Material: Ferritic Steel: F82H
Property: Cooling time (yr) versus Dose rate (Sv/hr)
Condition: Irradiated
Data: Experimental

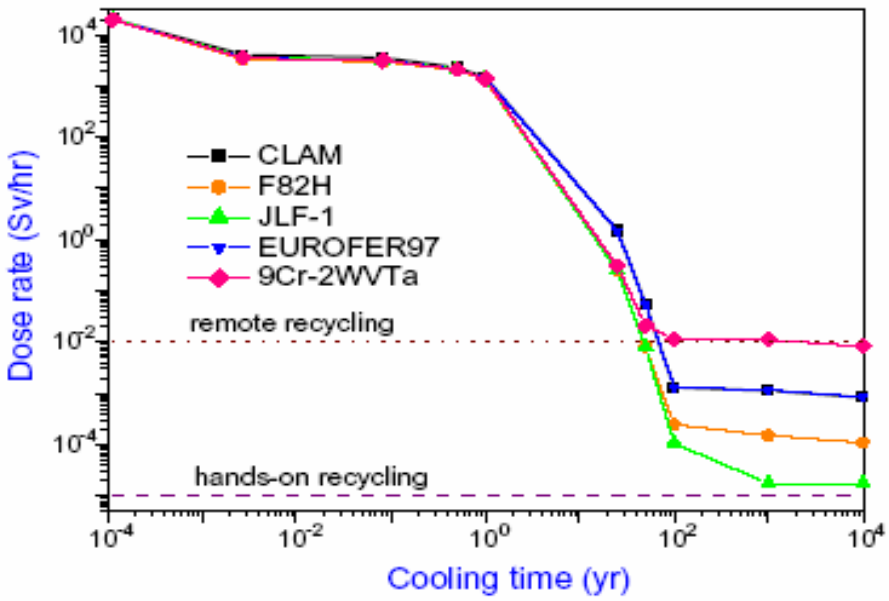


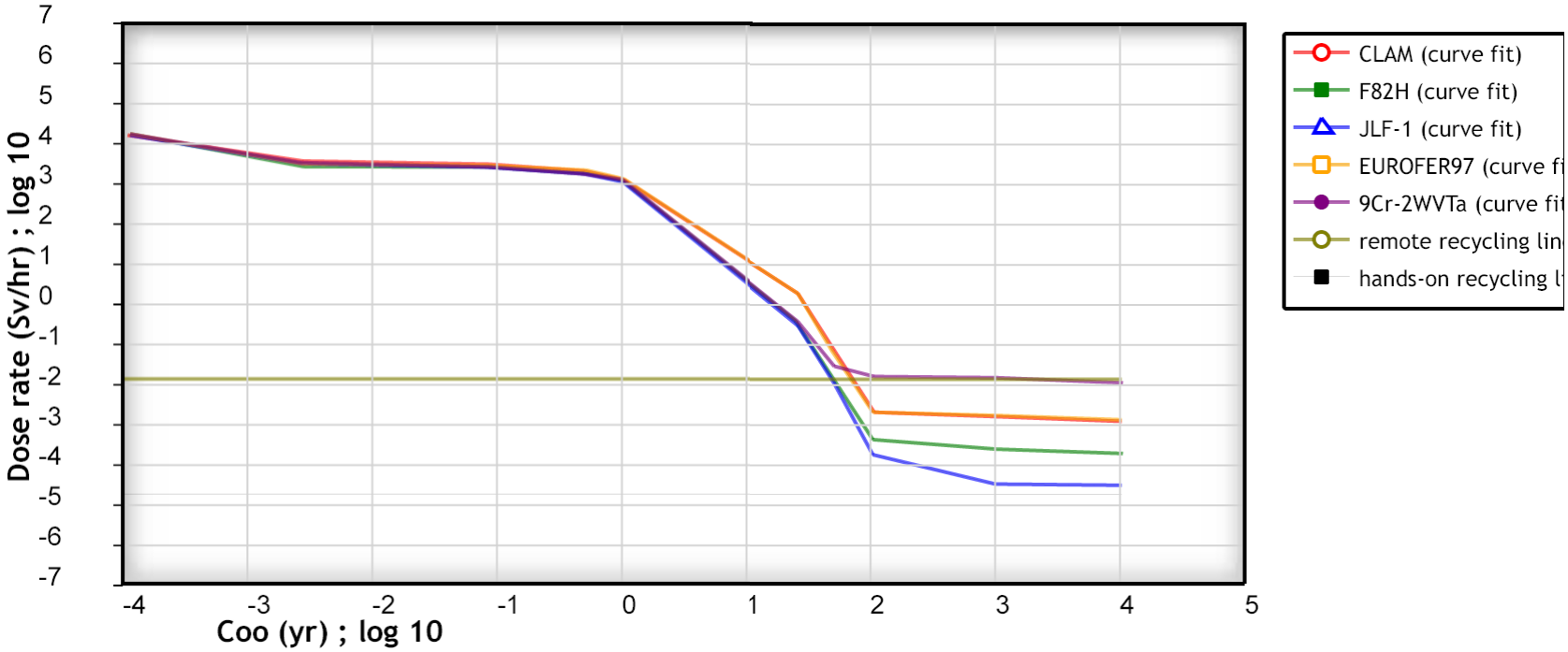
Fig. 4. Dose rates of RAFM steels as a function of cooling time.

Source:
Journal of Nuclear Materials, 329-333, (2004), 268-272

Title of paper (or report) this figure appeared in:
Study of Irradiation Effects in China Low Activation Martensitic Steel CLAM

Author of paper or graph:
Qunying Huang, Jiangang Li, Yixue Chen

Caption:
Dose rates of RAFM steels as a function of cooling time.



Dose rates of RAFM steels as a function of cooling time.

Reference:

Author: *Qunying Huang, Jiangang Li, Yixue Chen*

Title: *Study of Irradiation Effects in China Low Activation Martensitic Steel CLAM*

Source: *Journal of Nuclear Materials, 2004, Volume 329-333, Page 268-272*, [PDF]

View Data | Author Comments

Plot Format:

Y-Scale: ○ linear ◉ log ○ ln

X-Scale: ○ linear ◉ log ○ ln

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Study of irradiation effects in China low activation martensitic steel CLAM

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Abstract

Reduced activation ferritic/martensitic steels (RAFM steels) are presently considered as the primary structural materials for a demonstration (DEMO) fusion plant and the first fusion power reactors because of their attractive properties. Studies on various properties of China low activation martensitic steel (CLAM) are underway. The activation level of CLAM steel was calculated with the widely used inventory code FISPACT with the latest data library FENDL/A-2 based on the first wall (FW) neutron spectrum of the fusion-driven subcritical system (FDS) from the Monte Carlo transport code MCNP/4C calculation with FENDL-2 data library. The results were compared with the activation levels of other RAFM steels, such as EUROFER97, F82H, JLF-1 and 9Cr–2WVTa etc., under the same irradiation conditions. Furthermore, the dominant nuclides to γ-ray dose rate of CLAM steel were analyzed. The required control levels of impurities in CLAM steel will soon be implemented based on the hands-on and remote recycling dose rate limits.

1. Introduction

R&D of fusion materials, especially their activation characteristics, is one of the key issues for fusion research in the world [1–6]. Neutron-induced activation in fusion reactor components can be effectively controlled by the proper selection of materials for use in the first wall (FW) and the blanket etc., and is greatly influenced by the compositions and impurities in these materials. Research on reduced activation ferritic/martensitic steels (RAFM steels), vanadium alloys and SiC/SiC composites used as fusion structural materials is carried out worldwide during the recent 10–20 years to ensure the environmental and safety attractiveness of fusion nuclear power [7–13]. Vanadium alloys and SiC/SiC composites have many attractive properties such as superior high temperature thermal and physical properties, good resistance to neutron irradiation and low neutron activation level [4,5,14] and are considered as promising candidate structural materials for fusion reactor application in the future [1]. RAFM steels are presently considered as the primary structural materials for a demonstration (DEMO) fusion plant and the first fusion power reactors because of their attractive properties, such as the resistance to swelling and embrittlement under irradiation [15], low neutron activation level, good thermal properties i.e. low thermal expanding coefficient and high thermal conductivity etc. [16–18] compared with austenitic stainless steels [1,5,14,17], low industrial investment and much advanced technology [16] etc. compared with vanadium alloys and SiC/SiC composites. One of the main shortcomings of RAFM steels is their low limit on upper operation temperature [14,15]. A lot of work on RAFM steels has been being done during recent twenty years. Versions of RAFM steels, which are world-widely studied nowadays, include EUROFER97 [5,14], F82H [14,16], JLF-1 [17,19] and 9Cr–2WVTa [20] etc. The Chinese low activation martensitic steel CLAM [21,22] is under research in the Institute of plasma physics (ASIPP), Chinese academy of sciences. Activation levels of the CLAM steel and other RAFM

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steels mentioned above were calculated and compared in the paper under the same irradiation condition.

It is also well known that increased levels of undesirable elements such as Co, Nb, Ag, Mo, Ni etc. would dominate the activation level of fusion materials, and would substantially influence not only the recycling of used reactor materials but also the waste management of them [10–13]. The activation analysis of various fusion reactor structural materials including RAFM steels, vanadium alloys and SiC/SiC composites etc. were performed by Forty, Taylor, Butterworth, Forrest, et al. [23–25]. In this contribution, dominant nuclides to the γ-ray dose rate of CLAM steel were analyzed. The required control levels of various impurities in CLAM steel will soon be implemented, based on the hands-on and remote recycling dose rate limits i.e. 10 μSv/h and 10 mSv/h, respectively [26,27].

2. Model, codes and data for activation calculations

The conceptual design of a fusion-driven subcritical system (FDS) [28] is underway in ASIPP. There are alternative designs for multi-functional blanket modules of the FDS, such as the liquid LiPb–He gas dual-cooled fuel breeding blanket (FBB), the He gas-cooled Li_2O tritium breeding blanket (TBB) and the waste transmutation blanket (WTB) etc. [13,29,30]. They have the same plasma core and inboard blanket. The difference among them is the outboard blanket, just as the names show.

Comparison of activation levels among structural materials such as 316L, ODS-FS and V-alloys etc. used as the FW and structural material of the TBB of the fusion driven subcritical system (FDS-TBB) [13,30] was reported in Ref. [9]. Neutron spectrum, activation levels of CLAM steel and comparison of them with those of the other RAFM steels, dominant nuclides to dose rate of CLAM steel were introduced in the paper when they are used as the FW and structural materials in the FDS-TBB and irradiated by D–T fusion neutrons from the plasma with neutron wall loading of 0.5 MW/m^2 and neutron fluence of 15 MW yr/m^2.

Compositions of CLAM, EUROFER97, F82H, JLF-1 and 9Cr–2WVTa are given in Table 1 [5,16,17,31]. The geometrical and material configuration of the FDS-TBB is shown in Ref. [13,30], the difference is that the structural material is replaced by the above RAFM steels respectively in this paper. Neutron transport calculations were done with the Monte Carlo transport code MCNP/4C [32] and the latest released version of the IAEA fusion evaluated nuclear data library FENDL-2.0 [33]. The neutron spectrum at the outer FW is used as the input of the activity inventory

Table 1
Compositions of RAFM steels

Item	CLAM	F82H	JLF-1	EUROFER97	9Cr–2WVTa
Fe	Bal.	Bal.	Bal.	Bal.	Bal.
Cr	9.0 ± 0.1	7.46	8.87	8.82	8.90
C	0.10 ± 0.02	0.09	0.10	0.10	0.11
Mn	0.45 ± 0.05	0.21	0.48	0.37	0.44
P	0.003		0.002	<0.005	
S	0.002		0.003	0.003	
B				<0.0010	
N	0.02	0.006	0.0244	0.021	0.021
W	1.5 ± 0.1	1.96	1.9	1.1	2.01
Ta	0.15 ± 0.03	0.023	0.084	0.068	0.06
Si	0.01	0.10	0.24	0.005	0.21
Ti	<0.006			0.006	
V	0.20 ± 0.02	0.15	0.19	0.19	0.23
Ni	0.02			0.021	<0.01
Co	<0.005			0.005	
Cu	<0.005			0.0038	
Nb	<0.001	0.0001		<0.001	<0.01
O	<0.0026			0.0026	
Mo		0.003		0.0012	0.01
Al				0.008	
Sn				<0.005	
As				<0.005	
Y	0.2				

code FISPACT [34] to estimate the activation levels of the materials. The IAEA activation sub-library of FENDL/A-2.0 [33] is used in these calculations.

3. Results and analysis

Neutron spectrum, activation levels for the RAFM steels, and dominant nuclides contributing to the dose rate of CLAM steel were done and analyzed in the following sections, for the materials used as the FW of the FDS-TBB respectively.

3.1. Neutron spectrum

Neutron spectrum is one of the main reasons leading to different activation characteristics and one of the important input parameters for activation calculation. So it is necessary to know the characteristic of the neutron spectrum for activation analysis. The spectrum at the outer FW of the FDS-TBB is calculated first and shown in Fig. 1. It is clear that there is a peak in the neutron spectrum at the outer FW for 14.1 MeV D–T neutrons. Neutron fluxes for neutron energies less than 20 eV are much lower than the peak value at neutron energy of 14.1 MeV, and neutron fluxes for neutron energies between 20 eV and 14.1 MeV are about forty to three hundreds times lower than the peak value.

3.2. Activation levels of the RAFM steels

Activities, afterheats and decay gamma dose rates for the above RAFM steels varying with cooling time (CT) are shown in Figs. 2–4, respectively. It is clear that there is almost no difference for total activation values between CLAM and EUROFER97 and there is almost no difference for activities among the RAFM steels for CT less than 50 years. Difference of afterheat or dose rate among them is quite small for CT less than 1 year. The differences between them become larger with CT beyond

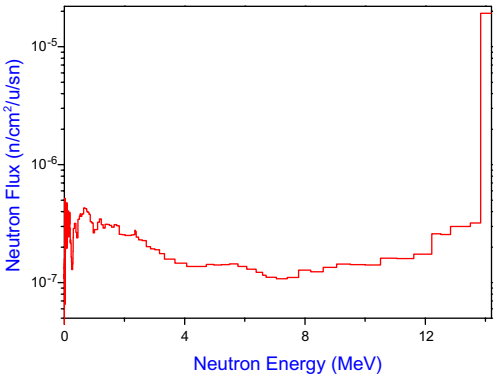

Fig. 1. Neutron spectrum of the outer FW.

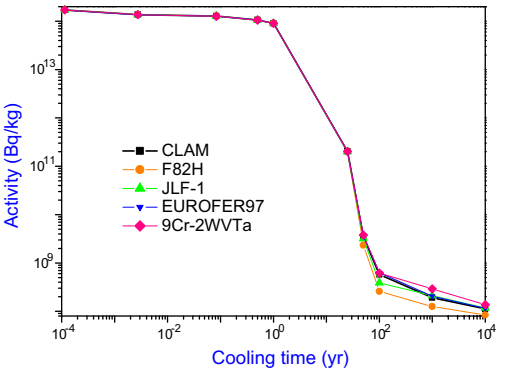

Fig. 2. Activities of RAFM steels as a function of cooling time.

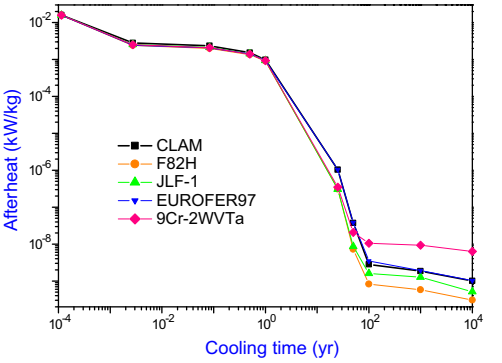

Fig. 3. Afterheats of RAFM steels as a function of cooling time.

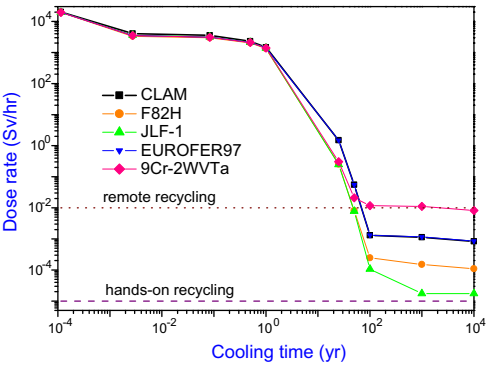

Fig. 4. Dose rates of RAFM steels as a function of cooling time.

50 years. That is because the dominant nuclides contributing to activation levels for shorter CT are mainly products from activation of the main compositions of the steels which are very similar for the above RAFM steels, and the dominant nuclides for longer CT are mainly products from activation of impurities in the steels which are quite different for these RAFM steels. Dose rates for the RAFM steels except 9Cr–2WVTa

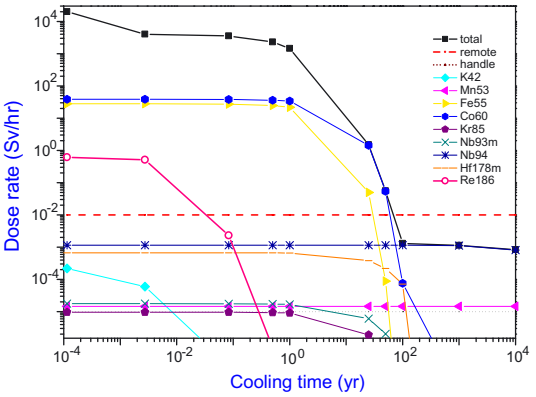

Fig. 5. Dominant nuclides contributing to dose rate of CLAM steel.

reduce to remote handling level when CT is ~50 years for F82H and JLF-1 or ~67 years for CLAM and EUROFER97, respectively. Dose rate for 9Cr–2WVTa is near the remote handling limit when CT is longer than 100 years. None of the dose rates for RAFM steels reduce to the hands-on recycling level during CT less than 10^4 years.

3.3. Dominant nuclides contributing to dose rate of CLAM steel

Fig. 5 shows the dominant radioactive nuclides contributing to contact dose rates of irradiated CLAM steel as a function of CT. Apparently, the isotopes ^{60}Co and ^{55}Fe, which are both short-life nuclides, dominate the total dose rate of CLAM steel to a CT of ~70 and 35 years, respectively. The nuclide ^{60}Co is mainly from the reactions ^{59}Co(n,γ)^{60}Co and ^{59}Co(n,γ)^{60m}Co(IT)^{60}Co, while ^{55}Fe is mainly from the reaction ^{56}Fe(n,2n)^{55}Fe. Afterwards, the element ^{94}Nb, which is a long-lived nuclide with half-life of 2×10^4 years and mainly from reactions ^{93}Nb(n,γ)^{94}Nb and ^{93}Nb(n,γ)^{94m}Nb(IT)^{94}Nb, becomes the dominant nuclide for the total dose rate of CLAM steel.

4. Conclusions

Activation levels of the RAFM steels such as CLAM, EUROFER97, F82H, JLF-1 and 9Cr–2WVTa were calculated and compared when used as the structural materials in the FDS-TBB under neutron wall loading of 0.5 MW/m^2 and neutron fluence of 15 MW yr/m^2. The neutron spectrum was calculated with MCNP/4C code and data library FENDL-2.0. The gamma dose rates of the RAFM steels and impurities control calculations were done with the FISPACT code and the IAEA data library FENDL/A-2.0. The following conclusions were obtained from the calculations and analysis:

(1) There is a peak in the neutron spectrum for 14.1 MeV neutrons at the outer FW of FDS-TBB. Neutron fluxes for the other neutron energies are about forty to three hundreds times or more lower than the peak value.
(2) There is almost no difference in total activation values among the RAFM steels for short CT. Difference between them become larger with longer CT. That is mainly because the dominant nuclides contributing to activation levels for shorter CT are products from activation of main compositions of the steels which are quite similar for the above RAFM steels, and the dominant nuclides for longer CT are products from activation of impurities in the steels which are quite different among these steels.
(3) Dose rates of the RAFM steels except 9Cr–2WVTa reduce to remote handling level when CT is ~50 years for F82H and JLF-1 or ~67 years for CLAM and EUROFER97, respectively. Dose rate for 9Cr–2WVTa is near the remote handling level when CT is longer than 100 years. None of these steels reduce to the hands-on recycling level during CT less than 10^4 years.
(4) Short-lived nuclides ^{60}Co and ^{55}Fe dominate the total dose rate of CLAM steel to a CT of ~70 and 35 years, respectively. Afterwards, the long-lived nuclide ^{94}Nb becomes the dominant nuclide to the total dose rate of CLAM steel.

Acknowledgements

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