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Major Goals for MARS

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ENVIRONMENT AND SAFETY;

MAJOR GOALS FOR MARS*

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ABSTRACT

The Mirror Advanced Reactor Study (MARS) is a conceptual design study for a commercial fusion power reactor. One of the major goals of MARS is to develop design guidance so that fusion reactors can meet reasonable expectations for environmental health and safety. One of the first steps in the assessment of health and safety requirements was to examine what the guidelines might be for health and safety in disposal of radioactive wastes from fusion reactors. Then, using these guidelines as criteria, the impact of materials selection upon generation of radioactive wastes through neutron activation of structural materials was investigated. A conclusion of this work is that fusion power systems may need substantial engineering effort in new materials development and selection to meet the probable publicly acceptable levels of radioactivity for waste disposal in the future.

INTRODUCTION

The current strong support in the U.S. for the fusion energy program is based upon the general consensus that controlled fusion reactions can be achieved, that fusion will provide an inexhaustible energy source, and that fusion will be a benign energy source with respect to health, safety and the environment. Continuing progress in fusion research reinforces the consensus that fusion will work, and that the energy source is inexhaustible. This progress has been the motivation for several conceptual design studies of fusion power reactors to begin defining areas where engineering and technology development will be needed to realize the full benefits from fusion power. The Mirror Advanced Reactor Study (MARS) is one of the latest conceptual design studies.¹ The tacit assumption that fusion is benign, however, will require more work.

One of the efforts in MARS is to consider the impacts of design and materials selections upon generation of radioactive wastes by neutron activation. A numerical index for classifying activated materials has been devised to rate quantitatively the performance of reactor designs and materials with respect to radioactive waste management.² The ratings are based upon the predicted levels of activation products for any given material and design, and upon existing and prospective trends in regulations for radioactive wastes.³ The results of applying these ratings to a first wall and blanket design for MARS are given in this paper.

WASTE DISPOSAL REGULATIONS

In this paper, it is assumed that a primary goal is to produce minimum amounts of radioactive wastes that can be disposed of primarily by near-surface land burial, possibly near the site of the fusion power plant. It is also assumed that the Nuclear Regulatory Commission (NRC) 10CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste" represents the probable type of regulation for fusion power reactor wastes. The remainder of this paper is concerned only with the implications of 10CFR61 in its present form. Specifically, the classification and method of disposal of wastes are assumed to be determined by the composition and the radioactivity limits given in Table I of 10CFR61. It is further assumed that most of the fusion power reactor wastes with high and long term activities will be treated as Class C Intruder Wastes as defined in 10CFR61. Under these conditions, the limits of isotopic activities for fusion wastes would be as shown in Table I. Isotopes with half lives greater than five years and which are not specifically listed are treated as Sr-90 (Surro-

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gate), Cs137 (Surrogate), or Enriched Uranium (Surrogate) as directed in Table I of 10CFR61. These isotopes ($t_{1/2} > 5$ years) are listed in Table II. The specific activities listed in Table I are the reference levels used to determine a quantity called the Waste Disposal Ratings (WDR). This is defined as:

$$WDR = \sum_i A(i)/L(i)$$

where $A(i)$ is the specific activity of isotope i and $L(i)$ is the corresponding limit from Table I.² For an alloy or material to be eligible for near-surface disposal, the condition $WDR \leq 1$ is required. If $WDR > 1$, then the material must be processed in some way to reduce the final WDR to unity or less for near surface burial, or it must be packaged and transported as high level waste to a site for disposal other than near-surface (such as a deep geologic repository for fission wastes). Thus, the WDR provides reactor designers with a quantitative measure to apply to materials selection and reactor neutronic designs for evaluating impacts on disposal of wastes from the reactors.

WASTE DISPOSAL RATINGS FOR FIRST WALL OF MARS

In most fusion reactor designs, it is expected that 80-90% of the radioactivity will be generated in structural materials in the regions adjacent to the reacting plasma of the reactor. Therefore, the selection of specific materials for the first wall can have a significant impact on waste disposal. The WDR methodology was used to compare three iron alloys for structural materials in the first wall region of a candidate central cell design

for MARS. The radial profile and composition of this cell is shown in Fig. 1. The neutron energy loading on the first wall is intended to be about 5 MW/m² and a typical operating time is two full power years. The radioactive inventories for the three different first wall materials were calculated for this central cell with the LLNL fusion neutronics package^{5,6,7,8} shown schematically in Fig. 2. (This package is available on the CRAY machine in the Magnetic Fusion Energy Computer Center.)

The three first wall materials were HT-9, SS316 and PCA. Their nominal compositions are shown in Table III.

The specific activities calculated for the three first wall alloys in the MARS central cell are shown in Table IV. Here, the isotopes are grouped according to the 10CFR61 categories as described above. Because of the uncertainties in many of the neutron reaction cross sections,⁹ in some decay schemes, and in the exact compositions of the alloys, the results have been rounded to one significant figure in the table.

When the specific activities in Table IV are combined with the specific activity limits in Table I, the Waste Disposal Ratings shown in Table V are obtained.

CONCLUSION

Based upon the criterion $WDR \leq 1$, it may be seen from the 50-year decay total WDR in Table V that none of the three alloys could be disposed directly by near-surface disposal when activated. If simple dilution in the final waste package were to be the process to

TABLE I
Specific Activity Limits for Near-Surface Burial
(Adapted from 10CFR61)

Isotope	Specific Activity (Ci/m ³)	
	Unalloyed Materials	In Metals/Alloys
Any with $t_{1/2} < 5$ yrs	700	no limit
H3	40	no limit
Co60	700	no limit
C14	8	80
H159	22	220
N163	70	7000
Nb94	0.02	0.2
Tc99	0.3	3
Sr90 (Surrogate)	150	7000
Cs137 (Surrogate)	44	4600
Enriched Uranium (Surrogate)	0.04	0.4

TABLE II

Isotopes Represented by Surrogates

<u>Surrogate for:</u>	<u>Surrogate for:</u>	<u>Enriched Uranium</u> <u>Surrogate for:</u>
Str90	Cs137	
Be10	A126	Pb210
Si32	Ar42	Bi210
Ar39	Fe60	Po210
Sr90	Nb92	
Zr93	Hf182	
C136		
Ca41		
Mn53		
Nb93m		
Mo93		

TABLE III

Nominal Composition of Structural Materials
(weight %)

<u>Alloy</u>	<u>PCA</u>	<u>316 SS</u>	<u>HT-9</u>
B	0.001		
C	0.05	0.06	0.20
N	0.01	0.007	
Al	0.03		
Si	0.5	0.46	0.4
P	0.01	0.03	0.02
S	0.005	0.01	0.02
Ti	0.3	0.04	
V	0.04		0.3
Cr	14.0	16.7	11.5
Mn	1.8	1.43	0.55
Fe	64.68	64.44	85.0
Co	0.03	0.03	
Ni	16.0	13.9	0.5
Cu	0.02	0.06	
As	0.02		
Zr	0.02		
Nb	0.03		
Mo	2.0	2.84	1.0
Ta	0.01		
W			0.5

reduce the WDR to unity or less, the ratios of dilutions would be

$$HT-9:SS316:PCA = 20:70:200$$

This indicates that HT-9 may be more desirable over SS316 and especially over PCA from the standpoint of size and/or number of waste packages that would have to be handled for waste disposal.

It is evident that Co60, the isotopes with half lives less than 5 years, and the isotopes represented by Cs137 are not significant in any of the alloys with respect to near-surface disposal under the present 10CFR61. Of the remaining isotopes in Table V, Nb94 is the most important isotope by far in causing the high WDR values for all three alloys. In the cases of HT-9 and SS316, the Nb94 comes from the molybdenum in the alloys. In the case of PCA, the Nb94 comes both from the molybdenum and the niobium constituents of the PCA.

If the alloys were modified by eliminating the molybdenum, both Nb94 and Tc99 would be removed and the resulting total WDR would be 0.2, 5, and 200 for HT-9, SS316 and PCA, respectively. If this is done, the nickel content becomes the determining factor in the WDR. Because of its relatively low nickel content, the modified HT-9 would be superior to the modified SS316 by a factor of 25. A reduction of molybdenum to about 3% of its normal amount in HT-9 would put this alloy into the range for direct disposal without any processing of the waste other than packaging it suitably for transportation and waste package mechanical stability. Changes in alloy composition such as those listed above could have significant adverse effects on the physical and chemical properties of the alloys used as structural materials for a fusion reactor. Thus it may not be an easy matter to alter the alloys just for the sake of waste disposal. A number of authors have examined various possibilities of developing new materials to reduce radioactive wastes from fusion reactors (see for example references 10 to 14).

So far, the discussion has dealt solely with the first wall of the central cell for a MARS reactor and only disposal of that component by itself has been considered. Although it is not a part of the analysis for this paper, other analyses indicate that, if the first wall components can be stored after use until the reactor is decommissioned, the first wall material could be mixed with shielding components from the central cell to obtain a material with a resultant WDR < 1 at least for HT-9 and probably for SS316. The case for PCA needs more examination. Thus, procedural methods of operation of a reactor can have major impact upon ultimate waste disposal.

Finally, it must be noted that the current disposal limits in 10CFR61 were set for fission wastes and there may have been unexpressed assumptions. There are essentially constant ratios of radioisotopes in high level fission wastes. Hence, only a few isotopes need to be

TABLE IV
Specific Activities (Ci/m³)
for MARS First Wall

Isotope	50 Years After Shutdown		
	HT-9	SS316	PCA
all with $t_{1/2} < 5$ yrs	2E2	2E2	2E2
Co60	2E1	8E2	9E2
C14	5E-3	1E1	2E1
N159	1E1	4E2	5E2
Ni63	7E2	2E4	2E4
Nb94	4	1E1	3E1
Tc99	1E1	4E1	3E1
Sr90			
Surrogate	8E2	2E3	2E3
Cs137			
Surrogate	3E-2	1E-1	3E-1
Total	2E3	2E4	2E4

TABLE V
Waste Disposal Ratings (WDR)
for MARS First Wall

Isotope	50 Years After Shutdown		
	HT-9	SS316	PCA
all with $t_{1/2} < 5$ yrs	3E-4x0	3E-4x0	3E-4x0
Co60	3E-5x0	1E-3x0	1E-3x0
C14	6E-5	1E-1	3E-1
N159	5E-2	2	2
Ni63	1E-1	3	3
Nb94	2E1	5E1	2E2
Tc99	3	1E1	1E1
Sr90			
Surrogate	1E-1	3E-1	3E-1
Cs137			
Surrogate	7E-6	2E-5	7E-5
Total	2E1	7E1	2E2

explicitly regulated and the others automatically fall below acceptable disposal limits. However, fusion wastes will not have any constant or typical isotopic composition. For instance, there will be no transuranics or actinides. Consequently, the current isotopes and limits in 10CFR61 may well be inappropriate for fusion and be too stringent as far as effective health and safety matters are concerned. The bases for setting the isotopic limits should be reexamined on the basis of the health and safety parameters for each individual isotope within the scenarios used by NRC to derive the limits in 10CFR61.

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Fig. 1. Radial Profile and Composition of the Model of a Candidate Central Cell for MARS

Fig. 2. Schematic Diagram of LLNL Neutronics Package

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