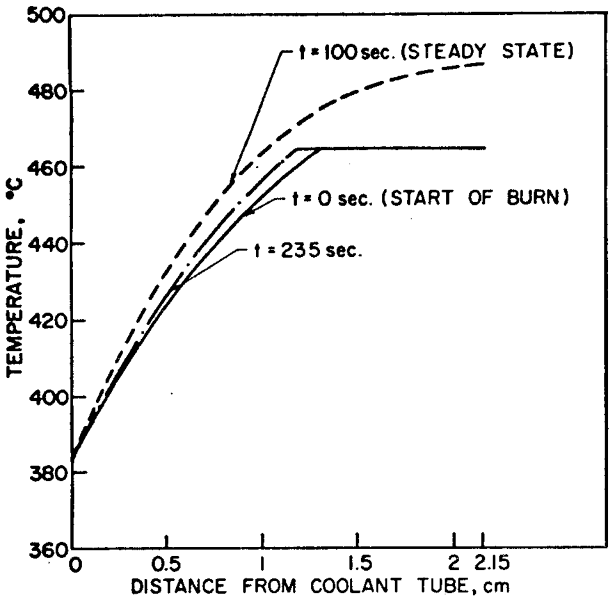


FIGURE 7 TEMPERATURE CHANGE OF THE BLANKET IN A BURN CYCLE (WITH PHASE CHANGE)

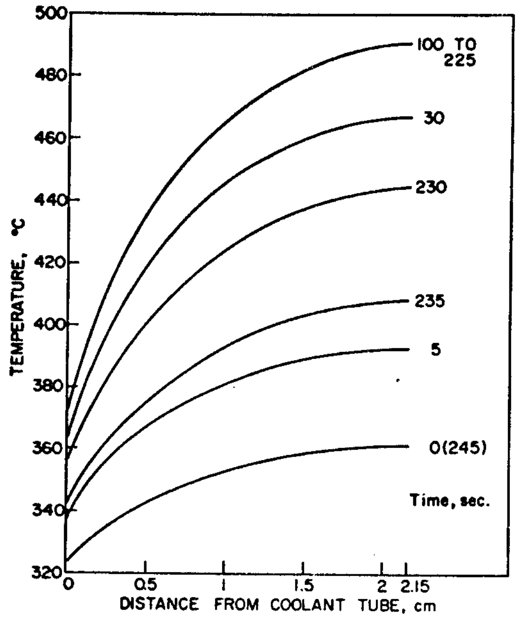


FIGURE 8 TEMPERATURE CHANGE OF THE BLANKET IN A BURN CYCLE (WITHOUT PHASE CHANGE)

burn cycle. One can clearly see the effect of the latent heat of the blanket material on the temperature changes in the blanket. After the burn is terminated, the liquid temperature drops to the melting temperature of $Li_{62}Pb_{38}$ in a short time. After this the latent heat of fusion supplies energy to the coolant tubes. The temperature change in the blanket during a complete burn cycle is only $\leq 30^{\circ}C$. The slope of the temperature curve at the coolant tube wall and, consequently, the energy supply to the power cycle remains almost constant during a burn cycle. For comparison, Fig. 8 shows the result for an identical system but without phase change. The maximum temperature change in the blanket is $150^{\circ}C$ and the slope change of the temperature curve becomes significant. The effect of phase change on the magnitude of the temperature cycling and the energy storage capacity in the blanket is clearly demonstrated in those two figures.

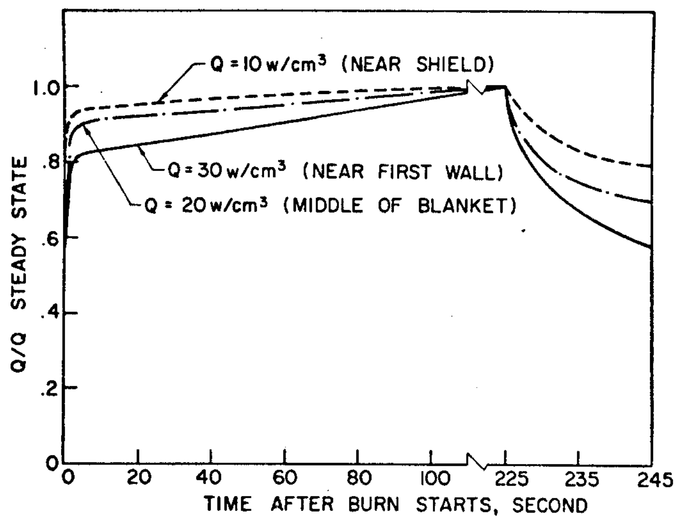


FIGURE 9 BLANKET ENERGY OUTPUT DURING A BURN CYCLE, FOR THREE DIFFERENT LOCATIONS IN BLANKET

Figure 9 shows the variation of the energy input to a coolant tube at three different locations in the blanket. For an ideal case, the curves should be constant. For the NUWMAK blanket, the maximum variation is about 30% from steady state. Figure 10 shows the benefit obtained from using latent heat energy storage. Without phase change in the blanket, the fluctuation in the blanket energy during a burn cycle is significantly larger. Such a system would definitely need auxil-

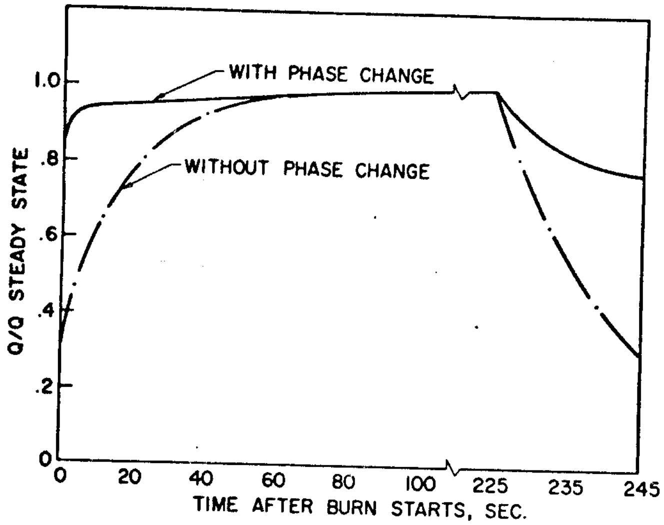


FIGURE 10 EFFECT OF PHASE CHANGE ON BLANKET ENERGY OUTPUT

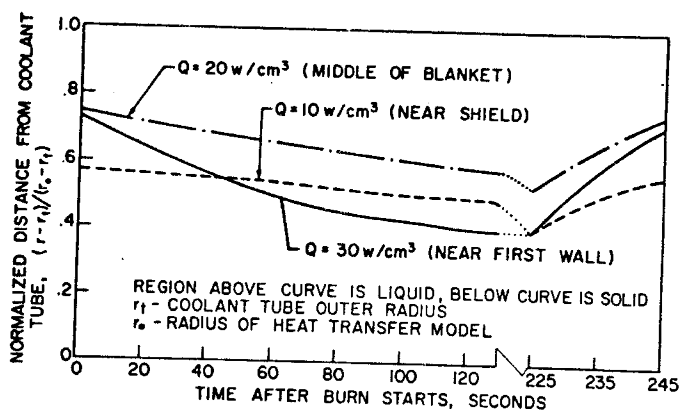


FIGURE 11 CHANGE OF SOLID-LIQUID INTERFACE IN A BURN CYCLE, FOR THREE DIFFERENT LOCATIONS IN BLANKET

iary thermal storage. In the NUWMAK blanket, the fluctuation of energy output is still unacceptable for use by a steam turbine. However, study is underway[12] on the possibility of using a stea drum and adjusting the feed water temperature to further smooth out the energy output such that it will be acceptable to operate a turbine. Figure 11 shows the change in the solid-liquid interface at the same three locations in the blanket. These are the constant temperature lines in the blanket and the movement of this interface changes the heat input to the coolant tube.

The power flow diagram for NUWMAK is shown in Fig. 12. The gross thermal efficiency is 34.5%. The total auxiliary power requirement is 65 MW, of which the magnets consume 60 MW. The net thermal efficiency is 31.5%.

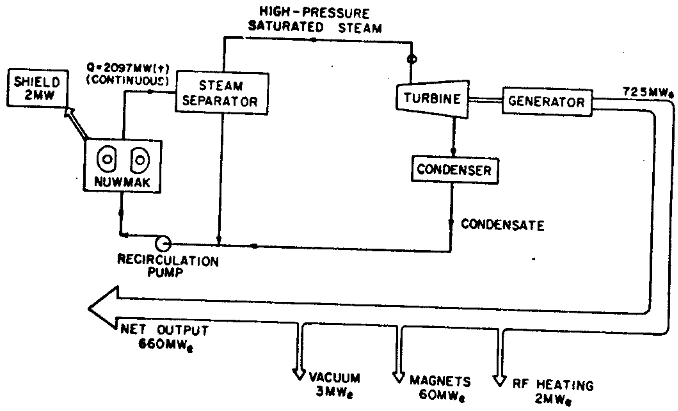


FIGURE 12 POWER FLOW DIAGRAM FOR NUWMAK

BLANKET SUPPORT CONSIDERATIONS

The blanket in NUWMAK is divided into 16 equal modules each consisting of an inner and an outer blanket segment. Figure 2 shows a cross-section of a blanket module. It is 5 m high, 3.2 m deep and is 1.5 m and 2.7 m wide at midplane on the inner and outer radii, respectively. The first wall in both inner and outer blanket segments consists of a continuous bank of tubes joined together which are connected to a toroidal header at the top and bottom. In order for the constant diameter tubes to fit the toroidal geometry in the outer blanket, they will have to be gradually flattened as they approach midplane.

Each blanket module will have radial plates 0.2 cm thick spaced every 20 cm, joining the first wall to the back plate. The side plates in each module are 0.3 cm thick. In addition, struts will be used to keep the cooling tubes within the body of the blanket evenly spaced and supported. The side and intermediate plates combine to form a very strong structure. The outer blanket segment is designed to be free standing and capable of supporting the full load of the breeding material. In actual practice, however, the inner blanket segment will support the overhanging portion of the outer segment. In this way the bending moment and the resulting stress at midplane are minimized. The weight of the blanket is transferred to the shield by direct bearing and is ultimately transferred to the reactor floor through columns between the TF coils.

CONCLUSIONS

The design of a blanket for NUWMAK, a compact medium power tokamak reactor, has been carried out with the aim of alleviating the effects of several generic problems of tokamak blankets, in particular, the cyclic plasma and the need for tritium breeding. By using boiling water as the coolant and the latent heat of the breeding material for energy storage, the energy output of the reactor has been smoothed out considerably, in spite of the cyclic nature of the plasma. The use of multi-layer coolant tubes throughout the blanket has minimized tritium diffusion into the coolant to a level where an intermediate loop is no longer needed. Elimination of the intermediate loop and steam generator should result in a significant cost saving to the reactor system.

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