Proliferation Resistance and Physical Protection of Current Nuclear Fuel Cycles

Thomas A. Edmunds
(925) 423-8982
edmunds2@llnl.gov

Fifty years of worldwide operation of nuclear power plants has generated a large inventory of nuclear materials that must be managed responsibly. The proliferation resistance of spent fuel from past and current operations must be characterized in order to provide perspective on emerging and proposed nuclear fuel cycles. By emerging, we refer to the trend towards higher fuel burnups in existing light (LWR) and heavy water reactor fuel cycles. We also place high-temperature gas reactors and their associated tristructural isotropic coated particles (TRISO) fuel into the class of emerging nuclear fuel cycles. New nuclear fuel cycles include proposed uranium extraction (UREX) fuel cycles in which actinides in spent nuclear fuel are not separated from the plutonium in order to reduce the utility of the material for weapons use.

We measure proliferation resistance in terms of three fundamental metrics: radiation field, plutonium isotopic composition, and heat generation rates. We develop quantitative estimates of these metrics for a number of different fuel cycle materials. We also identify process operations in nuclear fuel cycles that may be a source of proliferation or theft risk.

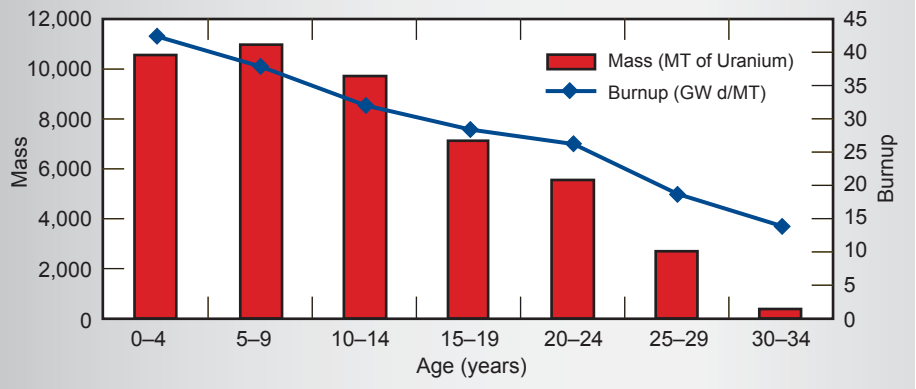

Figure 1. Characteristics of spent fuel in U.S. inventories. This figure shows that older spent fuel has lower burnup (irradiation time in a reactor). This low-burnup fuel scores lower with regard to all three proliferation resistance metrics: a lower radiation barrier, more attractive plutonium isotopics for weapons use, and lower heat generation rates.

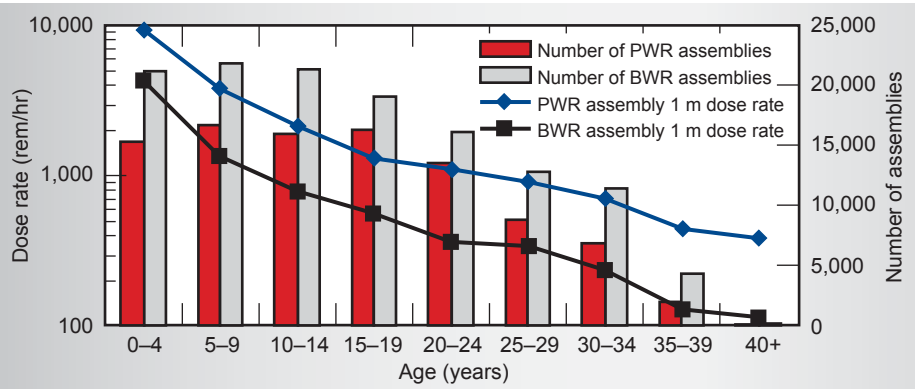

Figure 2. 2010 U.S. spent fuel assemblies and dose rates at one meter. This projection of average spent fuel properties for given vintages shows that many spent fuel assemblies will no longer have dose rates in excess of 100 rem/hr by 2010. (This is the dose rate needed to be "self-protecting" by the International Atomic Energy Administration definition.)

Project Goals

The goal of this project is to establish proliferation resistance benchmarks that can be used to assess the relative benefits of proposed nuclear fuel cycles. Characterizing existing commercial LWR fuel cycle materials and processes with regard to quantitative proliferation resistance metrics provides a reasonable benchmark. Characterizing the near-term evolution of commercial nuclear fuel cycles provides a measure of proliferation resistance goals that can be achieved within a short period of time without major structural changes in the industry.

Relevance to LLNL Mission

Nuclear nonproliferation and global climate monitoring have been longstanding missions at LLNL. Advising key government decision-makers regarding the impacts of energy policy decisions on the risks of nonproliferation and impacts on global carbon emissions requires a thorough understanding of current and proposed commercial nuclear fuel cycles.

FY2008 Accomplishments and Results

We developed estimates of spent fuel properties for a number of different nuclear fuel cycles. As indicated in Fig. 1, there is a trend towards higher burnup fuel in commercial LWRs. This higher burnup provides improved proliferation resistance. We implemented code and estimated dose rates from spent fuel derived from a number of different fuel cycles and reactor operating conditions (principally fuel burnup levels). Dose rate estimates are shown in Fig. 2 for spent fuel from LWR fuel cycles and in Fig. 3 for higher burnup TRISO fuel used in a pebble bed modular reactor (PBMR). We also conducted literature surveys and ran models to estimate the plutonium isotopic composition of spent fuel. Finally, we estimated heat generation rates from spent fuel.

We identified potential improvements in proliferation resistance. First, if the current regulatory limit of 5% enrichment of LWR fuel is increased, higher burnups might be possible that would increase proliferation resistance of the plutonium in spent fuel. However, higher enriched uranium fuel would be less proliferation resistant because the effort to further enrich the fuel to weapons grade uranium would be reduced. As shown in Fig. 4, we quantified the decrease in signatures of these operations when higher enriched uranium feedstocks are used. The second structural change would be a switch to high-temperature gas reactor fuel cycle and TRISO fuel. The higher burnups achievable with this technology and the inherent difficulty of chemical separation of plutonium from the fuel matrix offer improved proliferation resistance.

Finally, we evaluated the process steps in different fuel cycles to identify opportunities for proliferant nations and sub-national groups to acquire material and fabricate weapons. We examined physical processes and inspection regimes in order to identify points in the fuel cycle that may pose a risk.

Related References

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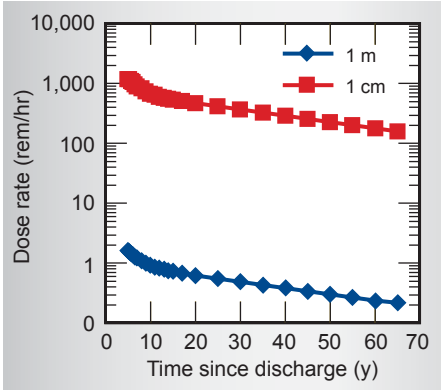

Figure 3. PBMR fuel sphere dose rates for 133 GWd/MT. This figure shows the dose rate for a 6-cm-diameter sphere of TRISO fuel used in a PBMR. This high-temperature reactor technology achieves high burnup levels that improve proliferation resistance. The high dose rate at 1 cm precludes handling spent fuel for protracted periods. Each sphere can contain up to 9 g of uranium or plutonium.

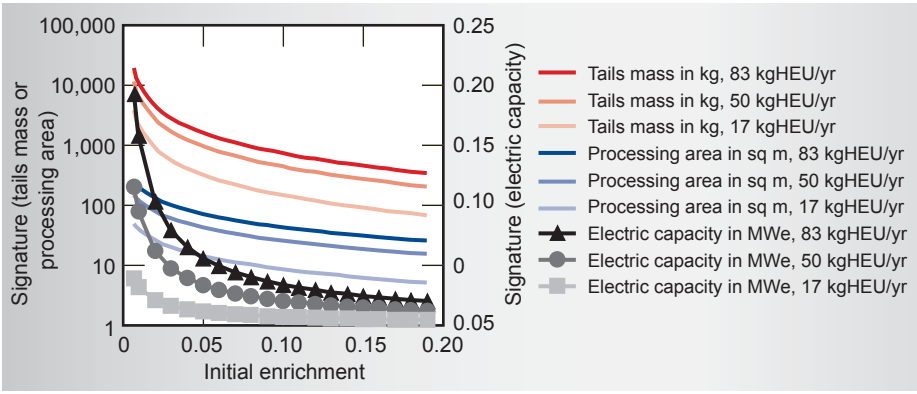

Figure 4. Clandestine enrichment plant signatures. Higher burnup fuel would require higher initial enrichments. This figure shows how signatures of enrichment from commercial to weapons grade uranium would decrease. Signatures decrease by a factor of two when initial enrichment is increased from the current NRC limit of 5% to just below 20%.