Activation Analysis for the LIBRA Light Ion Beam Fusion Conceptual Design

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ACTIVATION ANALYSIS FOR THE LIBRA LIGHT ION BEAM FUSION CONCEPTUAL DESIGN

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Abstract

Activation calculations have been performed for the LIBRA reactor. Replacing HT-9 by low activation modified HT-9 increases the activity by a factor of 2.5 at shutdown while the long term activity drops by a factor of 25. The reflector is classified as Class C low level waste when modified HT-9 is used. Using HT-9 will require deep geological burial for the LIBRA radwaste. The activity produced in the $Li_{17}Pb_{83}$ coolant has been determined. ^{210}Po is the major contributor to the coolant BHP between a week and a year after shutdown. During this period the ^{210}Po BHP values change from 7 x 10^5 to 1.2 x 10^5 km^3 of air.

Introduction

LIBRA is a commercial inertial confinement fusion reactor conceptual design driven by light ions. The reactor produces 1160 MW of thermal power and 330 MW of net electric power. The fusion targets are imploded by 4 MJ shaped pulses of 30 MeV Li ions at a rate of 3 Hz. The target gain is 80, leading to a yield of 320 MJ. The blanket is an array of porous flexible silicon carbide tubes with $Li_{17}Pb_{83}$ flowing downward through them. These tubes (INPORT units) shield the target chamber wall from both neutron damage and the shock overpressure of the target explosion [1]. The blanket region is 1.35 m thick consisting of 32.67% $Li_{17}Pb_{83}$ and 0.67% SiC and backed by a 0.5 m thick steel reflector which has 10% $Li_{17}Pb_{83}$ coolant. The options of using the ferritic steel alloy HT-9 or a modified low activation HT-9 alloy have been considered. A cross section of the LIBRA chamber is given in Fig. 1. In this paper, the results of the activation analysis performed for the LIBRA chamber will be presented.

Calculational Procedure

Neutron transport calculations have been performed for the LIBRA chamber using ONEDANT [2] and ENDF/B-V cross section data. The problem has been modeled in spherical geometry with materials and dimensions consistent with a cut through the midplane of the reactor. A point source was used at the center of the 3 m radius chamber. The LIBRA target neutron spectrum was used to represent the source spectrum. The source strength was normalized to the DT target yield of 320 MJ and the 3 Hz repetition rate.

A 2.6 m thick concrete shield which yields a dose rate of 1.4 mrem/hr during operation, is used in the activation calculations. The shield consists of 70% concrete, 20% carbon steel, and 10% He coolant. While the

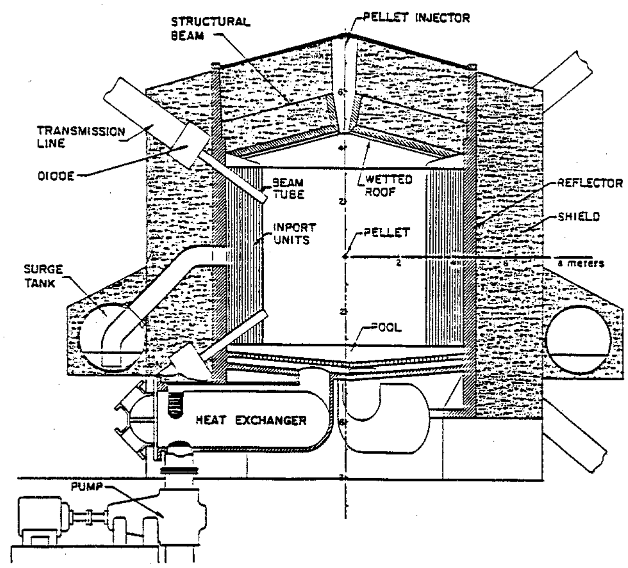

Fig. 1. Cross Section of Target Chamber.

initial LIBRA chamber design uses the ferritic steel alloy HT-9 as chamber structural material, activation calculations have been performed also for a modified HT-9 alloy which would have lower long term activity [3].

The neutron flux obtained from the neutron transport calculations has been used in the activation calculations. The radioactivity code DKR-ICF [4] has been used with the ACTL [5] neutron transmutation data library. The DKR-ICF code allows for appropriate modeling of the pulsing schedule. Using an equivalent steady state operation results in underestimating the produced activity, particularly at short times following shutdown. The pulse sequence used in the activation calculations is shown in Fig. 2. The reactor is assumed to be shut down for 5 days every month for routine maintenance and for 40 days every year for extended maintenance. This operational schedule corresponds to a reactor availability of 75%. The activity for the reflector and shield was calculated for the 40 year reactor lifetime while the activity for the SiC INPORT tubes in the blanket was determined for an operating time of 2 years. The coolant activity was calculated separately by modifying the operation schedule to allow for the fact that the coolant spends only half the time exposed to neutrons in the reactor. The coolant residence time in the reactor is assumed to be 10 seconds.

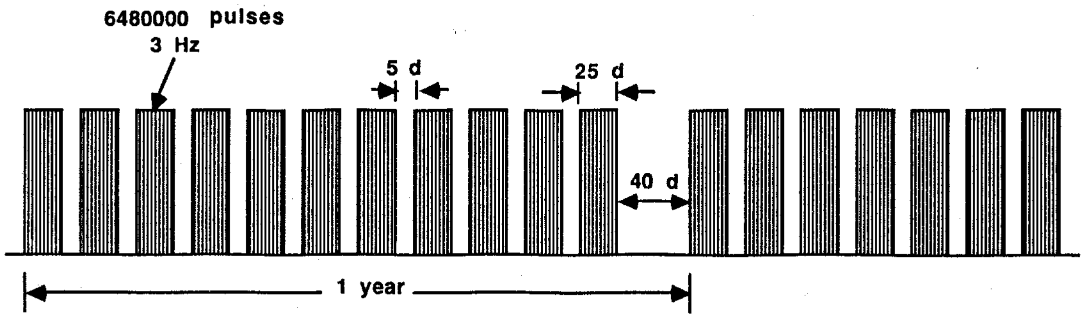

Fig. 2. Pulse Sequence Used in the LIBRA Activation Calculations.

<u>Activity, Biological Hazard Potential (BHP) and Decay Heat in the LIBRA Chamber Structure</u>

The total activity as a function of time after shutdown is given in Fig. 3 for the case when HT-9 is used as structural material. The results are given for the pulse sequence shown in Fig. 2 and for an equivalent steady state operation. Using the steady state operation results in a factor of two lower activity at shutdown with the difference being negligible only after about one month following shutdown. The large difference within a short time following shutdown is due to the fact that the activity is dominated by short lived radionuclides whose activities are sensitive to the operational schedule prior to shutdown due to buildup during the on-time with the subsequent decay between periods of operation. Notice that the average neutron flux used in the equivalent steady state calculation is lower than that during the on-time preceding shutdown. On the other hand, the long term activity is dominated by long lived radionuclides whose activity is determined by the total neutron fluence regardless of the temporal variation of the flux.

The effect of replacing HT-9 by the low activation alloy, modified HT-9, is shown in Fig. 4. The total activity at shutdown increases by a factor of ~2.5 while the long term activity decreases by a factor of ~25. This results from reducing the amount of Mo activity, while increasing the content of W which contributes to the short term activity. Table 1 compares the activity, biological hazard potential (BHP), and the decay heat at shutdown for the cases with HT-9 and modified HT-9. The modified HT-9 is recommended for the LIBRA reference design since the long term activity is more of a concern due to its impact on waste management.

Figure 5 gives the activity in the blanket, reflector, and shield as a function of time after shutdown. The total activity per unit of thermal power at shutdown is 1.36 Ci/W and drops to 0.16 Ci/W in one week. Almost all of the total activity results from the activation of the reflector structure. The contribution from the activity of the SiC used in the blanket is very small and drops rapidly after shutdown. The results for the BHP and decay heat are given in Fig. 6 and Fig. 7, respectively. The variation with time after shutdown is similar to that for the activity. The BHP value per unit thermal power at shutdown is 151 km^3/kW and the decay heat is 0.63%.

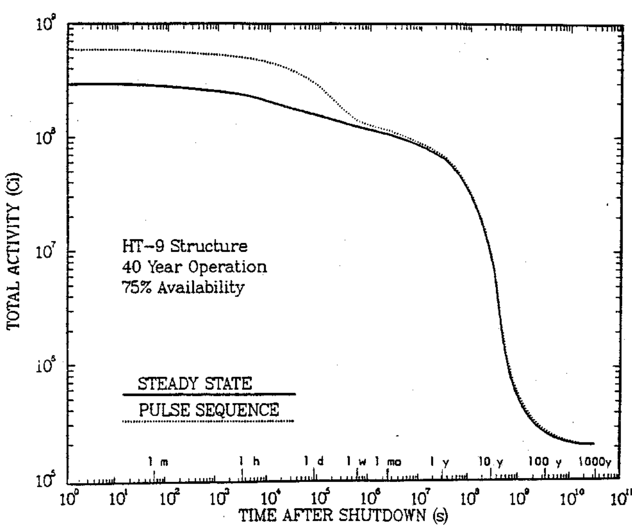

Fig. 3. Effect of Pulse Sequence on Total Activity in LIBRA Chamber.

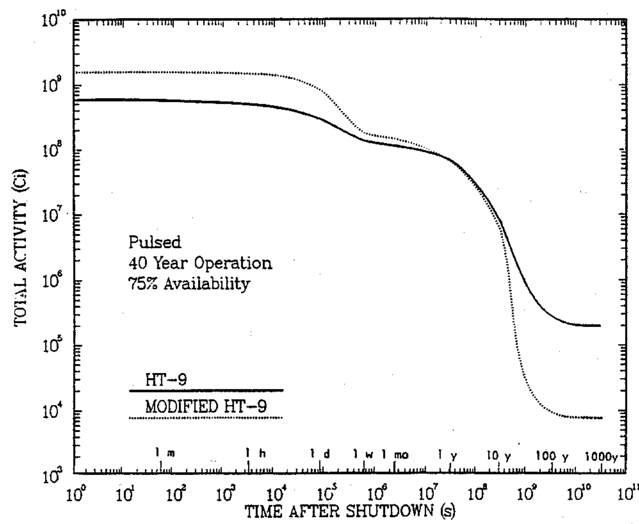

Fig. 4. Effect of Low Activation Structure on Total Activity in LIBRA Chamber.

Table 1. Effect of Reflector Material on Radioactivity Parameters at Shutdown

	Activity (Ci)		BHP (km^3 air)		Decay Heat (MW)	
	HT-9	Mod. HT-9	HT-9	Mod. HT-9	HT-9	Mod. HT-9
Blanket	2.77×10^7	2.77×10^7	9.35×10^5	9.35×10^5	0.47	0.47
Reflector	5.47×10^8	1.536×10^9	8.58×10^7	1.741×10^8	3	6.774
Shield	9.06×10^6	9.06×10^6	6.54×10^5	6.54×10^5	0.064	0.064
Total	5.838×10^8	1.573×10^9	8.74×10^7	1.757×10^8	3.534	7.308

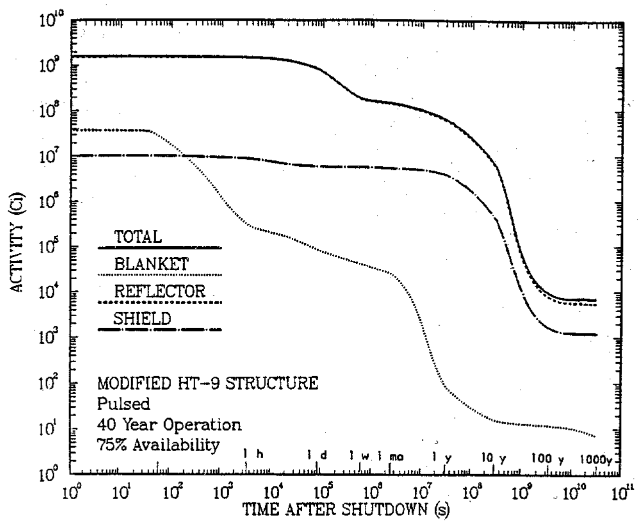

Fig. 5. Activity after Shutdown in Different LIBRA Chamber Regions.

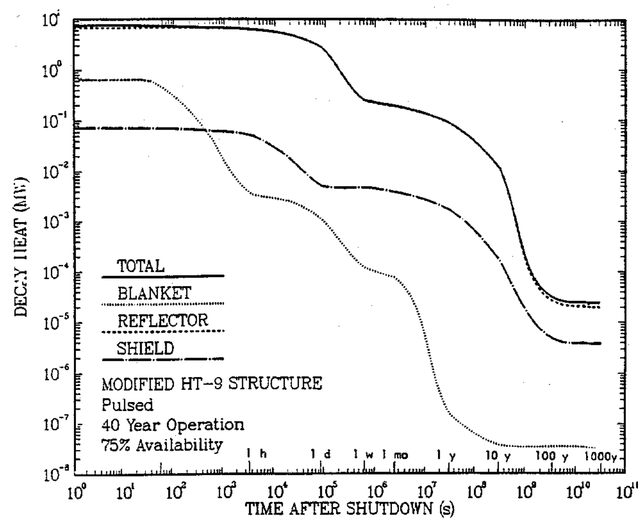

Fig. 7. Decay Heat in Different LIBRA Chamber Regions.

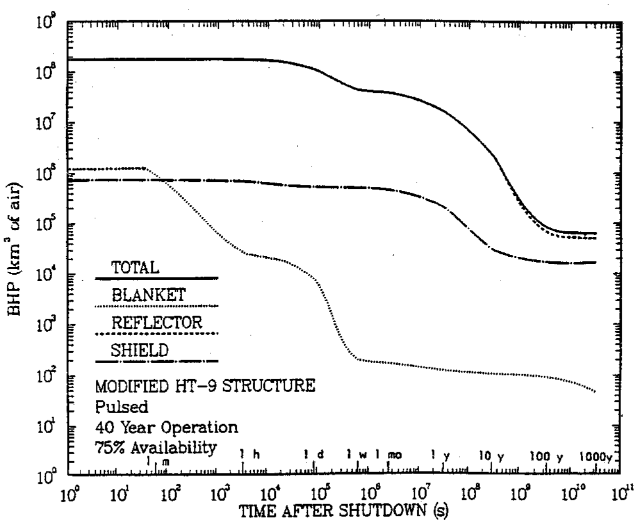

Fig. 6. Biological Hazard Potential in Different LIBRA Chamber Regions.

Waste Disposal Rating (WDR) of LIBRA Chamber Structure

The specific activities calculated for the different radionuclides have been used with the U.S. waste disposal limits (WDL) to evaluate the radwaste of the LIBRA chamber. The 10CFR61 limits [6] (the current U.S. legal limits) were used. Table 2 lists the calculated WDR values for Class C low level waste (LLW) for the different reactor regions. An operation time of 2 years is used for the blanket while the reflector and shield have an operation time of 40 years. The WDR is defined as $\sum C_i/WDL_i$, where C_i is the specific activity of the ith nuclide and WDL_i is the waste disposal limit. A WDR value ≤ 1 implies that the radwaste classifies as Class C LLW and qualifies for shallow land burial.

The results are given for both cases with HT-9 and modified HT-9 reflector structure. The non-compacted values are based on averaging over the total volume of the particular region implying that internal voids are to be filled with concrete before disposal. On the other hand, the compacted values correspond to crushing the solid waste before disposal. The WDR values are given also for the case when the reflector and shield are disposed of together. While the WDR values for the blanket and shield are much smaller than unity, the reflector WDR is larger than unity when HT-9 is used implying the need for deep geological burial. Replacing HT-9 by the low activation modified HT-9 results in the reflector being classified as Class C LLW.

^{14}C, generated from the $^{13}C(n,\gamma)$ reaction, is the only contributing radionuclide to the WDR for the blanket and shield. On the other hand, about 98% of the WDR for the

Table 2. Class C Waste Disposal Rating for LIBRA Chamber

	HT-9 Reflector		Modified HT-9 Reflector	
	Non-Compacted	Compacted	Non-Compacted	Compacted
Blanket	6.07×10^{-6}	9.06×10^{-4}	6.07×10^{-6}	9.06×10^{-4}
Reflector	708	789	0.72	0.8
Shield	2.73×10^{-4}	3.03×10^{-4}	2.73×10^{-4}	3.03×10^{-4}
Reflector and Shield	68	75	0.07	0.08

Table 3. Isotopic Contribution to Reflector WDR

	WDR	
Isotope	Mod. HT-9	HT-9
^{14}C	0.012	0.608
^{59}Ni	6.59×10^{-4}	5.5×10^{-2}
^{63}Ni	1.17×10^{-3}	9.03×10^{-2}
^{94}Nb	0.706	706
^{99}Tc	1.2×10^{-4}	0.446
Total	0.72	708

reflector is contributed by ^{94}Nb which is produced by the $^{93}Nb(n,\gamma)$ reaction and (n,p), (n,np), (n,d), and (n,t) reactions with the different Mo isotopes. This explains the three order of magnitude reduction in the reflector WDR by replacing HT-9 by modified HT-9. Table 3 gives the contribution of the different radionuclides to the reflector WDR.

Coolant Activity

The activity produced in the $Li_{17}Pb_{83}$ coolant has been determined. We assumed that the coolant volume in the loop outside the chamber is the same as that in the chamber. The residence time of the coolant in the chamber was taken to be 10 seconds. At shutdown, the major contributor to the activity and BHP is $^{209}Pb(T_{1/2} = 3.25$ h). ^{203}Pb is the major activity contributor between 6 hours and a week after shutdown. The long term activity is contributed by ^{108m}Ag, ^{204}Tl, and ^{205}Pb. ^{210}Po, which is produced from the Bi impurities, is an alpha emitter and volatile and represents a particular concern in LiPb systems. ^{210}Po is the major contributor to the coolant BHP between a week and a year after shutdown. During this period the ^{210}Po BHP values change from 7×10^5 to 1.2×10^5 km^3 of air. This is about two orders of magnitude lower than the BHP value for the tritium produced in the $Li_{17}Pb_{83}$.

Summary

Activation calculations have been performed for LIBRA with the reactor pulsing and maintenance schedule modeled accurately. Replacing HT-9 by modified HT-9 increases the activity by a factor of 2.5 at shutdown while the long term activity drops by a factor of 25. The modified HT-9 is recommended for the LIBRA reference design since the long term activity is more of a concern due to its impact on waste management. The activity, BHP, and decay heat values at shutdown per unit thermal power are 1.36 Ci/W, 151 km^3/kW and 0.63%, respectively. The reflector is classified as Class C low level waste when modified HT-9 is used. Using HT-9 will require deep geological burial for the LIBRA radwaste. The blanket and shield easily qualify for near surface burial. The activity produced in the $Li_{17}Pb_{83}$ coolant has been determined. ^{210}Po is the major contributor to the coolant BHP between a week and a year after shutdown. During this period the ^{210}Po BHP values change from 7×10^5 to 1.2×10^5 km^3 of air.

Acknowledgement

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