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July 7, 2011

U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852-2738

Attn: Ms. Vonna Ordaz
Director, Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety and Safeguards

Subject: NAC White Paper on Establishing a Balanced Perspective on Wet and Dry Storage of Used Fuel at U.S. Reactors

Dear Ms. Ordaz:

Based on the recent events at the Fukushima Daiichi plant in Japan, NAC International (NAC) has developed a white paper on establishing a balanced perspective on the proper mix of used fuel in both wet and dry storage at U.S. reactors. NAC has submitted the above paper to the Blue Ribbon Commission for its consideration.

Since the white paper offers some insights and clarifications in response to a range of actions being discussed for managing used nuclear fuel in wet and dry storage at U.S. commercial reactors, NAC is forwarding a copy of the above white paper for your information.

Please contact me if you have any questions regarding this matter via my direct line at 678-328-1221.

With sincere regards,

Craig Seaman
Senior Vice President
Engineering and Projects
NAC International

Enclosure: NAC White Paper "Establishing a Balanced Perspective on the Proper Mix of Used Fuel in Both Wet and Dry Storage at U.S. Reactors" – NAC International, July 2011

cc w/encl: Mr. Doug Weaver, U.S. NRC

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Establishing a Balanced Perspective on the Proper Mix of Used Fuel in Both Wet and Dry Storage at U.S. Reactors

July 2011

Introduction

With the events at Fukushima Daiichi still in the news and with the NRC Task Force performing a 90-day review of the implications of these events for U.S. reactors, there are already calls arising for the NRC to require movement of used fuel from wet storage pools at U.S. reactors into dry storage casks for fuel cooled as little as 5 years. With modern fuel cycles, 5 year cooled fuel has a fairly high decay heat content, so that the implications of such a requirement are not only non-trivial, they may well be harmful or less-safe, an unintended consequence of an over-reaction to a natural disaster that presented the Fukushima site with 3 substantially beyond-design-basis (BDB) events (earthquake, tsunami, and loss of off-site power) occurring within a few hours of each other.

As an initial observation, removing heat load from the pool should be just one possible approach that is reviewed. Clearly, a more direct approach that should be considered by all licensees for used fuel pool heat load management would be an increase in a pool's back-up cooling capability, whether through the addition of new systems and sources of water, incorporation of new redundancy in power supplies or pumping systems, or both.

This paper briefly summarizes why a policy for uniformly removing used fuel from wet storage pools into dry storage after only 5 years of cooling is neither rational nor necessary for adequate protection of the public or of nuclear plant worker health and safety and provides recommendations for considerations that may offer a more balanced approach.

Background on Wet Storage of Used Fuel in the U.S.

The used nuclear fuel currently stored in wet fuel storage pools at U.S. operating commercial reactors totals about 48,000 metric tons of uranium (tU). Much of this used fuel has been cooled in these wet pools for some time, with about 56% having been cooled for longer than 10 years. The data in Figures 1 through 4 provides input for a simple examination of used fuel inventories to determine how the characteristics of that used fuel in wet storage should influence a potentially revised protocol directing a required, earlier transition to used fuel dry storage. From that data, Table 1 has been generated to provide summary information about the characteristics of used fuel in wet storage at commercial U.S. nuclear reactors.

Fuel Cooling Period Since Discharge (Years)	Approximate Mass of Fuel in Group (tU)	Approximate Heat Generation of Group (kW)	Average kW per tU of Fuel
< 5	10,800 (22%)	49,000 (58%)	4.54
5 - 9	10,600 (22%)	19,000 (22%)	1.8
10 – 14	7,800	7,800	1.0
15 - 19	7,200	5,000	0.7
20 - 24	4,800	2,400	0.5
25 - 29	3,000	1,000	0.35
30 - 34	2,000	500	0.25
Remainder	2,000	300	0.15
Totals	48,200	85,000	1.76

Table 1 – Approximate Mass and Heat Generation Rate of Used Fuel in Commercial Reactor Pools by Aging Group [(%) represents the % of the total]

From the data in Table 1, it is clear that used fuel that has less than 5 years cooling since discharge is responsible for about 58%, on average, of all the used fuel pool heat generation in commercial U.S. reactor used fuel pools. Used fuel with cooling of 5 – 9 years is responsible for 22% of the total heat load, and all the rest of the fuel is responsible for about 20%. However, it is important to note that for a period of several months after the discharge of a fresh batch of used fuel into the pool at every reactor, the fuel that is cooled for less than 5 years may contribute 70% to 80% of the fuel pool heat load over that period. If a full core is discharged for some period into the pool, then the heat load from fuel cooled less than 5 years approaches 95% of total pool heat load for the period with a full core discharge in the pool. This is further demonstrated in Table 2, which provides fuel assembly heat generation rates over a period of years taken from Figure 4. What this information shows is that for many months following fuel reloading at every reactor, the fuel that has cooled for less than 5 years contributes more than 88% of the total used fuel pool heat load. Therefore, any substantive removal of fuel cooled more than 5 years will have very little impact on the time-weighted pool heat load.

Post-Discharge Cooling – Years	45 GWd/tU Heat Generation Rate (kW) Per PWR Assembly	45 GWd/tU Heat Generation Rate (kW) Per BWR Assembly	55 GWd/tU Heat Generation Rate (kW) Per PWR Assembly	55 GWd/tU Heat Generation Rate (kW) Per BWR Assembly
0.1	**27.1**	**10.9**	**29.4**	**11.8**
0.5	**9.9**	**4.0**	**11.0**	**4.4**
1	**6.0**	**2.4**	**6.7**	**2.7**
3	**2.0**	**0.8**	**2.4**	**1.0**
5	**1.2**	**0.48**	**1.47**	**0.59**
6	**1.06**	**0.43**	**1.29**	**0.52**
7	**0.9**	**0.36**	**1.15**	**0.46**
8	**0.81**	**0.32**	**1.08**	**0.43**
9	**0.76**	**0.31**	**1.06**	**0.43**
10	**0.74**	**0.3**	**0.99**	**0.4**

Table 2 – PWR and BWR Used Fuel Heat Generation Rates/Cooling Periods at Current and Prospective Industry-Wide Average Burnups of 45 GWd/tU and 55 GWd/tU

Expanding further on this point, if the discharge of a full core into a used fuel storage pool is ever desirable or is used as an industry practice, the used fuel pool heat load would be substantially higher. For such a discharge, it seems prudent for industry to consider compensatory measures during the period of such a discharge. These could include preparations for contingent rapid deployment of supplementary cooling or the use of probabilistic risk assessment for a risk-informed management of the discharge.

The issue of concern with used fuel pool heat load is the potential for the reduction of pool heat removal capability through loss of pumping systems, pumping power, or the ultimate heat sink for the pool heat load under accident or BDB events. Such an event could lead to heat-up of the used fuel, the potential evaporation and boil-off of used fuel pool water, the subsequent overheating of used fuel cladding that then reacts exothermically with steam and oxygen in the air (starting at around 900° C and accelerating rapidly above 1,100° C), and the ultimate failure of the cladding with the release of fission products and other radioactive materials to the used fuel storage building. Analysis and testing of fuel cladding under such conditions has been conducted and is reported in Ref. 3 to show the above results are credible if the heat transfer from very hot fuel is restricted radially to an essentially adiabatic condition. The NRC's 90 day task force, in its first briefing to the Commissioners on May 12, 2011, voiced this as one issue of substance in its review of the Fukushima events. Specifically, in reviewing the considerations for preventing used fuel damage and mitigating releases (slide 18), the staff reported this consideration, as follows:

Heat removal capability
- Water cooling
- Air cooling
- Fuel inventory

Such a presentation by the NRC senior staff tends to express that staff's current thinking on the relative importance of the potential actions that may be desired, and, indeed, corresponds to the order of considerations reflected herein.

This range and order for the bases of considerations by the NRC 90 day task force may result from the industry and regulatory focus that produced reactor plant and used fuel storage upgrades following the September 11, 2001, (9/11) attacks. Because of those upgrades, the U.S. industry is much better prepared for BDB events involving wet used fuel storage. The following summarizes the industry and regulatory upgrades affecting wet used fuel storage after 9/11.

Following the 9/11 events, the NRC issued EA-02-026, "Order for Interim Safeguards and Security Compensatory Measures" (the ICM Order) dated February 25, 2002. That order has a restricted distribution, but it modified then-operating licenses for commercial power reactor facilities to require compliance with specified interim safeguards and security compensatory measures. Section B.5.b of the ICM Order requires licensees to adopt mitigation strategies using readily available resources to maintain or restore core cooling, containment, and used fuel pool cooling capabilities that could be impacted following the loss of large areas of the facility due to fires and explosions from any cause, including BDB aircraft impacts and terrorist attacks.

After initial efforts by plants to provide compensatory measures to address the NRC order, the Nuclear Energy Institute (NEI) issued NEI 06-12, Revision 2, "B.5.b Phase 2 & 3 Submittal Guideline," in December 2006, also with restricted distribution. The NRC endorsed NEI 06-12, Revision 2, by letter dated December 22, 2006, as an acceptable means for developing and implementing the mitigation strategies requirement in Section B.5.b of the ICM Order. NEI 06-12, Revision 2, provides guidance for implementing a set of strategies intended to maintain or restore core cooling, containment, and SFP cooling capabilities under the circumstances associated with the loss of a large area of the plant due to explosions or fire. NEI 06-12 provides guidance in the following areas:

- Addition of make-up water to the used fuel pool
- Spraying of water on the used fuel in the pool
- Enhanced initial command and control activities for challenges to core cooling and containment, and
- Enhanced response strategies for challenges to core cooling and containment.

The B.5.b guidance and NEI 06-12, Revision 2, were used by each licensee in preparing information for submittal to the NRC that describes plant-specific approaches to implementing mitigating strategies and supports each plant specific license condition. The NRC staff has completed its review of the information submitted by each licensee, as well as information obtained during prior NRC inspections, and has issued a safety evaluation

(SE) that documents the bases for its approval of the license condition for each facility. Therefore, every U.S. reactor has an upgraded condition with respect to addressing the results of BDB events that other countries do not have. This is a singularly important reason why wet used fuel pools at U.S. reactors are already far better prepared for the types of loss of pool cooling events that resulted from the tsunami at Fukushima.

Further, the U.S. has a unique approach to regulation that involves both self-regulation through the Institute for Nuclear Power Operations (INPO) and the federal regulatory oversight from the Nuclear Regulatory Commission (NRC). These bodies are intrusive regulators that monitor and control through both rigorous inspections and measurement of key performance indicators, with the result that the safety of U.S. reactors is at the top of the measurement scale set by the independent World Association of Nuclear Operators (WANO), a third level of international inspection, evaluation, and reporting for U.S. reactors. U.S. nuclear plant safety performance has remained "at historically high levels," as reported in Ref. 4. Most other countries with commercial nuclear power facilities do not match-up to the standard set by U.S. commercial nuclear power plant operators.

With respect to reactor and used fuel storage facility operation, then, the U.S. is already far better prepared to address and recover from BDB events than other countries for a variety of technical, geographical, historical, and regulatory reasons. Nonetheless, the U.S. nuclear industry will conduct close reviews of the events at Fukushima for the purpose of critically assessing current designs, practices, and readiness for addressing significant BDB events. There will be important lessons learned from such reviews that industry will embrace for the enhancement of safety.

Background on Dry Storage of Used Fuel in the U.S.

Dry storage of used fuel has been deployed at U.S. reactors for almost a quarter century and is a well-known and well-proven process for extending the lives of operating reactors by expanding the plant's capability to store used fuel on-site outside of the used fuel pool.

More than 1,100 dry storage systems are currently in use in the U.S. Dry storage technology in the U.S. is now dominated by multipurpose canister system (MCS) designs that are typically licensed for both storage and transport. Additionally, the majority of these modern systems have been designed and licensed for high capacity fuel storage and transport, with used fuel capacities ranging from 32 to 37 PWR assemblies and 61 to 89 BWR assemblies. This represents fuel weight capacity of about 11 tU to 17 tU per system. High fuel capacity designs also have thermal (heat generation rate) capacities greater than older technology, with thermal capacities varying from about 28 kW to 43 kW, or even a bit more, to address fuel burnups in the range of 10 GWd/tU through 55 GWd/tU.

One feature of these modern, high capacity MCS is that some high heat-generation-rate, used fuel assemblies can be stored, as long as this hotter fuel is also loaded with much cooler fuel, a strategy that is known as "regionalized loading." However, most of these modern MCS systems have limits on the heat rates of this hotter fuel that are in the range of 2.8 kW per tU. Achieving regionalized loading with fuel of higher heat rates will require new designs and licensing, with the possible consequence of reduced used fuel capacity or system weights that cannot be accommodated at current reactors without expensive crane upgrades or greatly reduced shielding on transfer systems. Reducing a system's used fuel capacity would result in the less-than-desirable consequence of having to load more systems for the same amount of used fuel. Reducing a transfer system's shielding for hotter fuel will negatively impact operator doses during loading, with some potential for storage system site boundary dose rate consequences, as well.

With respect to MCS or other dry storage system (DSS) design and licensing, we know that systems with a very high design basis heat generation rate for the used fuel introduce several undesirable outcomes:

- lower MCS/DSS capacities because the practical limit for system heat removal to maintain the regulatory requirements for used fuel clad temperatures during a range of operations is well under 50 kW;

- lower MCS/DSS capacities mean more systems must be loaded, which further means there will be more operations time and higher cost and dose for transferring used fuel from pools to MCS/DSS;
- operational limitations on loading high heat MCS/DSS can restrict the times during the year when the they may be loaded;
- Shorter durations for performance of critical, time-limited (Tech Spec), controlled operations, which may increase the probability that Tech Spec requirements are not met and contingent actions are required;
- the ionizing radiation dose to operators will increase because the high used fuel heat results from a larger radiation source term in the used fuel; currently, average MCS/DSS are being loaded with fuel having in the range of 15 years cooling and heat loads in the range of 18 kW – 20 kW; these loadings result in average worker collective doses in the range of about 400 person-mrem per MCS/DSS; Figure 2 shows average fuel assembly dose rates by aging group, and if cooling times were to be reduced to the range of 5 years, used fuel dose rates go up by a factor of 2 to 3; this means that worker collective dose per MCS/DSS would likely increase by 50% to 100%, a substantial reversal of the declining trend in worker doses resulting from the historical implementation of dry storage.

These outcomes are projected from extensive experience, which can establish a practical range of recommended limitations on moving used fuel into dry storage. Such limitations will be further developed in the following sections.

Finally, it must be understood that current licensing issues may impact any revised strategy of early transition of used fuel into dry storage. For example, there would need to be a concerted effort to solve the licensing challenge regarding the transportation of high burnup fuel. If this issue cannot be timely resolved to assure transportability, it might be viewed as imprudent to accelerate dry storage of higher burnup used fuel.

Observations

As a response to the events in Japan at Fukushima, there seems to be a clear intent in the content of discussion within the U.S. about one important consideration: reducing the heat load in used fuel pools so that BDB loss of fuel pool coolant pumping power or pool damage that results in loss of pool coolant may be more easily accommodated without fuel failures and the concomitant release of radioactivity to the public. Further, however, there seems to be a less insightful extension of that consideration to a requirement that says all used fuel with in-pool cooling since discharge of greater than 5 years should be placed into dry storage. Such a protocol seems short-sighted and may not properly consider the law of unintended consequences. Rather, variations on the concept of early transition to dry storage that take into account each reactor's particular pool design and fuel contents, as well as preferred dry storage system, should be factors in any regulatory equation or protocol. Further, a more direct approach to used fuel pool heat load management may be the addition of new systems and sources of water, incorporation of new redundancy in power supplies or pumping systems, or both.

From the data in Tables 1 and 2, and Figures 1 - 4, the following observations are offered:

- Used fuel cooled less than 5 years offers too large a challenge to efficient dry storage to be realistically pursued; the average heat load of a fuel assembly cooled about 2.5 years, for instance, is above 2 kW for PWR fuel and 0.8 kW for BWR fuel; even 5 year cooled fuel at the average burnups of the near future have heat generation rates of 1.5 kW for PWR and 0.6 kW for BWR; therefore, it makes eminent sense to leave fuel with 0 – 5 years cooling in wet pools; that means that close to 60% of the current average fuel pool heat loads must remain in the pools; however, the storage patterns for such fuel in pools may be further examined and improvements achieved, consistent with the earlier-discussed B.5.b mitigation strategies;
- Fuel in wet storage with 5 – 10 years cooling represents only about 22% of average pool heat loads; fuel in wet storage with 11 – 50 years cooling represents about 20% of

average pool heat loads; following reactor discharge of a batch (or full core), these percentages become much smaller for 5 to 50 year cooled fuel;

- Current fuels are being discharged at burnups of 50 – 55 GWd/tU, which was not the case 5 years ago; a five year cooled assembly with such high burnups can be seen from Table 2 to have a decay heat of about 1.5 kW for PWR fuel and 0.6 kW for BWR fuel; this means that the heat content of fuel in both the 0 – 5 year and the 5 – 10 year cooling periods is increasing, on average, every year;
- Designing and licensing new MCS/DSS technology for the exclusive set of fuels in the 5 – 10 year cooling group could delay and complicate implementation of pool heat reduction efforts and have other negative effects on storage quantities and MCS/DSS efficiencies, time-of-year loading windows, and collective worker dose;
- Certainly, highly burned used fuel that has been in wet storage for a period in the range of 8 or more years can be accommodated by currently licensed MCS/DSS technology with regionalized loading;
- If industry believes that politics and policies necessitate some measured reduction in fuel pool inventory and heat loads, an improved strategy that calls for earlier transitioning to dry storage for used fuel from all aging groups beyond about 8 or 10 years, combined with more efficient and effective pool loading patterns for hot fuel that take into consideration BDB events seems to be a better plan; fuel with 8 to 10 years of cooling mixed with older, colder fuel from wet pools to permit efficient numbers of assemblies per cask (regionalized loading) is a well-proven and licensed design approach for dry storage; this will not empty the pools of 5 – 10 year cooled used fuel as fast as the use of an exclusive hot-fuel MCS/DSS, but it will assure that heat loads in used fuel pools are reduced (while not threatening efficient dry storage and ALARA worker doses) and will prevent fuel failures of hotter fuels that remain in the pool under BDB events; highly burned, 8-year cooled used fuel would, therefore, seem to be the best candidate for the most recently discharged used fuel for early offloading from wet storage into dry storage, because its storage would not result in new design and licensing of MCS/DSS;
- Besides early removal of some pool heat load, this improved strategy could, more importantly, also focus on increasing the pool space for storage of very hot fuel to permit

optimized wet storage configurations that would improve both water and, potentially, air cooling of such fuel, as discussed by the NRC 90 day task force (see above section on wet storage background) and determined by the testing and analyses outlined in Ref. 3.

Evaluation

- There seems to be a current focus in government and some industry circles on moving spent fuel into dry storage that achieves the largest credible decrement per assembly of thermal heat load in the pool; as stated above, the law of unintended consequences presents outcomes for such a strategy that result in higher worker doses and less efficient, more costly dry storage with a best-case impact of less than 20% on total pool heat load; indeed, for large portions of many years, the impact would likely be less than a 10% reduction in total pool heat load, under the hottest conditions in a pool;
- Testing and analysis, as reported in Ref. 3, show that potentially very localized storage patterns in wet pools, rather than general pool heat load conditions, may be more determinative of BDB event outcomes with respect to rapid used fuel cladding oxidation;
- The BDB event threat to U.S. used fuel storage pools does not seem to have been significantly altered as a result of the Fukushima accidents; U.S. reactors are already far better prepared than their international counterparts, and U.S. sites are not significantly susceptible to subduction earthquake tsunamis; therefore, any push for rapid change would seem to arise from a needless and unfounded sense of panic;
- If mitigation actions are deemed prudent, there needs to be a reasonable objective set for the level of heat reduction in each individual used fuel pool, based upon pool heat load, pool and cooling system design, type of used fuel, used fuel burnup history, and availability of preferred dry storage technology for those individual plant conditions; a goal of 15% to 20% pool heat load reduction from current levels over, say, a 10 to 15 year period, combined with other wet storage arrangement modifications to reduce BDB event threat risks, seems to be one approach that reflects prudence;
- Clearly, any shift in licensing posture that involves a transition to more dry storage of higher burnup, used fuel in transportable MCS/DSS (i.e., resulting from prescriptive

inclusion of at least some fuels cooled 5 – 8 years) will require further licensing of systems for transport and storage of high burnup, high heat fuels; this should be considered before storing significant quantities of 5 – 8 year cooled fuel, since such licensing, especially for transport, may have consequences as previously outlined;

° Ref. 3 provides the results of testing and analysis on the conditions in wet pools that enhance the prospects for rapid zircaloy clad oxidation in the event of a loss-of-pool-coolant event; using that information, it is possible to identify used fuel storage strategies for pools that essentially eliminate the BDB event threat of rapid oxidation of used fuel cladding while also maintaining a significant fraction of wet pool used fuel storage space.

Recommendations

- A rational approach to evaluating the real threat posed for U.S. used fuel pools from current heat loads should be the first step in achieving a balanced perspective on the proper mix of used fuel in both wet and dry storage at U.S. reactors; the NRC Commissioners must make sure this is the outcome of the 90 day review.
- Since it may be more productive and effective to enhance used fuel pool back-up and supplementary cooling, this approach should be given thorough consideration.
- NRC should shape dry storage transition considerations in terms of used fuel burnup, cooling times, and other plant-specific features, not just used fuel cooling times; such an approach provides opportunity for optimized, more timely, efficient, and less costly transition to dry storage.
- The process should set a reasonable objective for the level of heat reduction in each individual used fuel pool, based upon current heat load, pool and cooling system design, type of used fuel, used fuel burnup history, and availability of preferred dry storage technology for those individual plant conditions.
- One focus that has not been seriously addressed in current discussions is how less-than-5 year cooled and the remaining 5-10 year cooled used fuel (fuel not placed into dry storage) should be stored in a wet pool; several approaches and evaluations should be performed to more thoroughly assess and address this issue:

- Are there checkerboarding arrangements that eliminate used fuel clad rapid oxidation potentials for the great majority of these spent fuels in pools?
- Under the conditions of loss-of-pool-coolant, are average used fuel temperatures reduced when older, colder fuel is being stored adjacent to very hot used fuels when compared to having empty storage cells adjacent to hot fuels?
- What wet pool storage patterns of used fuel cooled from 0 – 10 years are most effective in extending time to fuel failure under BDB event threat conditions?

- For expansion of dry storage of high burnup used fuel, there must be an effort to solve licensing issues such as the challenge of the last decade involving the transportation of high burnup fuel; this issue should be resolved promptly, or progress may be slow on any accelerated program to transition hotter used fuel from wet storage to dry storage.

References

1. T.A. Edmonds, Lawrence Livermore National Laboratory (LLNL), "Proliferation Resistance and Physical Protection of Current Nuclear Fuel Cycles," FY08 Engineering Research and Technology Report, pg 88 – 89, LLNL, Livermore, CA
2. United States Nuclear Waste Technical Review Board (NWTRB), Evaluation of the Technical Basis of Extended Dry Storage and Transportation of Used Nuclear Fuel, December 2010, Washington DC
3. Durbin, SG, Lindgren, ER, Sandia National Laboratories; Investigations of Zirconium Fires during Spent Fuel Pool LOCAs; Presentation for the NEI Used Fuel Management Conference, Baltimore, Maryland, May 3, 2011
4. Nuclear Energy Institute (NEI) News Release, April 21, 2011: U.S. Nuclear Energy Industry Operated at High Levels of Safety in 2010, WANO Results Show

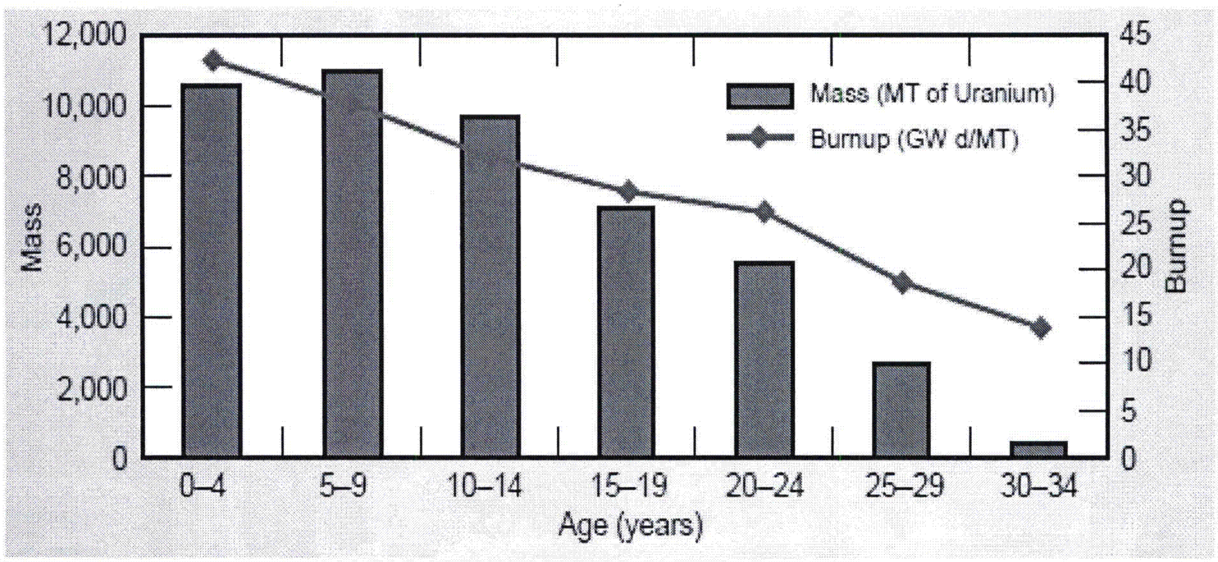

Figure 1 - Characteristics of Used Fuel in the U.S. Commercial Nuclear Reactor Inventory (From Ref. 1)

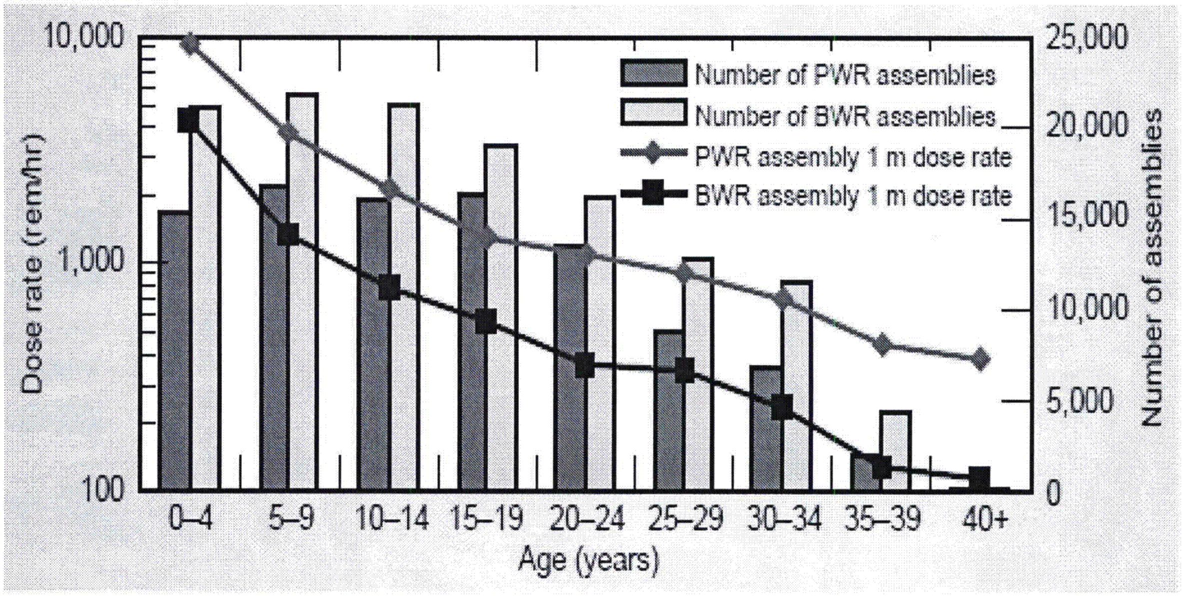

Figure 2 – Used Fuel Inventories for 2010: U.S. Commercial Nuclear Reactors by Aging Group, with PWR and BWR Assembly Dose Rates (From Ref. 1)

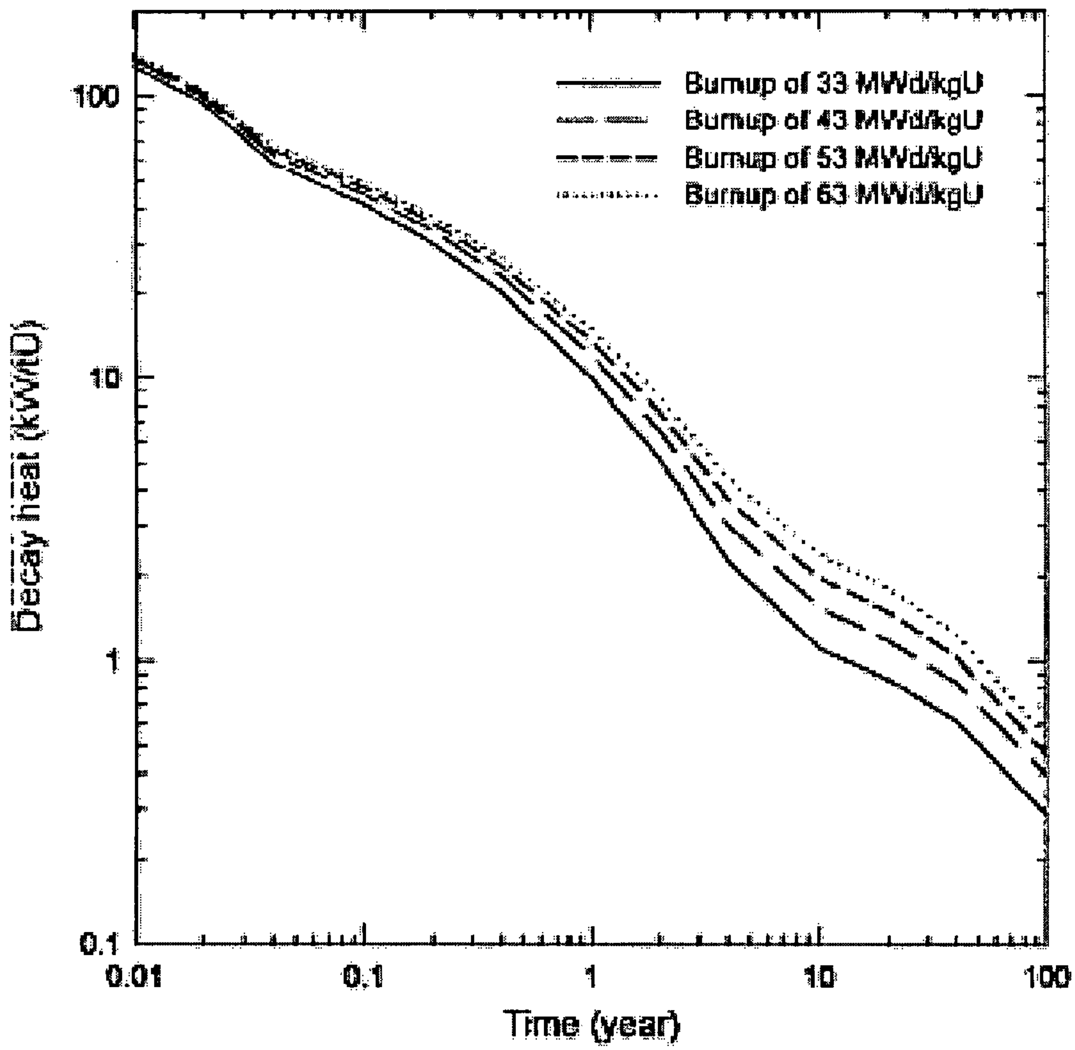

Figure 3 – Long Term Decay Heat per tU as a Function of Post-discharge Cooling Time for Used Fuel of Several Burnups (From Ref. 2)

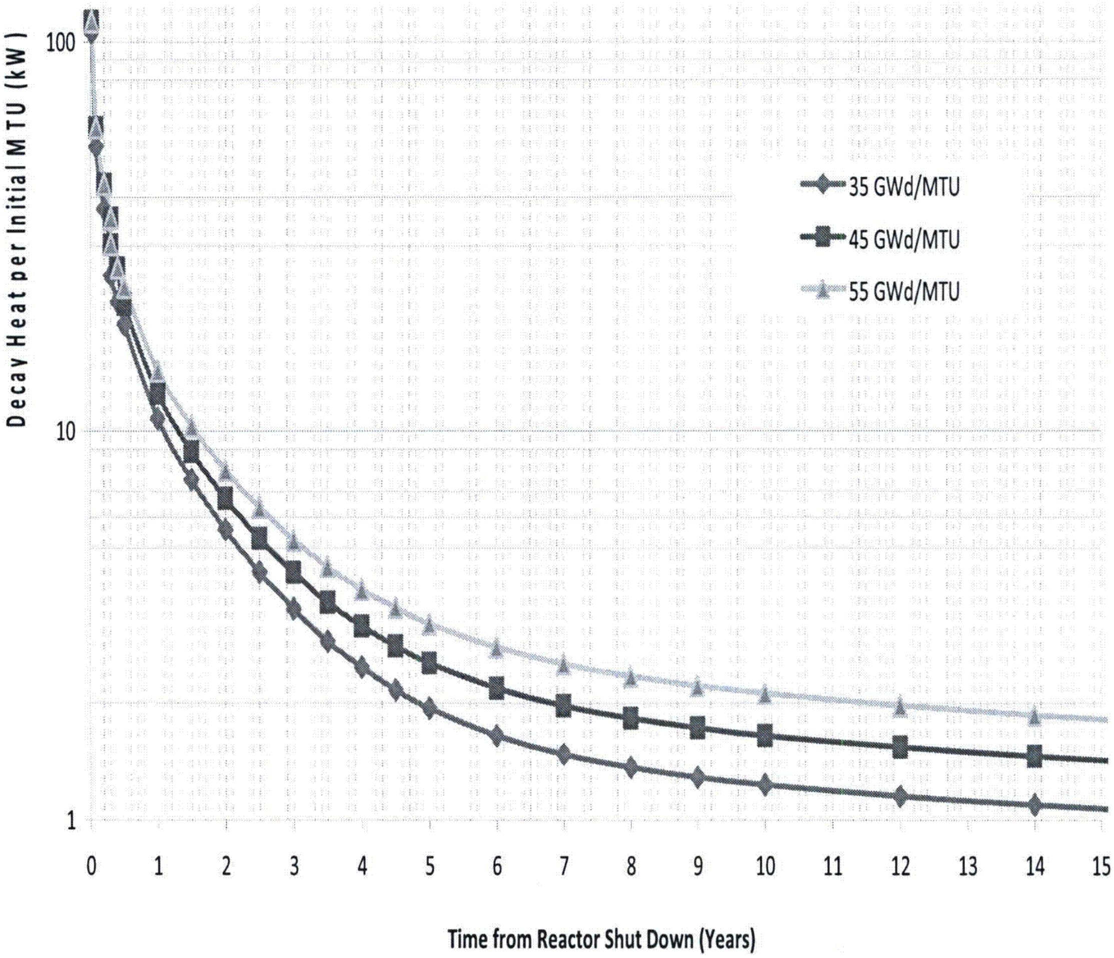

Figure 4 – Short Term Fuel Burnup and Cooling Time Effects on Heat Generation for Used Fuel Burnups of Current Interest