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July 2009

UWFDM-1373

Proceedings of 9th IAEA Technical Meeting on Fusion Power Plant Safety, July 15-17, 2009, Vienna, Austria. To be published by IAEA..

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Integrated Management Strategy for Fusion Activated Materials: US Position and Regulations

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Abstract

The vast majority of fusion designs developed to date demonstrated adequate performance in several safety and environmental areas. However, the potential problem of handling the anticipated quantities of activated fusion materials has been overlooked in many past studies and/or relegated to the back-end as only a disposal issue. The geological disposal is not an environmentally attractive option. Here, we propose an integrated management strategy that can handle the sizable, mildly activated materials and minimize the radwaste burden for future generations. Demo and power plant designs should consider recycling and clearance as much as practically possible. It is just a matter of time to develop the recycling/clearance technology and regulations. Internationally, numerous fission industries are currently developing advanced techniques for spent fuel reprocessing and several regulatory agencies have issued guidelines for the free release of clearable materials. Both developments will be of great importance to fusion.

1. Introduction

There is a worldwide interest in building fusion Demos and commercial power plants by 2020-2050 [1]. With regard to the environmental impact of such plants, the pressing question is: what should we do with the activated materials generated during operation and after decommissioning? Even though fusion offers salient safety advantages relative to other sources of energy, the expected sizable quantity of mildly activated materials tends to rapidly fill the low-level waste repositories [2,3]. At present, many US utilities that operate fission power plants store their low and high level radwastes onsite due to the limited and/or expensive offsite disposal option. Fusion cannot follow that precedent as burying large volumes of fusion activated materials in geological repositories is impractical. Alternate, more environmentally attractive approaches should be developed and incorporated at early design stages of fusion Demo and its successor power plants. The recycling (reuse of activated materials within the nuclear industry) and clearance (release to the commercial market, if materials contain only slight traces of radioactivity) approaches emerged as the only viable solution that mitigates concerns about the environment, radwaste burden for future generations, limited capacity of existing repositories, high disposal cost, and political difficulty of constructing new repositories.

Ever since the late 1990s, the three scenarios for managing fusion active materials (disposal, recycling, and clearance) have been applied to selected fusion power plant studies [2-6]. The recycling and clearance approaches became more technically feasible in recent years with the development of radiation-resistant remote handling (RH) tools and the introduction of the clearance category for slightly radioactive materials by the International Atomic Energy Agency (IAEA) and other national nuclear agencies. Most radioactive materials generated during fusion power plant operation are activated solid metallic materials from the main machine components and concrete from the biological shield, assuming liquid tritium breeders (such as LiPb, Li, and Flibe) are refurbished for reuse by future fusion devices. The dominant radioactive material mass stream is generated during the decommissioning stage (if we include the bioshield), but a significant amount – as far as radioactive inventory is concerned - is also produced during routine blanket and divertor replacements. A great deal of the decommissioning materials (up to 80%) has a very low activity concentration and can be cleared from regulatory control, especially when an extended period (up to 100 y) of interim storage is anticipated. The remaining 20% of the active materials could be disposed of as low-level waste (LLW) or preferably recycled using a combination of advanced and conventional RH equipment [2]. Most fusion active materials contain tritium that could introduce serious complications to the recycling process. A detritiation treatment prior to recycling is imperative for fusion components with high tritium content.

2. Status of US Repositories

The US has a few radioactive waste repositories open for disposal of commercial LLW [7]. The LLW repositories are located at Barnwell, South Carolina; Richland, Washington; and Clive, Utah (see Fig. 1). Barnwell and Richland are decades-old facilities; they accept A, B, and C LLW per 10CFR61.55 federal regulations. The Clive facility opened in 2001 and only accepts Class A waste, which is the least radioactive class of LLW. In June 2009, Waste Control Specialists, LLC, received an operating license for a new LLW facility near Andrews, Texas for Class A, B, and C LLW, and mixed LLW (that is, chemically toxic and radioactive LLW) [8]. However, the facility has a compact (a legal agreement) to serve the States of Texas and Vermont, as well as the federal government. This new facility may be able to accept 'out-of-compact' LLW. When new buildings are constructed at the site the Andrews facility can begin accepting LLW in late 2010 [8]. In mid-2008, the South Carolina legislature restricted waste acceptance by the Barnwell LLW facility to just its original three member states of South Carolina, New Jersey and Connecticut. This restriction left 36 states without access to a Class B or C low-level waste repository. The US Nuclear Regulatory Commission agreed to allow the nuclear power plants in affected states to store their LLW on site as an interim measure until a solution is found for the Barnwell closure. The Andrews facility may be able to accept the Class B and C LLW from these plants.

The US has one deep geologic storage repository, the Waste Isolation Pilot Plant (WIPP), outside Carlsbad, New Mexico. The WIPP opened in March 1999 and stores transuranic waste generated primarily from the nuclear weapons program. The WIPP storage areas are over 2,100 feet below the earth's surface. Another deep geologic repository, the Yucca Mountain Project (YMP), has been under development at Yucca Mountain, Nevada. The YMP was slated to store spent nuclear fuel from commercial nuclear power plants. In early 2009 the executive branch determined that the YMP, under development for twenty years at a cost of over $9B, was not politically viable and the project was not funded. A new search for a suitable site has been initiated by the Department of Energy. In the interim, the US Nuclear Regulatory Commission has approved 55 Independent Spent Fuel Storage Installation sites in the US. These are HLW storage and are mainly located at power plant sites, but also include the Idaho National Laboratory and one company, Private Fuel Storage in Utah [7].

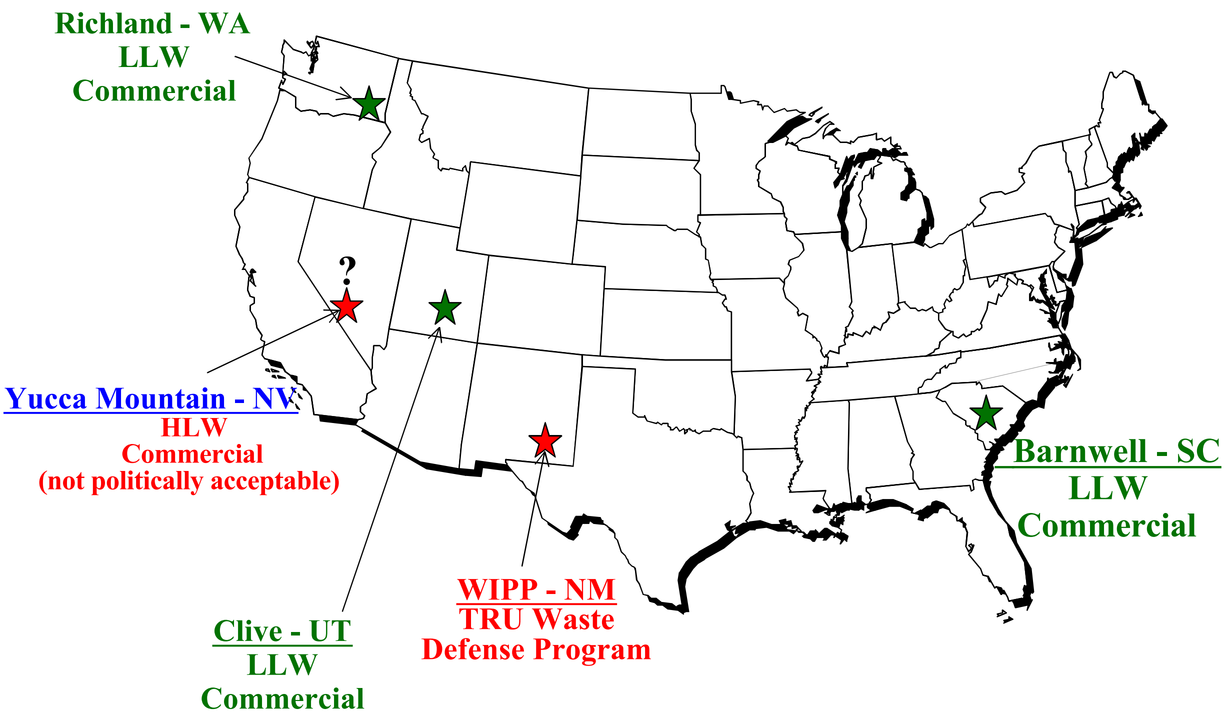

Figure 1. LLW and HLW commercial repositories in US.

3. US Industrial Experience with Recycling

The US metals industry is reluctant to accept metals that have been contaminated with any amount of radioactivity [9,10]. The US national laboratories and a US commercial firm have had successes with recycling within the nuclear industry: making lead-shielded steel casks from radioactive materials, casting lead shielding bricks from contaminated lead, and recycling surface contaminated and volumetrically activated scrap metals. Recycling within the nuclear industry has been proven to be viable and economical, and this approach is currently believed to be the best path forward [11,12]. Recycling into the nuclear industry means the materials are placed back into radiologically controlled environments where they are monitored. However, at present, the EnergySolutions company's induction furnace for melting radioactive scrap metal can only process on the order of 8,000 tons a year. A second company, Bull Run Metal, began fabricating waste containers in 2005 [11]. These containers are fabricated with recycled lead; 3,000 casks per year for five years, which means use of more than 5,000 tons of formerly contaminated lead each year. These steps are promising; however, the radioactive scrap metal generated by US decontamination and decommissioning (D&D) activities is much greater in quantity.

The other major constituent of mildly radioactive waste is concrete from D&D of buildings and structures. Considering that the concrete-and-rebar cooling tower at the Trojan fission power plant weighed about 41,000 tons, the amount of concrete to be disposed of is quite large at nuclear facilities. A typical pressurized water reactor might have a total of 69,500 cubic meters (~184,000 tons) of mildly radioactive concrete. The DOE also has large amounts of used concrete for disposal, roughly estimated to be more than a million cubic meters or 2.6 million tons. On-site disposal and unrestricted landfill disposal of concrete remain the primary methods used in the commercial industry. This concrete could be used in roadbeds, as aggregate in new concrete, or for other construction purposes.

4. NRC Clearance Guidelines

During the decade of the 1940s and continuing to the present, the Nuclear Regulatory Commission (NRC) and its predecessor agency have attempted to develop and give greater uniformity to the clearance standards while materials containing traces of radioactivity continued to be released to date on a case-by-case basis. More attempts by the NRC in the 1980s, 1990s, and just recently in 2003 declared materials with low concentrations of radioactivity could be deregulated [10]. Based on a detailed technical study, the NUREG-1640 document [13] contains estimates of the total effective dose equivalent (from which the clearance index can be derived) for 115 radionuclides that could be present in activated steel, copper, aluminum, and concrete from decommissioning of nuclear facilities. The NRC has not yet issued an official policy on the unconditional release of specific materials. Herein, the proposed annual doses reported in the NUREG-1640 document will be referred to as the proposed US limits.

5. Key Recycling/Clearance Issues and Needs

To enhance prospects for a successful integrated management strategy, we identified the key issues and needs for recycling and clearance. As a step forward, the US R&D program should tackle these issues, allowing further optimization of the radwaste management scheme and enhancing the possibility of recycling and clearance as much as practically possible.

5.1. Recycling issues and needs

Issues:

- Separation of various activated materials from complex components (such as magnets)
- Radiochemical or isotopic separation processes for some materials, if needed
- Treatment and remote re-fabrication of radioactive materials
- Radiotoxicity and radioisotope buildup and release by subsequent reuse
- Properties of recycled materials? Any structural role? Reuse as filler?
- Handling of T containing materials during recycling
- Management of secondary waste. Any materials for disposal? Volume? Radwaste level? Burn of long-lived products in fusion facilities [14]?

- Energy demand for recycling process
- Cost of recycled materials
- Recycling plant capacity and support ratio

Needs:

- R&D program to address recycling issues
- Radiation-resistant remote handling equipment for fusion use
- Reversible assembly process of components and constituents (to ease separation of materials after use)
- Efficient detritiation system
- Large and low-cost interim storage facility with decay heat removal capacity
- Nuclear industry should accept recycled materials
- Recycling infrastructure.

5.2. Clearance issues and needs

Issues:

- Discrepancies between proposed US-NRC & IAEA clearance standards [10]
- Impact on clearance index prediction of missing fusion radioisotopes [10] (such as ^{10}Be, ^{26}Al, ^{32}Si, ^{91,92}Nb, ^{98}Tc, ^{113m}Cd, ^{121m}Sn, ^{150}Eu, ^{157,158}Tb, ^{163,166m}Ho, ^{178n}Hf, ^{186m,187}Re, ^{193}Pt, ^{208,210m,212}Bi, and ^{209}Po)
- Radioisotope buildup and release by subsequent reuse.

Needs:

- Official fusion-specific clearance limits issued by legal authorities
- Accurate measurements and reduction of impurities that deter clearance of in-vessel components
- Reversible assembly process of components and constituents
- Large and low-cost interim storage facility
- Clearance infrastructure
- Clearance market (Some experience exists in several EU countries: Sweden, Germany, Spain, and Belgium. At present, US industry does not support unconditional clearance claiming it could erode public confidence in US products and damage US markets) [10,2].

6. Maturation of Recycling and Clearance Approaches

The fusion program should start now developing a recycling approach before designing/building Demo (by 2030-2050) and a clearance approach before decommissioning power plants (by ~2100), hoping that the US will be progressive with respect to recycling/clearance perspectives. As such, we recommend the following general guidelines for the maturation of the recycling and clearance approaches:

Fusion designers should:

- Minimize radwaste volume by clever designs
- Promote environmentally attractive scenarios such as recycling and clearance, avoiding geological disposal
- Continue addressing critical issues for all three options
- Continue developing low-activation materials (specifications could be relaxed for some impurities while more stringent specs will be imposed on others to maximize clearance)
- Accurately measure and reduce impurities that deter clearance of in-vessel components
- Address technical and economical aspects before selecting the most suitable radwaste management approach for any fusion component.

Nuclear industry and regulatory organizations should:

- Continue developing advanced radiation-resistant remote handling equipment capable of handling > 10,000 Sv/h that can be adapted for fusion use
- Consider fusion-specific materials and issue official guidelines for unconditional release of clearable materials
- Accept recycled materials from dismantled nuclear facilities
- Continue national and international efforts to convince industrial and environmental groups that clearance can be conducted safely with no risk to public health.

7. General Remarks

Numerous fusion studies indicated recycling and clearance are technically feasible for any fusion device employing low-activation materials, using advanced radiation-resistant remote handling equipment, and having clearance guidelines for slightly radioactive materials. However, such approaches are relatively easy to envision and apply from a science perspective, but a real challenge, particularly in the US, from policy, regulatory, and public acceptance perspectives. To make these approaches a reality, major rethinking, education, and research should be developed and pursued. In the near future, the US fusion development program should be set up to accommodate this new recycling/clearance strategy as proper handling of activated materials is important to the future of fusion energy.

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