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H.Y. Khater and the ARIES Team

Fusion Technology Institute
University of Wisconsin
1500 Engineering Drive
Madison, WI 53706

http://fti.neep.wisc.edu

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Hesham Y. Khater and the ARIES Team
Fusion Technology Institute
University of Wisconsin-Madison
1500 Engineering Drive, Madison, WI 53706-1687

ABSTRACT

Detailed activation analysis is performed as a part of the Stellarator Power Plant Study (SPPS). The reactor is assumed to operate for 30 full power years (FPY). The activity induced in the blanket at the end of its lifetime is lower than the activity induced in the shield after 30 FPY. At shutdown, the blanket and shield activities are 683 MCi and 3908 MCi, respectively. One year after shutdown the blanket activity drops to 22.3 MCi compared to 505 MCi for the shield. The total decay heat generated in the blanket at shutdown is 7.9 MW and drops to only 0.2 MW within one week. At shutdown, 46.6 MW of decay heat are generated in the shield. The shield's decay heat drops to only 1.71 MW within a day and 0.77 MW within the first year. One week after shutdown, the values of the integrated decay heat are 333 GJ for the blanket and 1605 GJ for the shield. The total Biological Hazard Potential (BHP) produced in the blanket and shield at shutdown are 469×10^9 and 492×10^9 m^3 air, respectively. The radwaste classification of the reactor structure is evaluated according to both the NRC 10CFR61 and Fetter waste disposal concentration limits. The first wall and blanket will only qualify for Class C low level waste according to both limits. The high-temperature shield can only qualify as Class C waste if the 10CFR61 limits are used. The low-temperature shield will have no difficulty qualifying for a Class A or Class C rating according to both limits. Assuming a 25 μSv/h limit for hands-on maintenance, only remote maintenance may be allowed at any location inside the containment building.

INTRODUCTION

Stellarators would have clear operational advantages over tokamaks as ignited steady-state reactors. A Stellarator Power Plant Study (SPPS) [1] was completed in 1994 to assess the main engineering and physics aspects of a 1000 MW_e modular Helias-like Heliac (MHH) stellarator design. The SPPS has a major radius of 14 m, peak field at coil of 16 T, and field periods generated by 32 modular nonplanar coils.

Detailed activation analyses were performed to identify the safety, environmental and radwaste characteristics of the SPPS reactor. The SPPS structure is made of vanadium alloy and cooled with liquid lithium. Several activation-related issues were investigated for each of the reactor structures. The activity, decay heat and Biological Hazard Potential (BHP) were calculated for up to 1000 years following shutdown. Such an evaluation of the structure activity and biological hazard potential is needed to evaluate the potential impact of radioactive inventory release at the onset of an accident. Results of the decay heat calculation are used to examine the thermal response of the reactor structure following a loss of coolant accident (LOCA) and/or a loss of flow accident (LOFA). The waste disposal ratings (WDR) of the reactor structure at the end of its lifetime were also evaluated. The waste disposal rating is needed to determine if a given structure would satisfy the regulatory criteria for shallow land burial as low level waste (LLW). Finally, to assess the possibility of hands-on maintenance, contact dose rates were calculated at selected locations inside the reactor containment.

CALCULATIONAL PROCEDURE

The neutron flux used for the activation calculation was generated by the one-dimensional discrete ordinates neutron transport code ONEDANT [2]. A 46-group neutron and 21-group gamma coupled cross section library containing P_3 Legendre expansions of the scattering cross sections based on the ENDF/B-V basic data files was used in the transport calculations. The SPPS peak and average neutron wall loadings are 2 and 1.3 MW/m^2, respectively.

The SPPS activation calculation was conducted using the DKR-ICF computer code [3] with activation cross sections taken from the new USACT93 [4]. The USACT93 library was developed by Dr. Fred Mann of Hanford Engineering Design Laboratory. It is based on neutron transmutation cross section and isotopic radioactive decay data from the ENDF/B-VI and EAF3 files. The neutron transmutation data used is in a 46-group structure format. The gamma source data is taken from the table of isotopes [5] and is in a 21-group structure format.

The reactor is assumed to operate continuously for 30 full power years (FPY) which corresponds to 40 years of operation at 75% availability. The SPPS was assumed to have a 28 meter diameter.

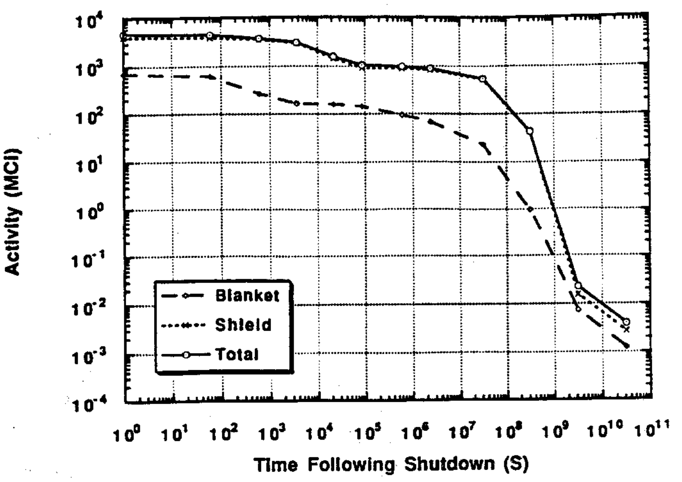

Fig. 1. Activity induced in SPPS.

Table I
Materials Used in the SPPS Analysis

FW	28.6% V-5Cr-5Ti , 71.4% Li
Blanket	10% V-5Cr-5Ti , 90% Li
HT-Shield	15% V-5Cr-5Ti, 80% Tenelon, 5% Li
LT-Shield	15% V-5Cr-5Ti, 80% Borated-Tenelon, 5% Li

The structure activation results were utilized in the radwaste calculations. The DOSE code [3] was used to calculate the contact doses behind the first wall, blanket, and high and low-temperature shields. The materials used in the first wall, blanket and shields are presented in Table I. The elemental compositions of the vanadium alloy (V-5Cr-5Ti) and the low activation austenitic steel (Tenelon) are taken from the Blanket Comparison and Selection Study (BCSS) report [6].

STRUCUTRE ACTIVITY, DECAY HEAT AND BIOLOGICAL HAZARD POTENTIAL (BHP)

The activity induced in the blanket at the end of its lifetime is lower than the activity induced in the shield after 30 full power years. At shutdown, the blanket and shield activities are 683 MCi and 3908 MCi, respectively. Fig. 1 shows the total activity induced in the different regions of SPPS as a function of time following shutdown. The blanket activity drops to 139 and 91 MCi within the first day and the first week following shutdown, respectively. One year after shutdown the blanket activity drops to 22.3 MCi compared to 505 MCi for the shield. The high-temperature shield dominates the activities induced in the SPPS shield.

The blanket short-term activity is dominated by ^{48}Sc ($T_{1/2}$ = 43.7 hr), ^{51}Cr ($T_{1/2}$ = 27.7 day), ^{47}Sc ($T_{1/2}$ = 3.349 day), and ^{45}Ca ($T_{1/2}$ = 162.7 day). On the other hand, the shield short-term activity after shutdown ($\leq$1 day) is dominated by ^{51}Cr, ^{54}Mn ($T_{1/2}$ = 312 day), ^{56}Mn ($T_{1/2}$ = 2.578 hr), and ^{187}W ($T_{1/2}$ = 23.9 hr). In the period between 1 day and 1 year after shutdown, ^{54}Mn, ^{60}Co ($T_{1/2}$ = 5.27 yr), and ^{3}H ($T_{1/2}$ = 12.3 yr) dominate the activity induced in the shield. During the same period of time, the blanket's activity is dominated by ^{49}V ($T_{1/2}$ = 337 day), ^{45}Ca, and ^{46}Sc ($T_{1/2}$ = 83.81 day). Finally, the long-term activities induced in both the shield and blanket are dominated by ^{14}C ($T_{1/2}$ = 5730 yr), ^{93m}Nb ($T_{1/2}$ = 16.1 yr), ^{94}Nb ($T_{1/2}$ = 2×10^4 yr), and ^{93}Mo ($T_{1/2}$ = 3.5×10^3 yr).

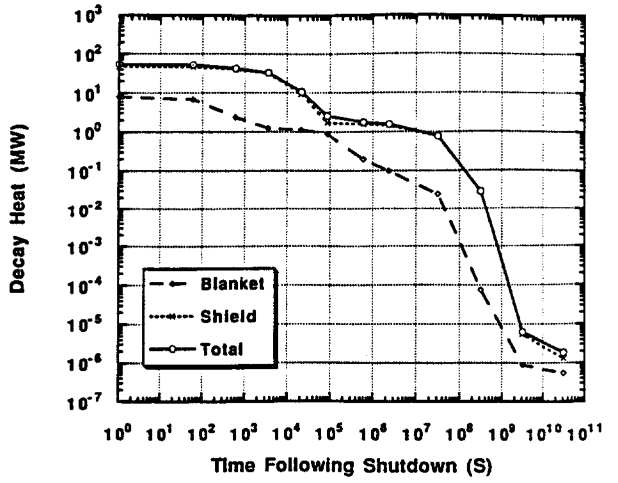

Fig. 2. Decay heat induced in SPPS.

The temporal variation of the decay heat generated in the blanket and shield is shown in Fig. 2. The total decay heat generated in the blanket at shutdown is 7.9 MW and drops to 1.2 MW within an hour and to only 0.2 MW within one week. At shutdown, 46.6 MW of decay heat is generated in the shield. The decay heat drops to only 1.71 MW within a day and 0.77 MW within the first year. The decay heat generated in SPPS is almost dominated by the same isotopes that dominate the level of activity in the reactor. The short-term decay heat generated in the blanket is due to ^{48}Sc and ^{52}V ($T_{1/2}$ = 3.76 min). ^{46}Sc and ^{49}V are the dominant nuclides up to one year following the reactor shutdown. ^{94}Nb and ^{14}C dominate the decay heat generated in the blanket several hundred years following the end of its lifetime. In the shield case, ^{56}Mn and ^{52}V produce most of the decay heat generated within the first 8 hours. Within the first year after shutdown, ^{56}Mn and ^{60}Co are the major sources of decay heat. The long-term decay heat is governed by the decay of ^{94}Nb and ^{108m}Ag ($T_{1/2}$ = 130 yr).

Fig. 3 shows the total integrated decay heat generated in the different regions of SPPS. One week after shutdown, the values of the integrated decay heat are 333 GJ for the blanket and 1605 GJ for the shield. These results are useful for predicting the thermal response of the blanket and shield to a LOCA and/or LOFA.

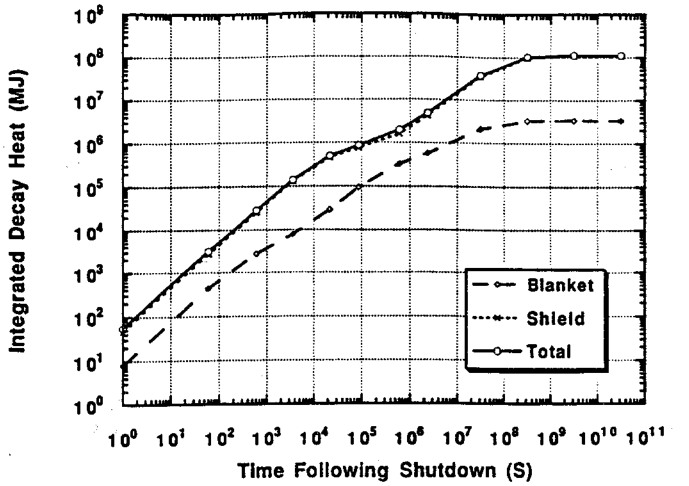

Fig. 3. Integrated decay heat in SPPS.

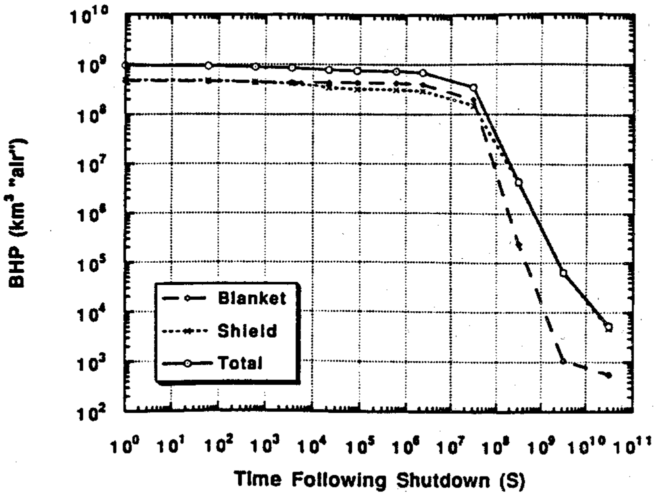

Fig. 4. Biological hazard potential in SPPS.

The biological hazard potentials were calculated using the maximum permissible concentration limits in air for the different isotopes according to the NRC regulations specified in 10CFR20 [7]. Fig. 4 shows the biological hazard potentials in air as a function of time following shutdown for the blanket and shield. The total BHP in the blanket at shutdown is 469×10^6 km^3. On the other hand, the total BHP generated in the shield at shutdown is 492×10^6 km^3 air. The short-term BHP is dominated by ^{49}V and ^{48}Sc in the case of the blanket, and ^{54}Mn, ^{56}Mn, and ^{52}V in the case of the shield. While ^{49}V is responsible for most of the BHP in the blanket for times $\leq$ 10 years, ^{60}Co and ^{54}Mn are the major sources of mid-term BHP generated in the shield. Finally, in addition to ^{94}Nb, the long-term BHP is produced by ^{93}Mo and ^{108m}Ag in case of the blanket and shield, respectively.

RADWASTE CLASSIFICATION

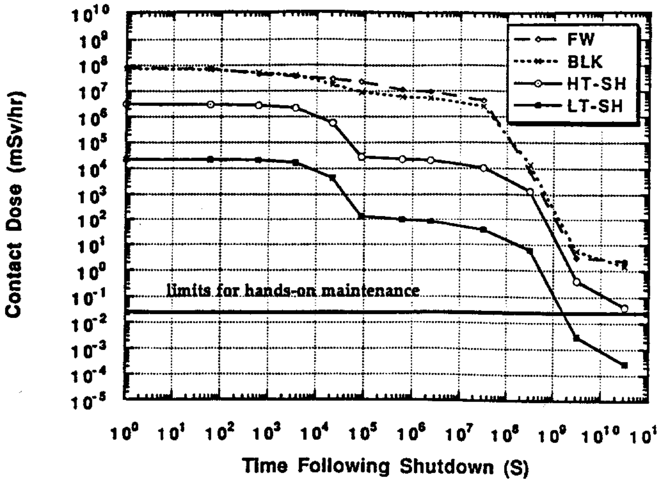

Fig. 5. Contact dose in SPPS.

The radwaste of the blanket and shield of SPPS were evaluated according to both the NRC 10CFR61 [8] and Fetter [9] waste disposal concentration limits (WDL). Specific activities calculated by the DKR-ICF code were used in the evaluation. The waste disposal ratings for Class A and Class C low level waste are shown in Table II. The values in the table are given for both non-compacted and compacted (between brackets) values. Non-compacted values are based on averaging the specific activities over the total volume of a particular region assuming that internal voids will be filled with concrete before disposal. On the other hand, compacted values correspond to crushing the solid waste before disposal. The 10CFR61 Class A WDR is given after a waiting period of about 10 years to allow for the specific activity of short-lived nuclides ($T_{1/2} \leq 5$ years) to drop below 7000 Ci/m^3. The 7000 Ci/m^3 limit is 10 times larger than the limit specified by the NRC for Class A disposal of short-lived nuclides where the waste form is not specified. In comparison with other isotopes for which limits are given for different waste forms, the factor of 10 is used for isotopes contained in metal waste. Since the NRC regulations do not specify any limit for short-lived activity for Class C LLW, the Class C WDR values were calculated after a 1 year cooling period for both 10CFR61 and Fetter limits.

As shown in the table, if the 10CFR61 limits are used, ^{3}H produces 80% of the Class A WDR for the first wall. ^{94}Nb is the second major contributor to the waste disposal rating. ^{3}H is also the main contributor to Class A in the case of the blanket and low-temperature shield with its high boron content. On the other hand, ^{94}Nb is the main contributor to Class A in the case of the shield. The other major contributor is ^{60}Co produced from the cobalt, nickel and copper impurities in the steel. According to the same NRC regulations, the Class C WDR of both the blanket and shield are dominated by ^{94}Nb. If Fetter limits are used, the first wall and blanket WDR are dominated by ^{94}Nb, ^{108m}Ag ($T_{1/2}$ = 130 yr) and ^{26}Al. The shield rating is dominated by ^{192m}Ir ($T_{1/2}$ = 241 yr) and ^{94}Nb.

It was concluded that at shutdown, the first wall and blanket would only qualify for Class C LLW according to both NRC and Fetter limits if the waste is not com-

Table II

SPPS Waste Disposal Ratings

WDR	FW	Blanket	HT-Shield	LT-Shield
Class A (10CFR61)	48 (166) ^{3}H (80%)	7.3 (73) ^{3}H (65%)	5.23 ^{94}Nb (65%)	0.68 ^{3}H (90%)
Class C (10CFR61)	0.83 (2.9) ^{94}Nb (80%)	0.25 (2.5) ^{94}Nb (85%)	0.4 ^{94}Nb (85%)	0.0055 ^{94}Nb (90%)
Class C (Fetter)	0.89 (3.1) ^{94}Nb (70%)	0.24 (2.4) ^{94}Nb (90%)	5.27 ^{192m}Ir (85%)	0.1 ^{192m}Ir (90%)

pacted. The high-temperature shield could only qualify as Class C waste if the 10CFR61 limits are used. Finally, the low-temperature shield would have no difficulty qualifying for a Class A (after a 15 year cooling period) or Class C rating according to both limits used in this analysis.

CONTACT DOSE

Contact dose rates were calculated for maintenance evaluation. The doses were calculated using the DOSE code, which combines the decay gamma source and the adjoint dose field to determine the contact dose rates at different times following shutdown. The decay gamma source at different times following shutdown was calculated using the DKR-ICF code. The adjoint dose field was determined by performing a gamma adjoint calculation using the ONEDANT code with the flux-to-dose conversion factors representing the source at the location where the dose was to be calculated. The contact doses were calculated at four different locations behind the first wall, blanket, HT-shield, and LT-shield. A limit of 25 μSv/hr for hands-on maintenance was used in this analysis, assuming that maintenance personnel work for 40 hours a week and 50 weeks a year. Results in Fig. 5 shows that by assuming the 25 μSv/hr limit for hands-on maintenance, only remote maintenance would be allowed at any of the locations considered inside the containment building. The contact dose inside the SPPS containment is mostly produced during the first few weeks by the decay of ^{48}Sc, ^{52}V, and ^{46}Sc.

CONCLUSIONS

The SPPS showed that stellarators have attractive environmental and radwaste characteristics. Most of the activity is generated in the shell component of the reactor shield. At shutdown, the blanket and shield activities are 683 MCi and 3908 MCi, respectively. On the other hand, the total decay heat generated in the blanket at shutdown is 7.9 MW, compared to 46.6 MW generated in the shield. Due to the high manganese content of the shield, the amount of integrated decay heat produced in the shield during the first week following shutdown is five times the amount generated in the blanket during the same period of time. The first wall and blanket qualify for disposal as Class C low level waste. The high-temperature shield qualifies for a Class C rating according to 10CFR61 limits only. The low temperature shield will have no problem qualifying for a Class A or Class C rating. Finally, only remote maintenance may be allowed inside the containment building.

ACKNOWLEDGEMENT

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REFERENCES

[1] R. L. Miller (ed.) and SPPS Team, "The Stellarator Power Plant Study," University of California San Diego report UCSD-ENG-002, in press.
[2] R. O'Dell et al., "User's Manual for ONEDANT: A Code Package for One-Dimensional, Diffusion-Accelerated, Neutral Particle Transport," Los Alamos National Laboratory report, LA-9184-M, 1982.
[3] D. L. Henderson and O. Yasar, "DKR-ICF: A Radioactivity and Dose Rate Calculation Code Package," University of Wisconsin Fusion Technology Institute report, UWFDM-714, vol. 1, April 1987.
[4] Private communication with D. L. Henderson, 1993.
[5] C. Lederer and V. Shirley, "Table of Isotopes," 7th ed., John Wiley & Sons, Inc., New York, 1978.
[6] D. Smith et al., "Blanket Comparison and Selection Study," Argonne National Laboratory report, ANL/FPP/TM-122, 1984.
[7] "Standards for Protection Against Radiation," Nuclear Regulatory Commission, 10CFR part 20, 1975.
[8] "Licensing Requirements for Land Disposal of Radioactive Waste," Nuclear Regulatory Commission, 10CFR part 61, *Federal Register*, **FR 47** p. 57446, 1982.
[9] S. Fetter, E. T. Cheng and F. M. Mann, "Long Term Radioactive Waste from Fusion Reactors: Part II," *Fusion Eng. Design*, **13**, p. 239, 1990.