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Some technological problems of fusion materials management

Boris N. Kolbasov[a,*], Laila El-Guebaly[b], Vladimir I. Khripunov[a], Youji Someya[c], Kenji Tobita[c], Massimo Zucchetti[d]

[a] National Research Center “Kurchatov Institute”, Moscow, Russia
[b] University of Wisconsin-Madison, Madison, WI, USA
[c] Japan Atomic Energy Agency, Japan
[d] EURATOM/ENEA Fusion Association, Politecnico di Torino, Torino, Italy

HIGHLIGHTS

- We studied effect of impurities on activated materials disposal, clearance and recycling.
- We revealed that only cryostat and bioshield are clearable among fusion power core components of advanced fusion power reactor.
- Among magnet constituents only the Cu stabilizer could be cleared shortly after plant shutdown.
- Recycling is the only viable option to avoid disposing the activated PFC materials and to minimize the radioactive waste volume assigned for underground repositories.
- Production of ^{14}C may cause problems for radioactive waste management.

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ABSTRACT

Within the framework of the International Energy Agency Program on Environmental, Safety and Economic Aspects of Fusion Power, an international collaborative study on management of fusion radioactive materials has been carried out to examine the back-end of the materials cycle. The strategy for handling fusion activated materials calls for three potential schemes: clearance, recycling and disposal. There is a growing international effort to avoid the underground disposal, for fusion in particular. Plasma facing components (divertor and blanket) normally contain high radioactivity and are not clearable. As clearance of sizeable components (such as biological shield, cryostat, vacuum vessel, and some constituents of magnets) is highly desirable, we identified the source of radioisotopes that hinder the clearance of these components and investigated the impact of impurity control. Another study assessed radioactivity build-up under repeated use of the divertor made of W–La_2O_3 alloy. Effect of impurities on activated materials management is illustrated by the examples of carbon-14 generation and impurities activation in concrete of biological shield. We think that consideration of activated materials management scenarios presented in this paper by example of blanket and divertor replacement is of interest as well.

1. Introduction

An international collaborative study on fusion radioactive materials management to examine a back-end of the materials cycle has been carrying out for seven years within the framework of the International Energy Agency Program on Environmental, Safety and Economic Aspects of Fusion Power. The participants of the study concentrated their efforts on different aspects of clearance, recycling and disposal of activated materials [1–5].

Fusion generates only low-level waste that qualifies for near-surface, shallow-land burial. Nevertheless, there is a growing international effort to avoid the underground disposal – for fusion in particular [2,4,6,7]. Clearance and recycling offer more environmentally attractive options through the reuse of activated materials generated during operation and decommissioning of fusion power plants (FPPs), minimizing their quantity categorized as radioactive waste needing disposal.

In principle, all the fusion component materials, could potentially be recycled [2,4,6,7] providing that advanced radiation-resistant remote handling equipment is capable of handling doses ≥10 kSv/h and could also be adapted for fusion use (component size, weight, etc.), although certainly in some cases recycling will require overcoming essential difficulties related to refabrication of large, and complex components made of radioactive materials. Meanwhile, the experience gained from advanced MOX fuel technology will be of great importance to fusion [6].

* Corresponding author. Tel.: +7 4959471100; fax: +7 4999430073.
E-mail addresses: kolbasov@nfi.kiae.ru, bkolbasov@yandex.ru (B.N. Kolbasov).

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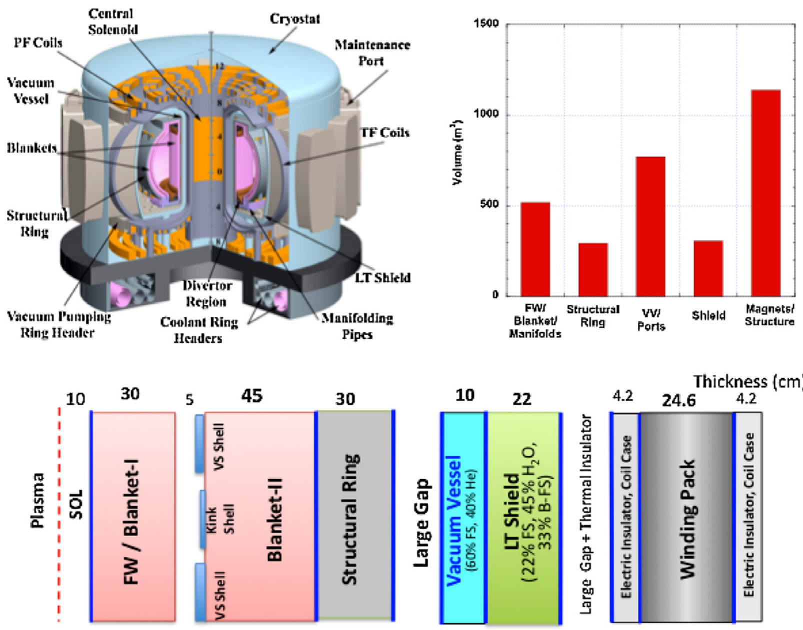

Fig. 1. ARIES-ACT-1 isometric, volumes of fusion power core components and OB radial build; VS – vertical stabilization, LT – low temperature.

Supply of fusion power engineering with some scarce materials without recycling is impossible. For example, it is necessary to bear in mind that world identified resources of beryllium are on the level of 80,000 t. World production of beryllium in 2012 was 230 t [8]. Amount of beryllium required for FPP PPCS-B (considered in frames of European Power Plant Conceptual Study – PPCS) is 560 t [9]. This amount of beryllium should be replaced every 5 years due to irradiation induced swelling.

Two assumptions were made in this report:

- for the demonstration reactors and FPPs of the first generation we considered present-day materials with minimum impurity contents reached by the industry.
- for the advanced FPPs of the second generation, e.g. for the ARIES (Advanced Research Innovation and Evaluation Study) designs [10], the materials with the lowest impurity content ever achieved in large-scale fabrication practices or restricted by technological requirements were considered.

Unfortunately, present-day materials often do not meet FPP requirements, in particular with respect to impurities concentration (e.g. U in beryllium, Nb, Co, Mo, Ag, N in beryllium and in other materials).

2. Radioisotopes hindering clearance of fusion components

Fig. 1 illustrates the isometric view of ARIES-ACT-1 – the most recent FPP design in the ARIES series [10]. All its components operate for ~50 years with 85% availability, except the first wall (FW), blanket-I and divertor (replaceable every ~5 years). The neutron wall loading averages 3.4 MW/m^2 at the outboard (OB) FW.

IAEA clearance indices (CIs) [11] for selected OB components are displayed in Fig. 2.

The CI of the shield, not shown in the figure, follows that of the vacuum vessel (VV), but at a slightly lower value. As noticed, only the cryostat and bioshield are clearable when their CIs drop to unity (for concrete of bioshield at ~1 year and for cryostat at ~70 years after plant shutdown). Even though the magnet is well protected by the blanket, VV and shield, it is not clearable even after 100 years of storage. Examining its individual components

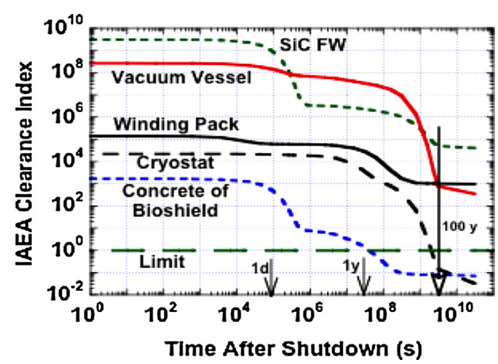

Fig. 2. Clearance indices of fully compacted OB components of ARIES-ACT-1.

(75% JK2LB steel structure, 12% Cu stabilizer, 2% Nb_3Sn conductor, 2.5% electric insulator, and 8.5% liquid He, by volume) reveals that the CI of Nb_3Sn conductor is the dominant and only the copper stabilizer could be cleared shortly after plant shutdown, as shown in Fig. 3.

A frequently asked question is: what materials or impurities deter the clearance of the VV and shield? It would be beneficial

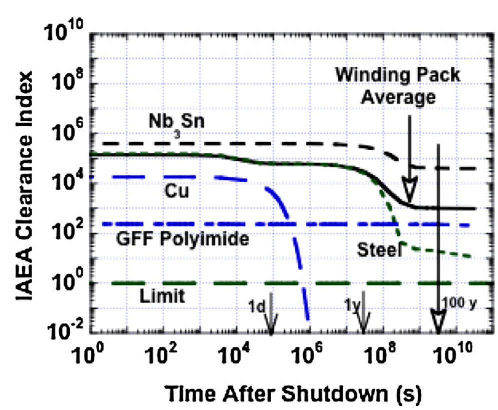

Fig. 3. CI of OB magnet constituents.