Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Journal of Nuclear Materials 329–333 (2004) 1610–1614
journal of nuclear materials
www.elsevier.com/locate/jnucmat

Waste management for JAERI fusion reactors

K. Tobita [a,*], S. Nishio [a], S. Konishi [b], S. Jitsukawa [c]

[a] Naka Fusion Research Establishment, Japan Atomic Energy Research Institute, 801 Mukouyama, Naka-machi, Naka-gun, Ibaraki 311-0193, Japan
[b] Institute of Advanced Energy, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan
[c] Tokai Research Establishment, Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki 311-1195, Japan

Abstract

In the fusion reactor design study at Japan Atomic Energy Institute (JAERI), several waste management strategies were assessed. The assessed strategies are: (1) reinforced neutron shield to clear the massive ex-shielding components from regulatory control; (2) low aspect ratio tokamak to reduce the total waste; (3) reuse of liquid metal breeding material and neutron shield. Combining these strategies, the weight of disposal waste from a low aspect ratio reactor VECTOR is expected to be comparable with the metal radwaste from a light water reactor (~4000 t).
© 2004 Elsevier B.V. All rights reserved.

1. Introduction

Whether an energy source is accepted by the public or not is determined by various aspects such as costs, safety, environmental impacts, mineral resources and waste. Environmental awareness in recent years provokes thought that waste is no more a matter of backend but a matter of Earth resources. In this sense, a philosophy of waste management will become more important than ever, in order to acquire the public acceptance of fusion in the future energy market.

Recent studies in waste management have focused on a minimization of the radiotoxicity and a reduction of the volume of the radioactive waste, attempting to find a solution by introducing the concept of 'clearance', by recycling of radioactive waste under regulatory control and by eliminating detrimental impurities in material [1–8]. Our research reported in this article is on common ground with these ideas. This article, however, presents different waste management strategies: (1) reinforced shielding; (2) compact reactor; and (3) reuse of tritium breeding material and neutron shield.

2. Calculation of waste

2.1. Fusion reactors and waste management

Table 1 lists a lineup of fusion reactors designed at JAERI since 1990. Waste management study for these reactors is not systematic but indicates the impact of various waste management strategies. For SSTR [9], 'clearance' was introduced to reduce radwaste. In order to reduce radwaste further, the impact of reinforced shield was investigated for A-SSTR2 [10]. For DEMO-2001 [11], possible tailoring of chemical composition and impurity content in F82H to avoid deep land burial was studied, which is out of scope in this paper. In VECTOR [12], impacts of compactness of reactor and reuse of radwaste were investigated.

2.2. Calculation and classification of waste

The induced activation of waste is calculated with the 1D toroidal model. Using the neutron spectrum obtained with ANISN, the induced activation of waste is calculated with a DCHAIN-SP 2001 code [13] with the

* Corresponding author. Tel.: +81-29 270 7520; fax: +81-29 270 7468.
E-mail address: tobitak@fusion.naka.jaeri.go.jp (K. Tobita).

0022-3115/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.jnucmat.2004.04.139

Table 1
Comparison of fusion reactors designed at JAERI

	SSTR[a]	A-SSTR2[a]	DEMO-2001[a]	VECTOR
Designed	1990–1992	1999–2001	2000–2001	2002-
Feature	F82H, water-cooled Li_2O/Be First steady state tokamak reactor	SiC/SiC He gas-cooled Li_2TiO_3/Be High power density with a high field/No center solenoid	ODS steel SCP water Li_2TiO_3/$Be_{12}Ti$ DEMO followed by A-SSTR2	SiC/SiC cool-ant(TBD) LiPb Compact supercon-ducting low-A reactor
R_p (m)	7	6.2	5.8	3.75
a (m)	1.75	1.5	1.5	1.9
B_T (T)	9	11	9.5	$\sim$5
P_{fus} (GW)	3.0	4.0	2.3	2
Weight (t)	27 600	27 750	28 760	12 406
Assessed waste manage	Clearance introduced	Reinforced shield	Composition and impurity control of F82H	Compactness, reuse of radwaste

[a] SSTR series.

FENDL/A-2.0 library. The induced activation of the poloidal field coils and cryostat is estimated using the neutron spectrum at the surface of the outer vacuum vessel.

It is assumed that fusion reactors are operated for 30 years at the availability of 80% and that the replaceable blankets are changed over at every two years during the operation. Classification of waste is carried out at 50 years after the decommissioning of each reactor.

We assume that criteria for fission power plants are applicable to classify fusion waste. According to the criteria, the waste categorized as low level waste (LLW) can be disposed of by shallow land burial; for that labeled as medium level waste (MLW), waste management by deep land reposition is required. MLW corresponds to 'high-$\beta\gamma$ low level' waste in the Japanese regulation. Clearance waste (CLW), regarded to have negligible waste hazard, would qualify for disposal as the waste exempted from regulatory control. The clearance levels used in this paper is based on our assessment considering the critical paths used in Japan for ingestion and inhalation of radioactive species. Most of the clearance levels are almost the same as the values suggested by IAEA [14].

3. A-SSTR2: reinforced shielding

In order to improve a value of fusion waste, it is important to increase the fraction of CLW so that a possible recycling market of the waste is expected to expand. When we apply the concept of CLW to SSTR, radwaste is reduced to about two thirds of the waste of the reactor: 2500 t of MLW, 15 000 t of LLW and 10 100 t of CLW. Although the introduction of CLW has an impact on waste management, it should not be overlooked that radwaste of 17 500 t would be still produced. An important point is that significant parts of radwaste originate from the outside of the neutron shield. This is because the thickness of neutron shielding is determined to function superconducting magnets under neutron environment. Since the ex-shield components are relatively massive, clearing them out of regulatory control has a tremendous impact to reducing radioactive waste. This can be realized by reinforcing the neutron shield enough to protect the outer components from considerable activation as shown in Fig. 1.

Applying this strategy to A-SSTR2, an extra neutron shield of 1140 t is required [15]. The impact of the reinforced shield is depicted in Fig. 2, indicating that all ex-shield components have a qualification as CLW. A-SSTR2 uses VH_2 or TiH_2 as shielding material to obtain sufficient shielding performance in a limited space in that, by numerical calculations, VH_2 and TiH_2 surpass ferritic steel-water in the attenuation of neutron flux per thickness. When the reinforced shield is applied to a

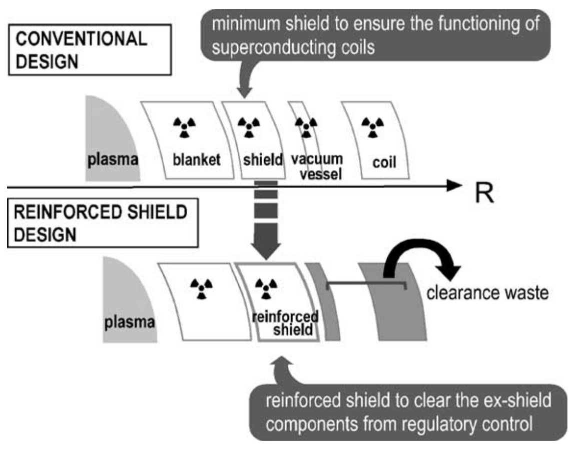

Fig. 1. Comparison between the conventional shield and reinforced shield.

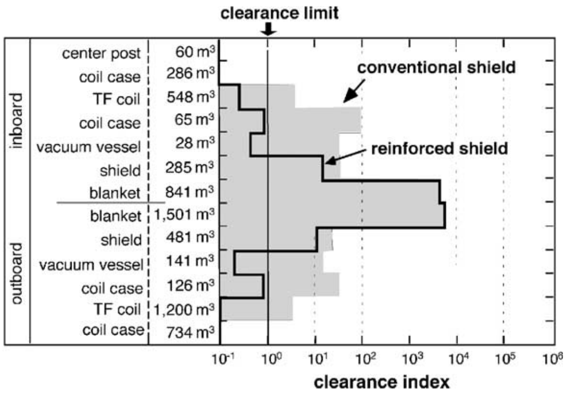

Fig. 2. Comparison of clearance index for structural components of A-SSTR2 between the original design and the new design adopting reinforced shielding.

compact reactor, the radial build does not always permit such reinforcement on the inboard side. In that case, applying the reinforced shield only on the outboard side would be effective.

4. VECTOR: compactness and reuse of radwaste

4.1. Impact of the reactor weight by pursuit of a compact reactor

Pursuing a compact reactor is of prime importance not only in waste management but in cost of electricity. In the past decade, JAERI had conducted fusion reactor design in the series of SSTR. An important lesson learned from the design activities is that a high field reactor can achieve high power density at a small major radius (R_p) with feasible plasma parameters but that the amount of required resources does not decrease even in smaller R_p, as indicated in Table 1. In such a reactor, the magnetic energy stored in the toroidal field coils becomes enormous, thus requiring massive coil support structure.

Recently, search for reactor parameters found that a very compact reactor is envisioned with feasible plasma parameters in low aspect ratio ($=R_p/a$) regime. A reactor concept derived from this design study is VECTOR [12], which is a superconducting tokamak reactor with the aspect ratio of 2.0–2.3. Its weight is 12 406 t, being about 60% of that of SSTR series with the conventional aspect ratio of ~4. Such a reduction of the weight would be significant cost advantage. The classification and waste weight for each components of VECTOR are listed in Table 2 when the reinforced shielding is applied only on the outboard. The weight of radioactive waste amounts to 7089 t, being more than that for A-SSTR2 (5000 t). The tritium breeding material for VECTOR (LiPb) is heavier than those for A-SSTR2 (Be and Li_2TiO_3). Taking this into account, the radioactive waste for VECTOR and A-SSTR2 can be said comparable. In this context, it is concluded that the significance of reducing reactor weight is to decrease the total amount of waste but that the amount of radioactive waste is less dependent of the total reactor weight. Therefore, a key to improving the quality of fusion waste is to resolve how we recycle or reuse the radioactive waste.

4.2. Reuse of radioactive waste

One of waste management strategies to reduce the amount of disposal waste is recycling of radwaste under regulatory control. For this purpose, the contact dose rate of radioactive waste must be less than about 10 mSv/h so that recycling processes can be feasible by remote handling or by hands-on. Assessment for SEAFP in Ref. [16] indicates that most of the material can be cleared from regulatory control, or recycled under the dose rate. According to our assessment, the contact dose

Table 2
Breakdown of waste from VECTOR

Component	Weight (t)		
	MLW	LLW	CLW
Toroidal field coils	–	272 (in.)	924 (out.)
Coil case (JK2)	–	308 (in.)	354 (out.)
Vacuum vessel (F82H)	–	76 (in.)	547 (out.)
Shield (TiH_2)	361 (in.)	1333 (out.)	–
Blanket structure (SiC/SiC)	19	1020	–
Breeder ($Pb_{83}Li_{17}$)	3700	–	–
Poloidal field coils	–	–	897
Cryostat	–	–	2595
Total	4080	3009	5317

(in. = inboard, out. = outboard).

rate of MLW and LLW from A-SSTR2 (SiC/SiC based) and DEMO-2001 (ODS steel based) also decreases to the recyclable level within 100 years after decommissioning as long as presently available high purity materials are used as reactor components. Consequently, almost all waste is recyclable in principle. However, this strategy has difficulties to be resolved as follows.

(1) A demand–supply balance of recycled materials seems difficult when their use is limited in a small recycle market such as nuclear facilities.
(2) Taking the successive recycles into account, deleterious impurities in recycled materials must be removed in economical recycle processes.
(3) In the processes to manufacture components for a fusion reactor, special chemical processing, precision machining and complicated installation work should be partly required by fully remote handling.

To our present knowledge, there is no evidence to give an affirmative answer to each problem above.

Considering the situation, we propose to design a fusion reactor suitable for reuse. Promising reuse components are neutron shield and liquid metal tritium breeding material. In VECTOR, LiPb is used as the tritium breeding and neutron multiplying material. At the decommissioning, LiPb is collected in a storage tank to cool down the radioactivity. The contact dose rate of LiPb after the decommissioning decreases as time evolves, dropping to $\sim$10 mSv/h within 100 years, as shown in Fig. 3. The dominant nuclides determining the contact dose rate are ^{207m}Pb and ^{207}Bi which originate from Pb. LiPb can be reused only by melting and simple compositional control. The simple processes may permit a higher contact dose rate than 10 mSv/h for reuse. The material for neutron shield adopted in VECTOR is TiH_2. The shield is composed of the assembly of steel (or

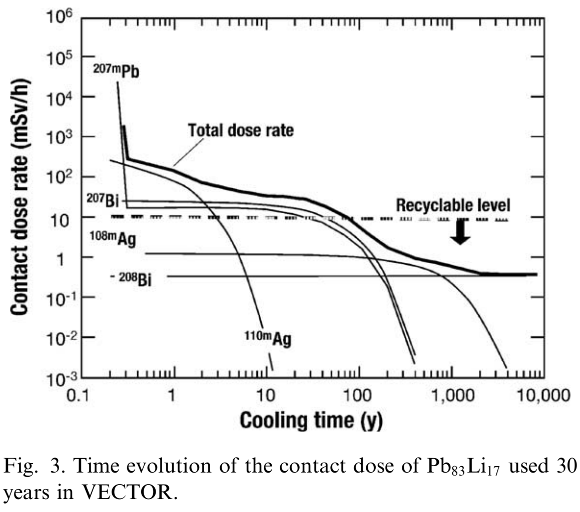

Fig. 3. Time evolution of the contact dose of $Pb_{83}Li_{17}$ used 30 years in VECTOR.

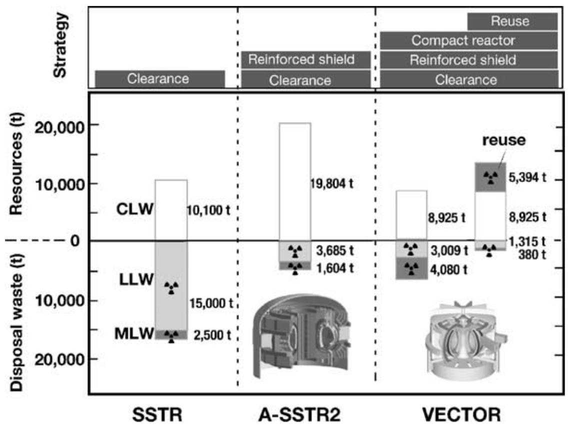

Fig. 4. Classification of waste from SSTR, A-SSTR2 and VECTOR when various waste management strategies are introduced.

SiC/SiC) containers filled with TiH_2. The contact dose rate of TiH_2 decreases to 10 mSv/h at 2 years after decommissioning. As to the neutron shield, processes needed for the installation to the next generation reactor are also expected to be simple, being suitable for reuse. Even if the shield consists of ferritic steel and water, the reuse of shield would be feasible.

When the tritium breeding material and neutron shield are disposed in once through, the spent LiPb is classified as MLW and most of the used shield must be disposed as mainly LLW and partly as MLW. In the reuse, the components do not require complicated processes for reproduction, which make the economical and technological problems insignificant. Considering these aspects, there would be much merit in reusing tritium breeding material and neutron shield. Fig. 4 shows the weights of disposal waste and reusable/recyclable waste, indicating that the minimum disposal waste is realized by the combination of the above strategies: (1) reinforced shielding, (2) a compact reactor and (3) reuse of the breeding material and neutron shield. The weight of disposal waste would be reduced to as low as 1685 t. The radwaste of ports and subsystems around the reactor, which are not included in the estimation, is expected to be a few thousands of tons. To include the additional radwaste, the total weight of disposal waste becomes comparable with the low level radwaste in metal from a light water reactor ($\sim$4000 t).

5. Summary

Practical strategies to reduce disposal waste from fusion reactors were proposed on the basis of fusion reactor designs at JAERI. The main points are summarized as below.

(1) We proposed to consider that the role of the neutron shield is to protect the outer structural components from considerable activation. Although this requires an extra neutron shield of 1000–2000 t, massive ex-shield structural components can be cleared from regulatory control.
(2) Low aspect ratio tokamak would reduce the total amount of resources to construct a reactor, indicating that it can contribute to reducing the total waste. From the point of view of Earth resources, this type of reactors has a significant advantage.
(3) A possible strategy to reduce disposal waste is to design a fusion reactor suitable for reuse of the breeding material and neutron shield. When LiPb is used as the breeding material, it would be reused in the next generation reactor without complicated remote recycling and machining processes. In the reuse of neutron shield, only simple processes would be required, as well.

References

[1] C.R. Gommer et al., Fusion Eng. Des. 11 (1990) 423.
[2] D.A. Petti et al., Fusion Eng. Des. 51&52 (2000) 435.
[3] M. Zucchetti et al., Fusion Eng. Des. 54 (2001) 635.
[4] P. Rocco, M. Zucchetti, Fusion Eng. Des. 58&59 (2001) 979.
[5] A.G. Serikov, R.A. Forrest, Fusion Eng. Des. 51&52 (2000) 617.
[6] W. Gulden et al., Fusion Eng. Des. 51&52 (2000) 419.
[7] H.W. Scholz et al., J. Nucl. Mater. 212–215 (1994) 655.
[8] E.T. Cheng, G. Saji, J. Nucl. Mater. 212–215 (1994) 621.
[9] M. Kikuchi, Nucl. Fusion 30 (1990) 265.
[10] S. Nishio et al., J. Plasma Fusion Res. 78 (2002) 1218.
[11] S. Konishi et al., Fusion Eng. Des. 63&64 (2002) 11.
[12] S. Nishio et al., Proc. 19th IAEA Fusion Energy Conf. Lyon, 2002 FTP1/21.
[13] T. Kai et al., DCHAIN-SP 2001: High Energy Particle Induced Radioactivity Calculation Code, JAERI-Code 2001-016, 2001, (in Japanese).
[14] International Atomic Energy Agency, 'Clearance levels for radionuclides in solid materials; Application of exemption principle – Interim report for comment', IAEA-TECDOC-855, 1996.
[15] K. Tobita et al., J. Plasma Fusion Res. 77 (2001) 1035.
[16] I. Cook et al., Fusion Eng. Des. 51&52 (2000) 409.