Recycling and Clearance of the Slightly Activated RTLs of the 2005 Z-Pinch Design

L.A. El-Guebaly, P. Wilson, M.E. Sawan

October 2005

UWFDM-1284

FUSION TECHNOLOGY INSTITUTE

UNIVERSITY OF WISCONSIN

MADISON WISCONSIN

Recycling and Clearance of the Slightly Activated RTLs of the 2005 Z-Pinch Design

L.A. El-Guebaly, P. Wilson, M.E. Sawan

Fusion Technology Institute
University of Wisconsin
1500 Engineering Drive
Madison, WI 53706

http://fti.neep.wisc.edu

October 2005

UWFDM-1284

1. Introduction

The transition to a more advanced Z-pinch design involved several changes to the chamber and RTL parameters that warrant updating the previous activation and waste stream analyses [1-3]. Table 1 documents the changes that impact such analyses. The most notable changes relate to the height of the RTL and its reprocessing time. Other design parameters and radiation limits that are essential for this assessment are presented in Table 2.

The main goal of the waste management task is to classify the radwaste materials into high-level waste (HLW) and low-level waste (LLW). For the latter, we further distinguished between radioactive waste and slightly activated materials. As the 2000s began, many countries have successfully issued clearance guidelines that allow solids containing traces of radioisotopes (such as the RTLs) to be cleared from regulatory control and unconditionally released to the nuclear industry (or commercial market) for reuse after a specific storage period (≤ 100 y). With the emergence of the new clearance standards in the US and abroad, we included both the national [4] and international [5] standards in our analysis and assessed the implications for the Z-pinch power plant.

The 3-D Monte Carlo MCNP code [6] has been used to compute the average neutron flux over the 2 m high RTL. It amounts to 7×10^{15} n/cm^{2}s and 1×10^{16} n/cm^{2}s for the Flibe and LiPb chambers, respectively. The spectral flux, displayed in Fig. 1, was coupled to the pulsed activation code ALARA [7] to estimate the activation responses, such as the radioactive inventory, waste disposal rating (WDR), clearance index (CI), dose to recycling equipment, etc. Despite the differences in the magnitude and spectrum of the Flibe and LiPb fluxes at the 2 m high RTL, the impact on the activation responses is negligible. The RTL material plays an essential role in the analysis. The reference material is the low-cost, easy-to-fabricate carbon steel (99.1 wt% Fe, 0.08 wt% C, 0.32 wt% Mn, 0.04 wt% P, and 0.05 wt% S).

As Fig. 2 indicates, recycling the RTLs helps limit the life-cycle inventory to 5000 tons, representing only 1% of the total machine waste. Every 10 seconds, the RTL/target assembly is inserted into the chamber, the shot is fired, portions of the RTL evaporate and mix with the breeder/coolant, the upper remnant of the RTL is removed, and the cycle is repeated. An online separation of the elements leaving the chamber would sort out the breeder and target debris from the RTL shrapnel. The RTL materials spend ~28 hr (~1.1 d) outside the chamber for remanufacturing, assembly, and inspection. The ALARA activation code modeled all pulses (~10,000) using the spectral flux (refer to Fig. 1) distributed over the 2 m high conical RTL.

Table 1. Major differences between the 2004 and 2005 analyses that could influence the RTL activation level

	FY04 Analysis	FY05 Analysis
Analysis	**1-D**	**3-D**
RTL height	5 m	2 m
RTL neutron flux	Lower	Higher ⇒ Higher activation
Reprocessing time	1.5 day	1.1 day ⇒ Higher activation
RTL inventory	Higher	Lower

Table 2. Key design parameters for Z-pinch activation analysis

Design Parameters:	
Target Yield	3000 MJ
Rep Rate	0.1 Hz
# of Units per Plant	10
RTL Thickness	0.142 cm
Compacted Volume / RTL	0.006 m^3
Mass / RTL	50 kg
Plant Lifetime	40 FPY (47 y)
Projected Plant Availability	85%
Radiation Limits:	
Waste Disposal Rating	1
Clearance Index	1
Remote Recycling Dose	3000 Sv/h

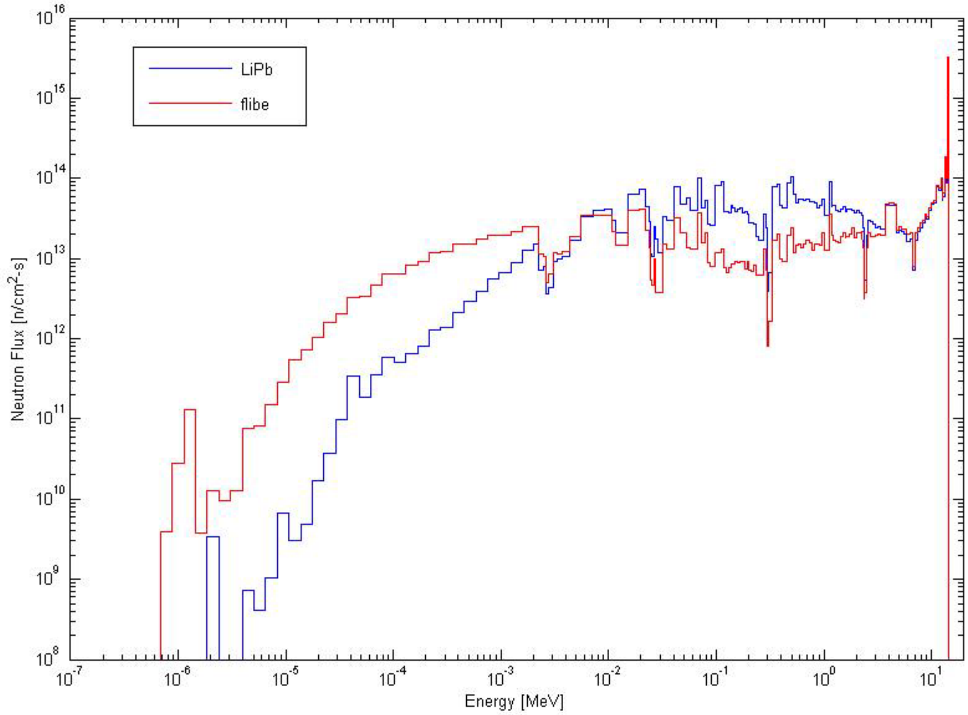

Fig. 1. MCNP calculated neutron flux at RTL for Flibe and LiPb breeder options.

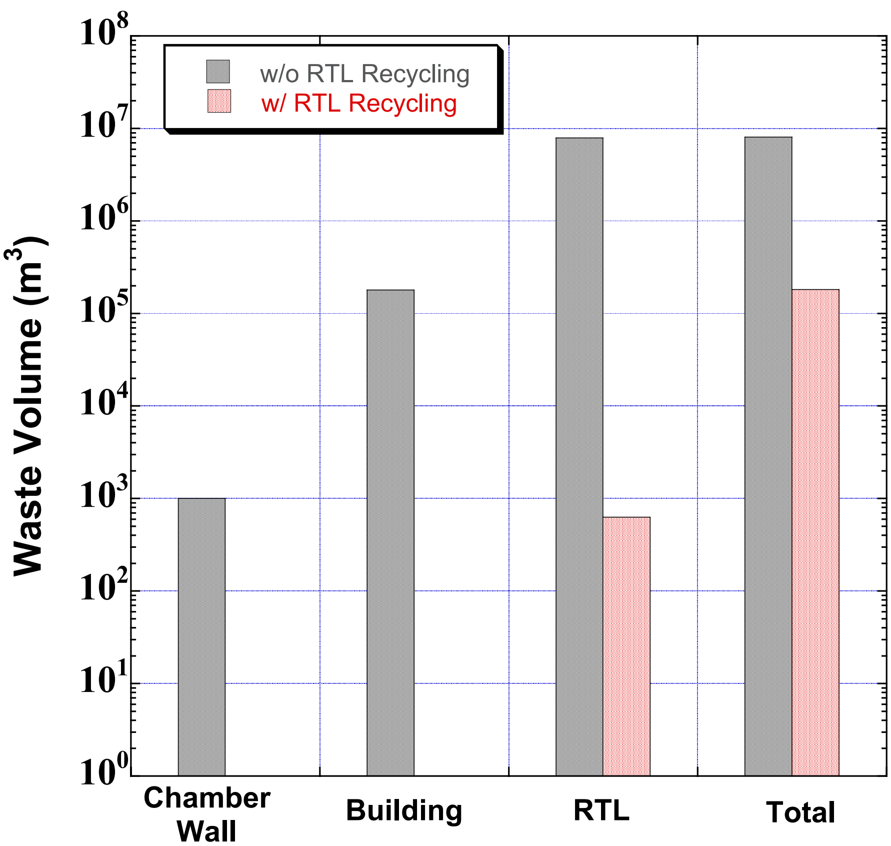

Fig. 2. RTL inventory and waste comparison.

2. Classification of RTL Activated Materials

This year's study adopted the same strategy as the previous 2004 assessment [1], applying the geological disposal, clearance, and recycling criteria to the disposition of activated materials. The disposal limits are those recommended by the US (NRC and Fetter) and IAEA. The results show that at the end of the plant life the RTLs generate a Class A very low-level waste (WDR=10^{-4}), the least hazardous type based on the US federal classification. The WDR meets the LLW limit with a wide margin. This means the RTLs contain traces of radionuclides, representing no risk to the public health and safety. Potentially, it could be cleared from regulatory control if the CI reaches unity after a certain storage period (< 100 y), and then released to the nuclear industry or commercial market for reuse. Note that the clearance offers an economic advantage as it saves substantial disposal cost for such a large quantity (5000 tons, 630 m^3) and frees ample space in the repositories for other radioactive wastes.

The variation of the RTL CI with time after decommissioning is shown in Fig. 3. The CI reaches unity after 85 y according to the US guidelines. The dominant radionuclides (in descending order) are the T (91%, $T_{1/2}$=12.3 y), ^{53}Mn (7%, $T_{1/2}$=3.7 My), and ^{60}Co (1%, $T_{1/2}$=5.3 y) for the US CI at 85 y and ^{53}Mn (87%), T (12%), and ^{14}C (0.5%, $T_{1/2}$=5.7 ky) for the IAEA CI at 100 y. During reprocessing, a considerable fraction of the tritium diffuses out of the carbon steel and thus the CI could reach unity at a shorter time (~ 50 y) as shown in Fig. 3. The results reported herein are conservative as no credit was given to the possible removal of the transmutation products during reprocessing. Continual removal of the slag (that contains some of the transmutation products) would shorten the storage period further, but accumulates a limited amount of undesirable radioactive waste that may raise radiological concerns. This issue needs further investigation.

3. Feasibility of Remote Recycling

Previous US and European power plant studies have employed recycling criteria based solely on the contact gamma dose rate, intended to reflect the ability to recycle the materials by remote handling (RH) means, if necessary. Reviews of the RH criterion suggest that the present 0.01 Sv/h limit is unduly conservative. A more realistic dose limit would be 3000 Sv/h for advanced RH equipment based on current industrial practices [8].

The impact of the revised RH criterion is illustrated in Fig. 4, showing the reduction of recycling dose with time following the removal of the RTL debris from the chamber. The main contributors to the dose at 1 day are ^{54}Mn (90%, $T_{1/2}$=312.2 d) and ^{56}Mn (9.6%, $T_{1/2}$=2.58 h). Several observations can be made:

- Hands-on recycling is not allowed
- No personnel access is permitted to the RTL fabrication facility
- RH with advanced equipment is feasible
- The dose remains below the 3000 Sv/h advanced RH limit at all times during the recycling process
- Removal of the slag and the continual addition of supplemental fresh material during reprocessing will lower the dose rate considerably.

4. Conclusions and Future Work

Unlike MFE concepts or other laser and heavy ion beam driven IFE concepts, the Z-pinch illustrates for the first time that an internal component inside the containment building contains only traces of radioactivity. This means the slightly activated 630 m^3 carbon steel can be cleared from regulatory control following a storage period of 50 y after plant decommissioning. An efficient slag removal system could shorten the storage period considerably by removing the troublesome radionuclides (^{53}Mn and ^{60}Co). The recycling process must be economically feasible with no hands-on manufacturing and in the absence of personnel access to the fabrication facility. Advanced remote handling equipment must be developed to handle 3000 Sv/h and the process should be accomplished remotely in 1.1 day. The effect of carbon steel impurities, if any, and the degradation of the RTL electrical conductivity due to neutron-induced transmutation products need further investigation. Should the RTL physics and fabrication technique permit RTLs made of non-steel materials, we strongly support fabricating the RTL out of breeding materials (Flibe or LiPb) to eliminate the need for the RTL separation process and reduce the RTL energy demand below 200 MW_e.

The online removal of the slag and continual supplement of fresh material to the RTL stream may positively impact the end results. With adequate knowledge of the efficiency of the slag removal system, isotopic inventory simulation can be used in the future to determine the changes in inventories throughout the RTL flow stream. Both ALARA [7] and MCise [9] systems are capable of handling such a problem. The newly developed MCise (Monte Carlo Isotopic Simulation Engine) system could simulate the details of the isotopic inventory with a more detailed modeling of the RTL flow, online chemistry/separations of radioisotopes, and recirculation process. A variety of calculations and analyses will be necessary to address other secondary impacts such as the waste disposal rating of the slag and the feasibility of hands-on recycling.

Acknowledgement

The work was performed under the auspices of the Sandia National Laboratory (contract #297000). The authors wish to thank C. Olson, G. Rochau, and B. Cipiti (SNL) for the helpful discussions and useful comments in preparing this manuscript.

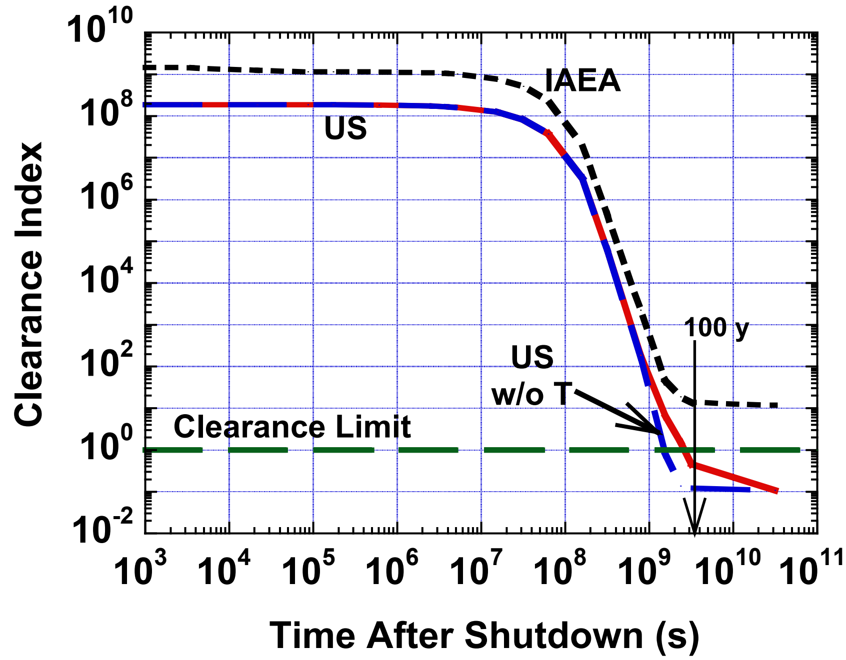

Fig. 3. Variation of RTL clearance index with time after plant decommissioning (no cooling period between shots and no removal of transmutation products).

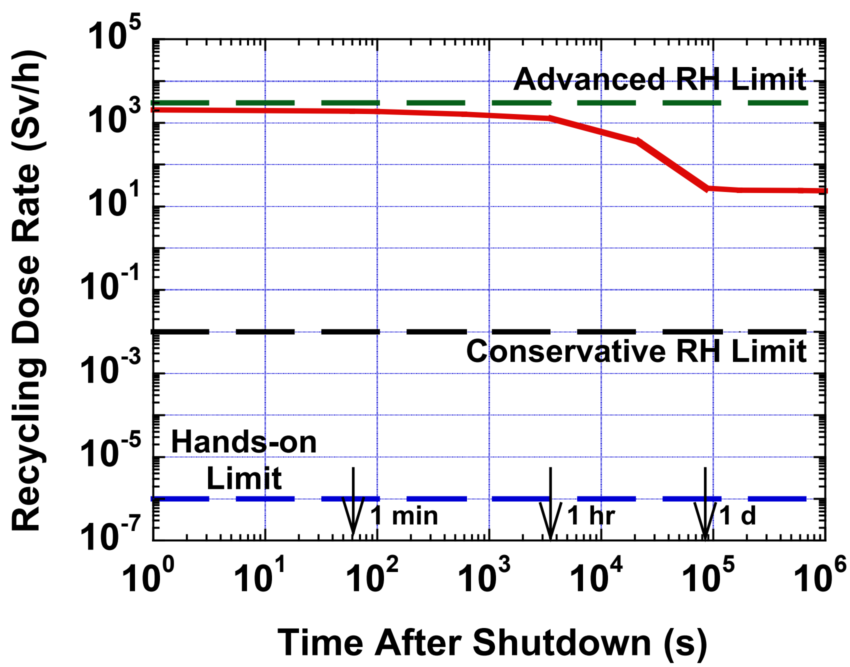

Fig. 4. Reduction of dose with time after RTL debris exits the chamber (no cooling period between shots and no removal of transmutation products).

References

[1] C. Olson, G. Rochau, M. Matzen et al., "Z-Pinch IFE Program – Final Report for FY04," Sandia National Laboratories Report, SAND-2005-2742P (April 2005).

[2] L. El-Guebaly, P. Wilson, M. Sawan, D. Henderson, and A. Varuttamaseni (invited), "Recycling Issues Facing Target and RTL Materials of Inertial Fusion Designs," Nuclear Instruments & Methods in Physics Research, Section A, **544,** 104-110 (2005).

[3] L. El-Guebaly, P. Wilson, and D. Paige, "Evolution of Clearance Standards and Implications for Radwaste Management of Fusion Power Plants," Journal of Fusion Science & Technology (Jan 2006). Also, University of Wisconsin Fusion Technology Institute Report, UWFDM-1271. Available at: http://fti.neep.wisc.edu/pdf/fdm1271.pdf

[4] Nuclear Regulatory Commission, "Radiological Assessments for Clearance of Materials from Nuclear Facilities," Washington, D.C., Main Report NUREG-1640 (2003). Available at: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1640/

[5] International Atomic Energy Agency, "Application of the Concepts of Exclusion, Exemption and Clearance," IAEA Safety Standards Series, No. RS-G-1.7 (2004). Available at: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1202_web.pdf

[6] X-5 Monte Carlo Team, "MCNP - a General Monte Carlo n-Particle Transport Code," Version 5- Volume II: users guide, LA-CP-03-0245, Los Alamos National Laboratory (2003).

[7] P. Wilson and D. Henderson, "ALARA: Analytic and Laplacian Adaptive Radioactivity Analysis Code Technical Manual," University of Wisconsin Fusion Technology Institute, UWFDM-1070 (1998).

[8] M. Zucchetti, L. El-Guebaly, R. Forrest, T. Marshall, N. Taylor, and K. Tobita, "The Feasibility of Recycling and Clearance of Active Materials from a Fusion Power Plant," Proceedings of ICFRM-12 Conference, Dec. 4-9, 2005, Santa Barbara, CA.

[9] P. Phruksarojanakun, P.P.H. Wilson, "Monte Carlo Techniques for the Comprehensive Modeling of Isotopic Inventories in Future Nuclear Systems and Fuel Cycles," University of Wisconsin Fusion Technology Institute Report, UWFDM-1282 (October 2005). Available at: http://fti.neep.wisc.edu/pdf/fdm1282.pdf