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## EMERGENCY COOLING OF THE MARS LiPb BLANKET

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### ABSTRACT

The thermal effect of a loss of flow accident and afterheat to the MARS blanket are investigated. The temperature response of the first wall, as well as the whole blanket, is calculated with a finite difference method. For a loss of flow accident, the plasma has to be quenched within 10 to 35 seconds, beyond which loss of the first wall may occur. Active cooling will be required for the blanket for afterheat within the first day after the plasma is shut off. After the first day, the reflector will provide a heat sink for passive cooling of the blanket.

### INTRODUCTION

The design philosophy of MARS, the Mirror Advanced Reactor Study, is to emphasize the unique features of a tandem mirror reactor, TMR, to obtain an attractive design of a fusion power reactor. It is aimed at maximizing the strengths of the tandem mirror while mitigating its weaknesses. The end product should be a safe, reliable, maintainable and a relatively economic power reactor. This paper presents the emergency cooling and afterheat calculations for the MARS blanket. The other aspects of MARS are presented in various articles in this meeting.

The unique safety problems associated with a DT fusion reactor blanket are mostly related to tritium breeding. The chemical reaction of lithium or lithium bearing compounds with water, and tritium confinement are the primary areas of concern. Such a system can be designed to either minimize the possibility of an accident or else minimize the consequences of an accident. The second approach results in a simpler system and has, therefore, been adopted here. In order to minimize the consequences of an accident, the breeding material must be relatively inert toward water and should have a low tritium solubility. Hence  $\text{Li}_{17}\text{Pb}_{83}$  has been selected for this purpose.

Early design studies have attempted to

utilize high temperature and advanced technology to obtain higher efficiency thermal cycles and thus minimize environmental impact. However, it was soon realized, particularly for tokamaks, that high temperature systems present severe problems, especially in areas of tritium confinement and radiation damage. It also became apparent that higher efficiency does not always translate into better economics. In the MARS design we have chosen a moderate temperature for the blanket and a high pressure steam cycle for the power conversion system. We believe this results in a reliable and economically attractive reactor.

Perhaps the most attractive feature of the TMR is the simplicity of the central cell. The design philosophy has been to take full advantage of this basic cylindrical geometry to come up with a blanket which is simple to fabricate, lends itself easily to mass production and can be realistically maintained by remote control. The basic blanket design is similar to the WITAMIR-I blanket.<sup>(1)</sup> It consists of a series of tube banks running circumferentially around the central cell. Coolant/breeding material is manifolded at the top and bottom of the tubes and can be made to flow in either direction. MHD problems are not considered to be serious because of the low magnetic field and the small plasma radius.

### BLANKET DESCRIPTION

The MARS blanket chooses  $\text{Li}_{17}\text{Pb}_{83}$  as the coolant and breeding material and HT-9 as the structural material. The  $\text{Li}_{17}\text{Pb}_{83}$  is chosen primarily for its relative inertness with air and water,<sup>(2)</sup> and its low tritium solubility. The primary reason for choosing HT-9 is its high resistance to void formation.<sup>(3)</sup> Swelling in this material under fast neutron irradiation is at least one order of magnitude lower than for  $^{316}\text{SS}$  (cold worked), for irradiations of  $1 \times 10^{23}$  n/cm<sup>2</sup> ( $E > 0.1$  MeV). Water cooled Fe-1422 is used as the reflector to increase the blanket energy multiplication.<sup>(4)</sup> This is primarily due to the large gamma production in Mn.

The blanket of MARS consists of three distinct zones:

1. The tube zone which is composed of two rows of close pack tubes.
2. The beam zone consisting of a single row of hollow rectangular beams which provide the structural support for the tubes.
3. The water cooled reflector zone.

Figure 1, which is a cross section of the central cell, shows the flow path of the  $\text{Li}_{17}\text{Pb}_{83}$ . The molten breeding material  $\text{Li}_{17}\text{Pb}_{83}$  comes in through a single header feeding a blanket module, is distributed longitudinally in the top manifold, then flows circumferentially around the plasma, collecting in the bottom manifold and exiting through a single return header. The major parameters related to heat transfer problems are listed in Table 1.

TABLE 1. MARS Parameters

Fusion Power	2574 MW
Thermal Power	3378 MW
Neutron Wall Loading	$3.65 \text{ MW/m}^2$
First Wall Thermal Load	$6 \text{ W/cm}^2$
Structural Material	HT-9
Coolant and Breeding Material	$\text{Li}_{17}\text{Pb}_{83}$
Coolant Temperature	$350/500^\circ\text{C}$
Maximum Structural Temperature	$550^\circ\text{C}$
Maximum Coolant Pressure	1.2 MPa

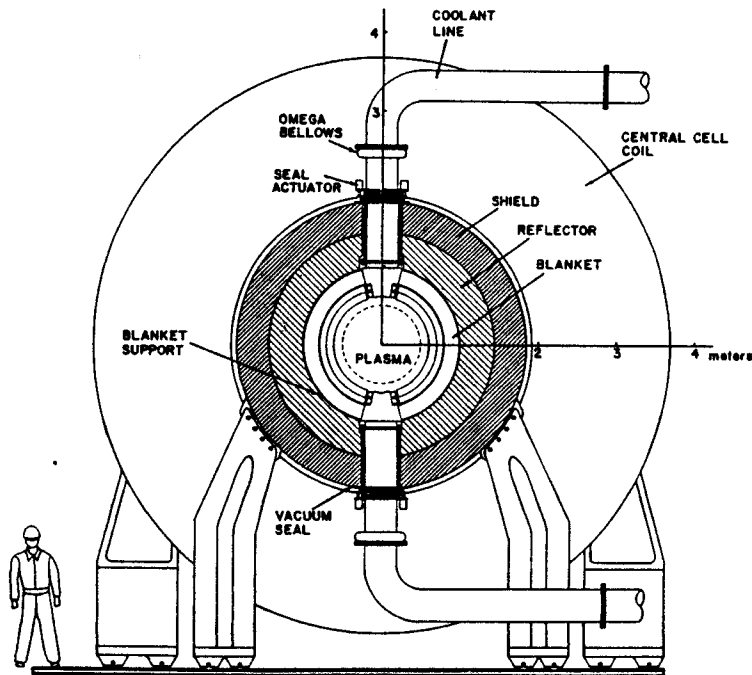


Fig. 1. Cross section of MARS central cell.

## LOSS OF FLOW AND LOSS OF COOLANT ACCIDENTS

During reactor operation, loss of flow and loss of coolant accidents may occur. Failure of the pump constitutes one of the possible causes of accidents. The plasma is still at full power. It is essential to calculate the temperature response of the first wall to estimate how soon the plasma has to be quenched. The heat transfer model assumes a stationary or empty blanket and calculates the first wall temperature under nuclear heating. The nuclear heating curve is obtained from neutronic calculations and is shown in Fig. 2.

The temperature response of the first wall due to a loss of flow and loss of coolant accident is calculated and shown in Fig. 3. The rate of the first wall temperature rise is very similar in the two cases. The reason for this unexpected result is due to the much higher volumetric heat capacity for steel ( $\rho c_p = 3.6 \text{ J/cm}^3\text{-}^\circ\text{C}$ ) than for the  $\text{Li}_{17}\text{Pb}_{83}$  ( $\rho c_p = 1.5 \text{ J/cm}^3\text{-}^\circ\text{C}$ ). Therefore, in the loss of flow accident case, the temperature rise of the  $\text{Li}_{17}\text{Pb}_{83}$  is actually faster than that of the structure although the volumetric heating rate is less. The coolant will heat up the first wall and, consequently, the first wall is heated up faster than the loss of coolant accident case. As time reaches  $\sim 20$  seconds, the  $\text{Li}_{17}\text{Pb}_{83}$  further away from the first wall and, consequently, with a much lower volumetric heating, starts to cool the first wall by conduction. This explains the crossover point of the two temperature response curves.

If loss of flow or loss of coolant occurs, the blanket will suffer permanent damage if the plasma is on for ten seconds. If the plasma is not stopped in  $\sim 35$  seconds, the first wall will melt.

In a liquid metal flow system, a surge tank is always provided to maintain a free surface. The  $\text{Li}_{17}\text{Pb}_{83}$  in the surge tank can be used as the emergency coolant by using gravitational force to pump. A coolant velocity of 7 cm/s can be reached by using the gravitational head. The temperature response of the first wall, shown in Fig. 4, will reach a maximum of  $800^\circ\text{C}$  in  $\sim 30$  s. The coolant volumetric flow rate required is  $5 \text{ m}^3/\text{s}$  for the entire reactor. The total emergency cooling time provided has to be optimized between surge tank cost and accident detection time.

## AFTERHEAT CALCULATIONS

The afterheat is calculated by the ANISN

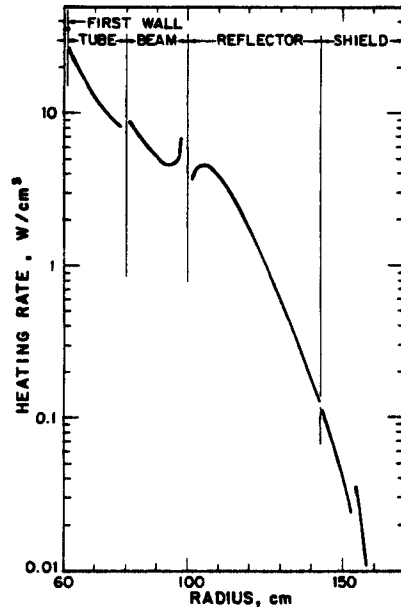


Fig. 2. Nuclear heating rate of MARS blanket.

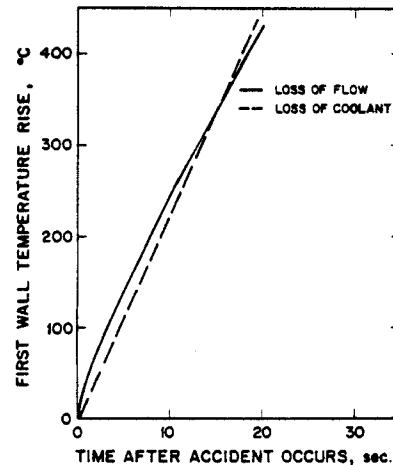


Fig. 3. First wall temperature response due to loss of flow and loss of coolant accidents.

and DKR codes. A forward 25 neutron 21 gamma group ANISN run was done in order to obtain the steady state flux throughout the blanket and shield region. This output was then fed into the DKR program. This produced a delayed gamma

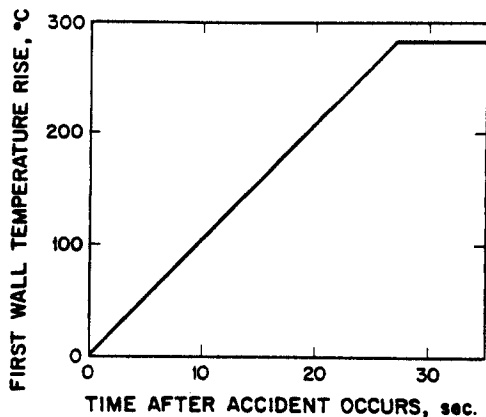


Fig. 4. Temperature response of first wall with gravitational coolant flow.

source spectrum and also gave the total beta heat produced in each zone. The gamma source was then fed back into the ANISN program and a forward 21 group gamma transport problem was run. In this calculation, activation cross sections were used to determine the heat deposition in each region, and in each material. This calculation was performed for both the case of the  $\text{Li}_{17}\text{Pb}_{83}$  remaining in the reactor and the case of  $\text{Li}_{17}\text{Pb}_{83}$  drained from the blanket. In all, a total of 12 ANISN runs were made. Finally, the beta heat from the DKR and the gamma heat from ANISN were summed up to give the total afterheat in each zone. The results of these calculations are given in Figs. 5 and 6. Figure 5 shows the afterheat with the blanket still filled with  $\text{Li}_{17}\text{Pb}_{83}$  while Fig. 6 shows it with the  $\text{Li}_{17}\text{Pb}_{83}$  drained.

Table 2 shows the adiabatic temperature rise rate in different regions of the blanket and shield. It can be noted that at 1 hour after reactor shutdown, the temperature of the blanket and reflector will increase  $\sim 1^\circ\text{C}$  per 10 seconds. Therefore, active cooling is clearly required. About 1% of the normal cooling rate is needed at 1 hour after shutdown. The very high afterheat in the reflector after shutdown should be noted. This is due to the  $^{56}\text{Mn}$  in Fe-1422. The half life of  $^{56}\text{Mn}$  is 2.6 hours and, therefore, the afterheat of the reflector decays rapidly in the first day. After one day, the reflector can be used as the heat sink for radiation cooling of the blanket. The blanket needs active cooling for the first day. It can be cooled effectively after that and maximum temperatures due to afterheat may reach  $390^\circ\text{C}$ .

Table 3 summarizes the thermal radiation calculation for the blanket one day after the

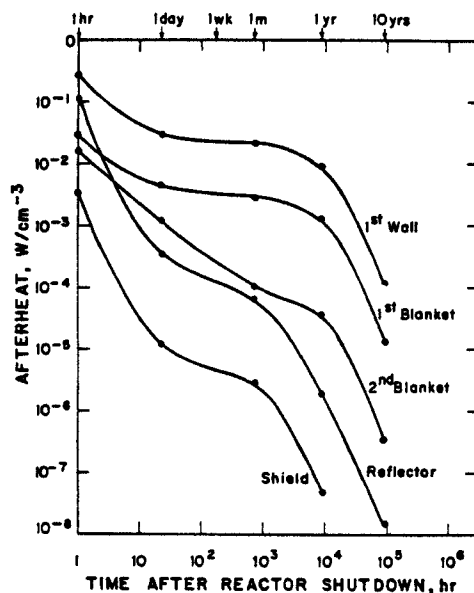


Fig. 5. Total afterheat in different regions with blanket filled with  $\text{Li}_{17}\text{Pb}_{83}$ .

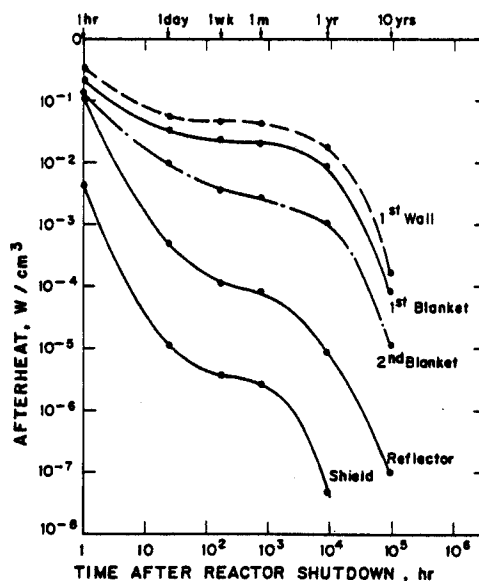


Fig. 6. Total afterheat in different regions after  $\text{Li}_{17}\text{Pb}_{83}$  is drained.

TABLE 2. Adiabatic Temperature Rise Rate

	WITH $Pb_{83}Li_{17}$		WITHOUT $Pb_{83}Li_{17}$	
	1 Hr After Shutdown	1 Day After Shutdown	1 Hr After Shutdown	1 Day After Shutdown
1st wall	$7.7 \times 10^{-2}$	$7.6 \times 10^{-3}$	$1.0 \times 10^{-1}$	$1.6 \times 10^{-2}$
1st blanket	$1.7 \times 10^{-2}$	$2.5 \times 10^{-3}$	$6.2 \times 10^{-2}$	$9.3 \times 10^{-3}$
2nd blanket	$9.1 \times 10^{-3}$	$6.9 \times 10^{-4}$	$3.5 \times 10^{-2}$	$2.7 \times 10^{-3}$
Reflector	$3.3 \times 10^{-2}$	$9.7 \times 10^{-5}$	$3.3 \times 10^{-2}$	$1.4 \times 10^{-4}$
Shield	$1.0 \times 10^{-3}$	$3.3 \times 10^{-6}$	$1.0 \times 10^{-3}$	$3.3 \times 10^{-6}$

Temperature rise in °C/s

TABLE 3. Radiation Cooled Blanket Temperature

	Maximum Blanket Temperature °C		
	Steel Tube Emissivity		
	0.5	0.4	0.2
1st wall	357	390	508
2nd wall	347	379	493
3rd wall	331	360	467
4th wall	307	332	426
2nd blanket	272	290	363
Reflector	200	200	200

Forced Cooling Stopped One Day After Shutdown

reactor is shut down. It can be seen that the blanket can be cooled effectively by thermal radiation. The best estimate of emissivity of the steel tube under corrosion and high temperature is 0.4. The maximum temperature that can be reached is 390°C at  $\epsilon = 0.4$ .

## CONCLUSION

The thermal effect of afterheat and loss of flow accident for the MARS  $Li_{17}Pb_{83}$  cooled blanket have been studied. The following conclusions can be made:

1. The loss of flow and loss of coolant accidents should be detected and the plasma quenched within 10 to 30 seconds.
2. About 1% of the normal cooling rate is required for active cooling of the blanket at reactor shutdown.
3. About 1 day after reactor shutdown, the reflector can provide a heat sink for passive cooling of the blanket.

## ACKNOWLEDGMENT

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## REFERENCES

1. D.K. SZE and I.N. SVIATOSLAVSKY, "Thermal and Mechanical Design of WITAMIR-I Blanket," *Proceedings of the Fourth Topical Meeting on the Technology of Controlled Nuclear Fusion*, King of Prussia, Penn. Oct., 1980.
2. P.A. FINN et. al., "The Reactions of LiPb Alloys with Water" *Trans. Am. Nucl. Soc.* 34, 55 (1980).
3. S.N. ROSENWASSER et al., "The Application of Martensitic Stainless Steels in Long Lifetime Fusion First Wall/Blanket," General Atomic Co., San Diego, CA.
4. J.H. HUANG and M.E. SAWAN, "Neutronic Analysis of MARS Li-Pb Blanket and Shield," *5th Topical Meeting on the Technology of Fusion Energy*, Knoxville, TN, April 1983.