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Section 15. Discussion sessions
15.1. Low activation materials
(Session Organizers: T. Noda, R. H. Jones and G. J. Butterworth (not present))

Low activation materials

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Abstract

Low or reduced activation materials are currently being developed and evaluated as structural materials for fusion energy systems. The goal of developing low activation materials is to provide fusion energy systems with a competitive edge over fission energy systems where high level waste issues abound. The primary low activation materials being developed by the international fusion materials community are: (1) ferritic/martensitic steels, (2) vanadium alloys and (3) SiC/SiC composites. These three materials offer a range of temperature and coolant design options and would likely be the optimum choices even without a low activation criteria. However, there are a number of activation, safety and disposal issues that must be solved to achieve an optimum blanket design.

1. Introduction

Organizer's Intention: Low activation is one of the key issues in developing fusion reactor materials. Guidelines on activation for the ITER and commercial reactors are discussed based on the newest nuclear data and evaluation materials such as ferritic steels, vanadium alloys, SiC composites, and other related materials are reviewed and discussed for future studies. Topics are (1) overviews of national and international programs, (2) criteria for low activation materials, (3) nuclear database and (4) progress in materials development.

Limitations to other alloy systems would likely have led to the choice of ferritic/martensitic steels, vanadium alloys and SiC/SiC without the 'low activation' goal. Limitations include: (1) austenitic stainless steels – inadequate thermal–physical properties, (2) nickel based alloys – He generation rate and phase instabilities, (3) molybdenum alloys – radiation effects on DBTT, (4) titanium alloys – hydrogen solubility and permeability, (5) aluminum alloys – limited temperature capability, (6) niobium alloys – possible candidate but sensitivity to gaseous impurities and field joining are issue's and (7) copper alloys – possible candidate but low temperature radiation limit.

The three candidate materials being evaluated provide the designer with a range of temperature and coolant options. However, they differ in their data and industrial experience base, fabrication experience, test standards and design codes. In general, the three material systems can be listed with these factors as increasingly favorable in the following order: SiC/SiC – vanadium alloy – F/M steels. Design codes will clearly be different for the ceramic composite materials relative to the metallic materials. An ASME pressure/vessel design code is being developed for ceramic composite materials.

These three candidates also offer a range in nuclear after-heat and safety related behavior with SiC having the least afterheat on shutdown, vanadium alloys have intermediate values and F/M steels the greatest. Some accident scenarios can be designed around but it is necessary to consider both the structural material and coolant because each coolant, i.e. water, helium or lithium, poses a unique set of safety/environmental challenges.

Elements that are attractive from an accident safety point of view are not necessarily as attractive from a waste disposal point of view. The primary elements considered for the low activation materials, Si, C, V and Fe are all inherently low activation. Alloying additions

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and impurities tend to dominate the waste classification of these materials. For instance, elements that must be controlled in these materials include Nb, Mo, Al, Ag, Co, and Bi. Better nuclear data and more experimental measurements of cross-sections at fusion relevant neutron energies are needed.

Fusion is an internationally coordinated program with research often conducted on a common alloy and heat of material. Agreements on impurity limits are needed in the production of these heats of material. However, there is no internationally agreed to low level waste criteria. Fusion energy systems will be built and disposed of within a given country and must therefore meet that countries criteria. But the fact remains, that todays joint LAM research is inhibited by the lack of an internationally agreed to low level waste criteria.

2. Why low activation materials?

This question was addressed at a recent Fusion Power Associates meeting held at Snowmass Village, CO, in a presentation given by Bloom [1]. His summary reviewed the origin of the idea of building fusion power plants with low activation materials as dating to the 1970s, a 1982 DOE panel chaired by R.W. Conn with a report publication date of 1983 and a US fusion program goal stated by ESECOM in the mid to late 1980s. The essence of this report was that fusion will have a difficult time gaining any electrical production capacity on the basis of economics but that fusion could offer the following advantages with respect to safety and the environment: (1) reduced risk from reactor accidents, (2) substantial reduction in high-level waste that requires deep geologic disposal and (3) reduction in some important links with nuclear weaponry.

To meet the ESECOM goal, it was apparent that materials were needed that: (1) had the required physical, chemical, mechanical and radiation properties, (2) low afterheat and volatility and (3) low long half-life radioactivity. This has led the international fusion materials community to focus their attention on: (1) ferritic/martensitic steels, (2) vanadium alloys and (3) SiC/SiC composites. However, it is very likely that these materials would be among the top choices regardless of the low activation goal because of limitations to many of the other choices. Therefore, these three materials have a double rationale for their choice: (1) they have the potential to meet the performance requirements and (2) they meet the low activation criteria.

3. Performance comparison of LAMs

The three materials being developed by the international fusion materials community offer a range of design options. These are: (1) F/M steels: 400–550°C wall temp., He coolant, (2) vanadium alloys: 400–650°C wall temp., Li coolant and (3) SiC/SiC composites: <1000°C wall temp., He or Pb–Li coolant. However, these materials are each at different stages of development. A summary of their relative ranking is given below in Table 1.

Some pertinent unirradiated physical and mechanical properties [2,3] for these three materials are given in Table 2.

The density and thermal expansion of SiC/SiC are markedly lower than that of F/M steels and vanadium alloys. The lower density will translate into a lighter structure while the low thermal expansion will complicate transition joints between SiC/SiC and other metallic components outside the high flux region. A range of thermal conductivities are given for SiC/SiC because recent developments [4] have resulted in material with a thermal conductivity of 35 W/m K while the value of 10 is typical of commercial material at 800°C. (see Table 3.)

The largest difference between the mechanical properties of the F/M steels and vanadium alloys and SiC/SiC is in the elongation and fracture toughness. This difference is the result of a totally different fracture behavior for SiC/SiC relative to F/M steels and vanadium alloys. This difference will require the use of a different design criteria such as the one being developed by ASME as noted above.

4. Safety criteria and issues

Accident safety depends on the entire system: the structural material, coolant, breeder, multiplier (if necessary) and the design. Coolant is included because each coolant poses a unique set of safety/environmental challenges. For example: (a) the production of hydrogen from water, (b) the risk associated with a high-pressure system for He and (c) the chemical reactivity of Li.

Accident safety must consider: (1) decay heat, (2) activation products, (3) the presence of tritium, and (4)

Table 1
Developmental status of LAMs

Category	F/M steels	Vanadium	SiC/SiC
Industrial base	Large	Small	Small
Database			
Unirradiated	Large	Moderate	Small
Irradiated	Large	Small	Very small
Fabrication experience	Large	Small	Very small
Test standards	Yes	Yes	Partial
ASME design code developmental	Yes	Yes	

Table 2
Unirradiated Physical Properties of LAMs

Property	F/M steels	Vanadium	SiC/SiC
Melting temp., °C	1420	1890	2800 (s)
Density, g/cm^3	7.8	6.1	2.7
Specific heat, kJ/kg C	0.58	0.8	0.6
Thermal exp., 10^{-6}/C	10.5	12.6	3
Thermal cond., W/m K	35.3	27.7	10–35

Table 3
Unirradiated Mechanical Properties of LAMs

Property	F/M steels	Vanadium	SiC/SiC
Elastic modulus, GPa	200	131	150
UTS, MPa	760	420	500
Total elong., %	22	30	1
Poisson's ratio	0.27	0.36	0.2
Thermal stress factor, W/cm	90	140	70
Fracture toughness, kJ/m^2	500	>500	24 [a]

[a] MPa m$^{1/2}$.

toxic and radiological hazards. Elements that are attractive from an accident scenario, i.e. low decay heat, are not necessarily those that are attractive from a waste disposal perspective. This may result in assigning a preference to the choice of a low activation material on the basis of accident or waste disposal performance. However, the most significant contributor to the activation product source term is tokamak dust from plasma facing components so the possibility that the selection of a structural material based on an accident criteria may be greatly reduced. Other safety issues include worker safety and effluents during normal and maintenance operations.

A great deal can be learned from the ITER design activity. One lesson learned from ITER is that many accident issues can be 'designed around'. For instance, even though ITER is a water cooled, stainless steel machine it satisfies IAEA no-evacuation criteria. Shielding can help reduce activation of critical components but the shielding material itself may create activation problems. Likewise, isotopic tailoring can reduce activation problems in some instances, but this may not be economically attractive.

5. Waste disposal comparison

All of the base materials of the three candidate low activation materials, i.e. Fe–Cr, V–Cr–Ti and Si and C, are low activation. Vanadium and SiC are somewhat better in the short-term while for some criteria F/M steels are better in the long-term. The newly recommended cross-sections for ^{26}A1 production improves the long-term waste disposal prospects of SiC. A comparison of the blanket waste disposal rating for F/M steels (RAF), V and SiC are compared to Type 316 SS in Fig. 1 [5]. It is apparent from this figure that F/M steels, vanadium and SiC all satisfy a low level waste criteria when the entire blanket is considered while Type 316 SS does not.

Impurities and minor alloying elements produce the major activation issues for waste disposal. Therefore, it is imperative that certain impurities be controlled to achieve waste disposal goals. Some impurities that need to be restricted include: (1) F/M steels – Nb, Al, Mo, (2) V alloys – Nb, Mo, Ag, Co, Bi and (3) SiC – Al, Ag, Mo. There are also some minor alloying elements that may face restrictions. These include: (1) W in F/M steels and (2) Ti and Si in V alloys.

Some recommendations for future directions include: (1) development of an international waste disposal criteria, (2) reduction of uncertainties in nuclear data and (3) improved characterization of activation environments with 3-d neutronic, activation and decay heat calculations. Although the international fusion materials program is attempting to develop common low activation materials there is no common basis on which to compare these materials because there is no common waste criteria. The problem is illustrated by the criteria given in Table 4 which shows the low level waste criteria for most countries participating in fusion materials development. There is little in common. One approach would be an international consensus on working ranges of allowable alloying and impurity element concentrations.

6. Issues with current LAMs

Issues associated with the current LAMs can be summarized as follows: (1) for all three there is an

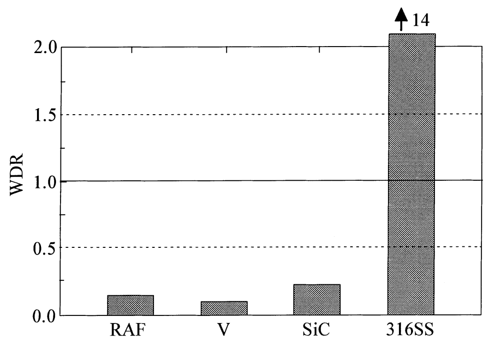

Fig. 1. Comparison of blanket waste disposal ratings for 1500 MW 'DEMO' WDR = Actual concentration/Critical concentration.

Table 4
International low level waste criteria (not specifically for fusion technology)

Country	Waste type	Low level waste criteria
USA		Isotope specific (Shallow land burial/intruder scenario)
Japan	Solid	37–37 000 MBq/m^3
	Liquid	0.037–37 MBq/m^3
	Gaseous	37–37 000 Bq/m^3
	Alpha	<4 MBq/kg
	Beta, Gamma	<12 MBq/kg
France		Isotope specific
Germany		Isotope specific
Sweden	Alpha	1010 Bq total site
	Beta, Gamma	1013 Bq total site
Russia	Solid alpha	3.75–375 kBq/kg
	Beta	0.0375–3.75 MBq/kg
	Gamma	0.0003–0.3 mSv/h
	Liquid	<370 MBq/m^3
IAEA	Solid	<2 mSv/h
proposal	Liquid	0.037–37 MBq/m^3
	Gaseous	<3.7 Bq/m^3

From ITER-CDA Team 'ITER Safety', ITER Doc. Series 36, IAEA, Vienna, 1991.

inadequate database for irradiated material, (2) for vanadium alloys the industrial base and fabrication experience is limited, (3) for SiC/SiC the industrial base and fabrication experience is very limited, (4) there is a need for more information on the effects of impurities on waste disposal, (5) fusion is an international program but waste criteria is not, and (6) there is a need for a better nuclear data base.

7. Summary

The current choice of materials, i.e. F/M steels, vanadium alloys and SiC, would likely be among the top choices for structural applications in fusion systems even if there were no goal to achieve low activation. This results because many of the other choices have inadequate thermal-physical properties, phase instabilities, unacceptable He generation rates, unacceptable shifts in DBTT with irradiation, high hydrogen solubility and permeability or limited temperature capabilities. Therefore, F/M steel, vanadium alloys and SiC/SiC composites offer the potential for both the optimal low activation characteristics and radiation performance. The three LAMs currently being developed by the international fusion materials community offer a range of design options ranging in temperature from 400°C to 1000°C with He or Li coolants. However, there are many unresolved issues associated with activation, safety and disposal that must be answered before the optimal choice can be made.

8. Comments

P. Fenici: In the blanket/cooling system list, also Pb–17Li should be included with water, helium and lithium. The industrial capability for SiC/SiC exists if you consider better the CMCs including C/C composites. For CVI materials there is no manufacturing difference between C/C and SiC/SiC.

P. Rocco: Fusion will be an energy producing system after 2050. If you envisage to solve fusion waste management with shallow land burial after the year 2070, it is most likely that this option will not be acceptable for environmental problems. Concerning fusion waste management, many countries do not allow shallow land burial; hence, if the waste management option chosen is recycling, the contact dose is the governing parameter. Then the control of impurities is important in V-alloys but not in steels where you must control components.

9. Panel discussion

9.1. Y. Seki [a], T. Tabara [b], I. Aoki [a], S. Ueda [a], S. Nishio [a] and R. Kurihara [a]: 'Impact of Low Activation Materials On Fusion Reactor Design'

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The major reason for developing fusion reactors is in its potential in attaining the high level of environmental safety and good public acceptance which cannot be achieved by fission reactors. In a fusion reactor, the environmental effect can be kept at a sufficiently low level not only in actual situation by adequate containment design but also in the case of a postulated severe accidents in which case a certain fraction of radioactive material inventory is assumed to be released to the environment. In a fission reactor, the probability of such a severe accident may be sufficiently reduced to exclude the possibility but impossible to demonstrate low environmental effect on the fractional release because of the inherent large inventory of radioactive materials. The low activation materials play the key role in realizing such an environmentally safe and societally acceptable fusion power reactor which may be constructed near the big cities where most electricity is consumed. The impact of low activation material on fusion reactor design is as follows:

(1) Reduce radioactive impact to the environment in case of severe accidents.

(2) Reduce decay heat in case of loss of cooling accidents.

(3) Reduce gamma-ray dose during the maintenance.

(4) Reduce the amount and lower the level of radioactive waste from replaced components and at the decommissioning of a fusion reactor.

In order to reduce environmental impact in case of severe accidents to the level such as to enable construction near big cities, the low activation material must be of very low activity such as only achievable by SiC/SiC composite. Reduction of decay heat impacts the design by simplifying the cooling system and or by decreasing the safety system against accidents caused by decay heat. Reduction of gamma-ray dose during the maintenance of a fusion reactor simplifies the remote maintenance schemes and could improve the plant availability. Lowering the level of radioactive waste results in the reduction of radioactive waste disposal cost and could improve the public acceptability of fusion reactors.

This paper is summarized as follows:

(1) Low activation is only one of the requirement for fusion reactor blanket material but it is the most important to achieve the safe and environmentally attractive fusion reactor.

(2) Radioactive waste disposal is only one aspect of the impact of low activation material on fusion reactor design.

(3) From the view point of fusion reactor design, SiC/SiC composites offer the possibility of siting fusion reactor near big cities and its development is highly desired.

F. Tavassoli: While realizing the advantages of SiC/SiC, mainly its high temperature application potential, this material is still at the early stages of development. Several critical issues remain to be resolved. These include joining, permeation barrier, or even the possible risk of energetic neutrons passing through the blanket and activating other parts of the system.

Y. Seki: I fully recognize that there are many issues with SiC/SiC. I propose that these issues be solved so that SiC/SiC may be used to realize a really attractive fusion reactor.

9.2. C.B.A. Forty: 'Conflicting aims in LAM design? Accidental releases Vs. activated material management'

(UKAEA Fusion, Culham, Abingdon, Oxfordshire OX14 3DB, UK)

A guiding principal behind the development of LAMs over many years has been the attempt to reduce induced activation in the 'long-term', where waste management issues are important. By elemental substitution and strict impurity control, "orders-of-magnitude" improvements have been possible. Today, we feel confident that modern LAMs will contribute greatly to the S&E case for fusion power.

Although this is undoubtedly the case, one should also ask the odd difficult question, such as:

1. Are these LAMs optimised fully, and indeed, are they optimised for all activation response functions? And
2. Are the requirements for activation minimisation in the 'long-term' the only role for LAMs?

In this short presentation, We shall briefly explore these two questions with the aid of a few interesting examples.

M.L. Grossbeck: Was it reasonable to assume 0.5 mass ppm for U and Th impurities in your study?

C.B.A. Forty: I thought it was, and besides U and Th levels at orders of magnitude lower concentration would still be discernable in the inhalation dose curves.

K. Ehrlich: A lot of calculations have been made for the structural materials to be used as first wall and structural alloys. Have similar in-depth investigations also been made for other components and materials like solid breeders, liquid breeding/cooling systems, divertor materials and other components down to the main structures of the magnetic coils and where can such general informations be found?

C.B.A. Forty: The present study was done for the European SEAFP study.

9.3. Paolo Rocco: 'The Potential of LAMS in Decommissioning and Waste Management'

(European Commission, Joint Research Center, Institute for Advanced Materials - 21020 Ispra, Italy)

Limits on the contact dose rate proposed in fusion analyses for hands on operation and remote handling are 10 μSv/h and 10 mSv/h, respectively. For both decommissioning and recycling these limits should be reached after 50 years.

Clearance (declassification to non-active waste) of materials having low radioactivity levels is based on limits on the specific activity of the material. Clearance levels, i.e. the specific activities of each radioactive nuclide which allows the clearance of a waste where this nuclide is the only contaminant, have been proposed in a 1995 IAEA interim report. They are based on the potential hazard offered by the nuclide (energy of beta and gamma emission, allowable limit of intake by inhalation and ingestion) and vary between 3×10^2 and 3×10^6 Bq/kg. However these clearance levels arise from a study and are not yet accepted. As a consequence, decommissioning of fusion waste to non-active waste based on these levels should be approved by the Competent Authorities.

As waste contains a mixture of nuclides, the contribution of each nuclide to the waste specific activity should be weighted on the basis of its clearance level. A 50 years decay is suitable also in this case.

Some examples based on previous limits show the potential of low activation materials (LAMs).

They refer to waste management but the advantages offered by LAMs look evident also when transferred to decommissioning. It can be stated that:

(1) A blanket structure made with conventional martensitic steel has to be disposed of, whereas if made with a low-activation steel it may be recycled.
(2) Similarly, the outer layer of outboard vacuum vessel made with a low-activation austenitic steel may be recycled or cleared, which is not possible if it is made with AISI316.
(3) The comparison of the radioactive behaviour of two V–4Cr–4Ti compositions having respectively low and high impurity contents shows that in this low activation alloy the control of impurity is essential.

In a more general way, a comparison is made between the total waste (periodical substitution of in-vessel components + decommissioning) arising from a fusion power reactor adopting low activation steels as structural materials and a similar reactor where structures are made with conventional steels. The waste arising is 69 000 ton in both reactors. The low activation version allows to recycle 48% of the total amount and to clear 39%, whereas 13% has to be disposed of. The non-recyclable fraction is reduced to 3% if a the decay is prolonged to 70–80 years. In the conventional version the fraction to be disposed of rises to 29%, whereas 40% could be recycled and 30% cleared. An increase in decay time to 70–80 years dose not offer significant advantages.

The contribution of M. Zucchetti, Polytechnic of Turin, is gratefully acknowledged.

9.4. H.L. Heinisch[a], E.T. Cheng[b], F.M. Mann[c]: 'Activity for Fusion Materials'

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Nuclear data and computer codes for evaluation of induced activity allow us to predict the activity of materials irradiated in virtually any neutron environment, even one that does not yet existed, such as a commercial fusion power plant. Motivated by multinational cooperation in fusion technology and the limited world-wide resources for nuclear data research, the International Atomic Energy Agency/Nuclear Data Section has played an important role in nuclear data development for fusion materials for over twenty years. Under IAEA/NDS auspices, international nuclear data developers exchange data relevant to fusion technology, evaluate nuclear data, and reach consensus on its reliability. They critically examine the database and determine priorities in addressing the deficiencies for fusion technology applications.

The Fusion Evaluated Nuclear Data Library (FENDL) is coordinated under the IAEA/NDS, and its contents are selected from a worldwide collection of national nuclear data libraries. The recently complied activation cross-section library FENDL/A-2.0 contains about 13 000 reactions, including long-lived activation reactions specifically examined under the IAEA Coordinated Research Program on 'Activation Cross-Sections for the Generation of Long-lived Radionuclides of Importance to Fusion Technology'. The impact of this activation library update is that levels of production of several radionuclides important to fusion technology are predicted to be less than calculated using the previous activation library FENDL/A-1.1. The production of ^{26}Al by two-step reaction from ^{28}Si is now predicted to be one-tenth the previous estimate.

The world presently has the best nuclear data available for fusion technology complied in one place, and it will continue to have this as long as activities such as FENDL are supported. Improving the nuclear database requires more experimental measurements.

A. Kohyama: About new FENDL 2.0A, you indicated the reaction of $Si^* \rightarrow Al$ has been revised to be reduced about factor of 10. How much this new data have been included. For example, Dr Y. Seki's data in this session is based on the new data or not? How about the strong statements from the US National Labs. on this reaction provided in Obninsk.

H. Heinisch: Dr Seki's calculations did not utilize the FENDL/A-2.0 cross sections, but calculations that do use them are presented at this conference by other researchers, for example, the papers by Dr Cheng (P2-C129) and by Drs Rocco and Zucchetti (P2-C130). There are many national nuclear data libraries, some of which get updated more regularly than others. It would be easy to suggest that the FENDL/A-2.0 library should now be used in all activation calculations. This may take considerable time, as some computer codes for activation calculations will have to be modified or replaced. Since the cross sections for many reactions are the same in both FENDL/A-2.0 and the other libraries, there is no problem using them as long as the researcher is aware and careful. Until a worldwide standard is firmly in place, all reports of results should at least identify the data libraries used, which is already common practice.

9.5. F. Abe and T. Noda: 'Recent Progress of Impurity Control in Heat Resisting Steels'

(National Research Institute for Metals (NRIM), 1-2-1, Sengen, Tsukuba 305, Japan)

For the development of reduced-activation steels, it is essential to minimize the impurities which detrimentally affect the activation level of the steels. The present report concentrates on the recent progress in purification and impurity control of engineering steels in Japanese industry. The production of high purity engineering steels has been required for the improvement of mechanical and chemical properties such as temper embrittlement, stress corrosion cracking and so on. At the beginning of 1980s, Japanese steelmaking companies established today's divided refining process composed of hot metal pretreatment, combined blowing and secondary refining. At present, the concentration of impurities can be controlled to low levels; $C < 10$, $P < 25$, $S < 3$, $N < 5$ and $O < 5$ (ppm).

The purification of high alloy steels such as high-Cr ferritic/martensitic steel and austenitic stainless steels has been performed by Electro Slag Remelting (ESR), where impurities can be eliminated by metal–slag reactions. For example, superclean 12% Cr rotor forging of 76 ton, 1.75 m in diameter and 4.2 m in length for steam turbine was successfully produced by ESR at Mitsubishi Heavy Industry and Kobe steel. The superclean means the reduction of Si and Mn as low as possible to improve toughness and creep strength. The superclean 12Cr rotor steel contained 0.06–0.08% Si and 0.04–0.05% Mn. The ESR process is effective not only to reduce the Si and Mn levels but also to minimize the segregation of alloying elements.

The minimization of harmful impurity Nb, which detrimentally affects long-term induced activity of steels, was investigated for 8Cr–2WVTa steel (F82H) by NKK. The Nb content in a 5 ton ingot produced by vacuum melting was 0.5–0.7 ppm. It should be noted that the main source of Nb in the ingot was found to be the raw material Cr. This suggests that the purification of Cr as well as iron is required to meet low activation criteria. In austenitic stainless steels, most of the impurities P and S also come from the raw material Cr. At present, the purity of engineering Cr reaches to 99.986%, containing impurities of 0.5 Si, 0.2 Al, 90 O, 15 N, 10 H and 10 (ppm) S.

9.6. M. Takeda: 'Purification of Silicon Carbide Fibers'

(Nippon Carbon Co., 27 Takauchi, Ohsawano, Toyama 939-22, Japan)

SiC/SiC composites are substantially promising materials for fusion reactor application because of their excellent high temperature mechanical properties and low activation nature after neutron irradiation. However, some impurities in the composites would cause the change into higher level waste. Impurity reduction is required from radwaste disposal after shutdown. As for reinforcement (SiC fibers), two types of impurities should be considered. One is metallic impurity which derived from raw materials and contamination in production process, and another is nitrogen ($^{14}N \rightarrow {}^{14}C$, $t_{1/2} = 5730$ yrs) from raw materials and process conditions (nitrogen working gas). As a result, metallic elements such as iron and nickel in the fiber (Hi-Nicalon) was contained in relatively high level (24 and 12 ppm, respectively). Nitrogen concentration of SiC fiber (Hi-Nicalon type S) was 400 ppm. In order to achieve the goal (N: < 80 ppm), dramatic purification of SiC fiber is needed.

P. Rocco: Why it is so important that the SiC/SiC radwaste should be the low level waste?

R. Yamada: It is difficult to find even medium level lend disposal sites, especially in Japan because of the space limitation and the difficulty to get public acceptance. Therefore, it is quite important for radwastes of SiC/SiC composites to be categorized as the low level waste level for the view point of public acceptance and sense of the disposal land again for other purposes.

K. Ehrlich: If we compare the activation calculations for the major structural materials groups presented at this conference with those presented at earlier ICFRM's, we see a consolidation of data. This is due to two points; Reasonable levels of impurities have been taken into account for the main alloy groups and so-called sequential reactions have been introduced in some of the used codes like FISPACT. As a result, the real variation of the long-term activation properties like the dose rate narrows down to about two orders of magnitude for the major materials groups like f/m-steels, vanadium alloys and SiC/SiC ceramic composites.

9.7. Summary of discussion session

The following issues are pointed out for further study.

(1) It is necessary to evaluate and develop LAMs from the aspects of accidental and environmental safety along with LAMs for minimizing the long-term activation.

(2) The international standard criteria for waste disposal and recycling will be required.

(3) Nuclear data file, FENDL, of which contents are world-widely selected under IAEA/NDS coordination will be improved and utilized as a common library for the evaluation of induced activation.

(4) Data for irradiated material should be accumulated for all candidate low activation materials. The industrial base and fabrication experience are required for vanadium alloys and SiC/SiC composites.

(5) The efforts purifying the candidate materials with an industrial scale will be expected.

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