Fact Sheet

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NRC Review of Paper on Reducing Hazards From Stored Spent Nuclear Fuel

Introduction

The NRC staff has reviewed the paper, "Reducing the Hazards from Stored Spent Power-Reactor Fuel in the United States," April 21, 2003, Robert Alvarez, et al., (published in *Science and Global Security*, spring 2003) and concludes that it fails to make the case for its central recommendation.

The basic argument of the paper is that the risks and potential societal costs of terrorist attacks on power reactor spent fuel pools justify complex and costly measures to improve the safety of fuel storage. The main recommendation made in the paper is the removal of all spent fuel cooled more than five years from the storage pools, storage of that fuel in dry storage casks, and modifying spent fuel pools to open-frame storage for the remaining fuel at an estimated cost of $3.5 to $7.0 billion. The benefits attributed to this proposal are that the amount of spent fuel stored in the pools would be substantially reduced (by approximately a factor of four) and the remaining fuel could, with open-frame storage, be rendered coolable even if the pool water were entirely lost. Additional measures to improve fuel cooling and reduce the risk of a severe spent fuel pool accident are also discussed.

The paper suffers from excessive conservatisms throughout its cost benefit evaluation. Therefore, the recommendation for an accelerated program of complex and costly measures does not have a sound technical basis. In the United States, spent fuel, in both wet and dry configurations, is safe and measures are in place to adequately protect the public.

Analysis

Our review of the paper indicates that it is a deficient study of the hazards associated with the storage of spent fuel. Many of the 114 cited references are NRC studies or NRC contracted studies conducted for a variety of purposes, and most are not applicable to terrorist attacks. Some of the studies are generically applicable, others are plant specific, and all of the studies are based on assumptions that do not appear to have been sufficiently considered by the authors. For example, the authors' analysis of societal costs is based on a 1997 Brookhaven National Laboratory study which was performed for a reactor site location that represents an extremely high surrounding population density and is not representative of an industry average. However, the authors suggest that it is a characteristic site appropriate for broadly assessing industry costs and benefits. In another example, the author's quote a cesium-137 release fraction from an NRC publication. However, the value chosen in the NRC publication was acknowledged to be a bounding assumption that was not based on analysis. Valid scientific studies carefully search past data and analyses, carefully evaluate them and then draw conclusions based on the facts, augmenting the data or analyses when necessary.

Anecdotal information is sprinkled throughout the study. However, in many cases insufficient or no context is provided. For example, a means cited in the paper for removing water from the pool is to boil the water as a result of a jet fuel fire. The paper acknowledges that in the event of a jet fuel fire, only a relatively small fraction of the heat would go into the pool. Yet the paper states that burning 30 cubic meters of kerosene would release enough heat to evaporate 500 tons of water. This corresponds to the theoretical 100% absorption of the released energy to evaporate the mass of water and is a vast misrepresentation of expected physical behavior. Even after making this inappropriate assumption, the authors fail to note that for a typical pool the loss of 500 tons of water corresponds to only a modest drop in water level such that the fuel is still safely covered by an ample inventory of water. Mentioning a potential hazard, in this case which assumed evaporating spent fuel pool water with jet fuel, without explaining the expected consequences (in this case no consequences) is misleading.

Additionally, the report does not attempt to compare the risks associated with spent fuel storage with the risks associated with other critical civilian infrastructure, e.g., storage of hazardous materials. Without putting the risks associated with spent fuel storage in context with other risks, it makes little sense to do cost-benefit analysis and propose solutions.

The NRC staff has reviewed the paper and have concluded that it suffers from significant flaws. We have identified four major areas where the authors have, based on their own analysis or referenced findings of earlier studies, introduced unrealistic conservatisms into their risk assessment and cost-benefit evaluation–1) no justification for the postulated probabilities of worst-case spent fuel pool damage; 2) overestimation of radiation release; 3) overestimation of consequences and societal costs for the postulated severe event; and 4) underestimation of the costs of the authors' main recommendation. Each area is discussed below.

No Justification for Postulated Probabilities of Worst-Case Spent Fuel Pool Damage

The paper does not offer a probabilistic analysis of the likelihood of a terrorist attack leading to severe damage of a spent fuel pool and its fuel. Indeed, the paper quotes the NRC staff comment that "No established method exists for quantitatively estimating the likelihood of a sabotage event at a nuclear facility." (Terrorist and sabotage events are addressed by the NRC's regulatory requirements without quantitative estimation of the likelihood.) Instead, the paper simply states probabilities of success for an attack leading to worst-case fuel damage which the authors claim would justify, on a cost-benefit basis, removing older fuel from pools, storing it in dry casks, and storing remaining fuel in an open-rack configuration. The authors deduce that if there is a .7 percent chance in a 30-year period of a terrorist attack leading to a complete release of a spent fuel pool's cesium-137 inventory or an approximately 5 percent chance in a 30-year period of a terrorist attack leading to the release of one tenth of a spent fuel pool's cesium-137 inventory, then the authors' estimated $3.5 to $7 billion cost of relocating the older spent fuel into casks would be justified, but they do not provide any basis for these probabilities.

The authors suggest by their discussion of various threats to a spent fuel pool that the cited likelihoods of an attack leading to worst-case fuel damage are reasonable. Specifically, in discussing a potential terrorist attack using a large aircraft, the paper cites past NRC studies which <u>assumed</u> a high conditional probability that the turbine shaft of a large plane would penetrate and drain the spent fuel pool, if the aircraft struck the pool. A second reference to simplified models for penetration of a reinforced concrete wall is cited as support for the view that penetration "cannot be ruled out."

The past NRC reports referenced, NUREG/CR-5042, "Evaluation of External Hazards to Nuclear Power Plants in the United States," and NUREG-1738, "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants," used very conservative <u>assumptions</u> with respect to the conditional probability of pool penetration by the turbine shaft of a large plane in part because even with those conservative assumptions the risk was acceptably low for the intended purpose, and more detailed analyses were not needed at the time. However, when assessing potential spent fuel pool vulnerabilities to terrorist events, using these very large conservatisms is inappropriate and provides misleading results.

Since the attacks of September 11, 2001, the NRC has sponsored additional research regarding the penetrability of concrete structures by aircraft engine turbine shafts. The analyses have been performed using both detailed physical response modeling and experimentally validated models developed by Sandia National Laboratories and the U.S. Army Corps of Engineers. These models have been specifically developed to assess penetration of materials by hard projectiles under a variety of size, speed, and orientation conditions. While the analyses are ongoing and specific results are classified, the results strongly indicate that prior assumptions regarding the probability of engine turbine shaft penetration are conservative by orders of magnitude. These latest improved calculations retain significant, yet realistic, conservatism. For example, the analyses do not generally consider the beneficial effects of the steel liner on the inside of the pool or the effect of the pool water itself in reinforcing the concrete wall. The effect of these conservatisms is to further support the conclusion that prior assumptions related to engine turbine shaft penetration of the pool wall are overly conservative for a realistic assessment. Therefore, analyses which rely on these assumptions, as does the subject study, as underpinning for judging the conditional probability of pool failure due to a terrorist attack using a large aircraft, are not reflecting the actual structural capabilities of power reactor spent fuel pools.

The authors hint at various other ways that terrorists might attack a spent fuel pool to justify their postulated probabilities of a terrorist-induced spent fuel pool drain-down event (.7 percent to 5 percent over a 30 year period). However, in doing so the paper does not adequately credit either the physical features of the pools or the security, unmatched elsewhere in our nation's critical civilian infrastructure, surrounding such spent fuel pools. Nuclear power reactor spent fuel pools are neither easily reached nor easily breached. Instead, they are strong structures constructed of very thick steel-reinforced concrete walls with stainless steel liners. In addition, other design characteristics of these pools, not analyzed in the paper, can make them highly resistant to damage and can ease the ability to cope with any damage. Such characteristics can include having the fuel in the pool partially or completely below grade and having the pool shielded by other plant structures.

The likelihood of a terrorist attack cannot be ascertained with confidence by state-of-the-art methodology and any attempt at quantification or even qualitative assessment of the likelihood of terrorist attack is highly speculative.[1] Nonetheless, spent fuel pools at operating power reactors are protected by robust licensee security measures, which have been further augmented as a result of NRC's February 25, 2002 and April 29, 2003 Orders, the details of which are sensitive. Even prior to September 11, 2001, licensees had multiple barriers and sensors, well-armed and trained guards, ready to defend from prepared positions. The February 25, 2002 and April 29, 2003 Orders augmented those capabilities through requirements for increased patrols, augmented security forces, additional security posts, greater vehicle stand-off distances, more frequent training, preparation to defend against a larger design basis threat, and enhanced coordination with law enforcement authorities. In short, the Commission believes that the combination of the physical features and security of spent fuel pools make them highly resistant to terrorist attacks.

<u>Overestimation of Radiation Release</u>

In estimating fuel damage, the paper again makes reference to past NRC studies which conservatively <u>assumed</u> bounding pool configurations for cooling analysis and conservatively <u>assumed</u> the extent of radiation release. In the 1997 Brookhaven National Laboratory (BNL)

[1] Private Fuel Storage, L.L.C. (Independent Spent Fuel Storage Installation), CLI-02-25, 56 NRC 340, 350 (2002).

study, "Severe Accidents in Spent Fuel Pools in Support of Generic Safety Issue 82," (NUREG/CR-4982), it was assumed that 10-100% of the cesium-137 was released to the atmosphere. Similarly in NUREG-1738 the base case assumed the release of 75% of the total cesium-137 inventory. The assumption of such a large release in NUREG-1738 was a large conservatism which was tolerable for the purposes of that study. However, it is neither a realistic estimate nor an appropriate assumption for a risk assessment of security issues where realism is needed. Ongoing research to address these issues includes more detailed realistic analyses of the thermal response of fuel to loss of water scenarios and more detailed, realistic analyses of the radionuclide releases for those scenarios where adequate cooling is not maintained. Based on preliminary analyses, we conclude that spent fuel in pools is more easily cooled even in the event of a complete loss of water. Further, preliminary analysis indicates that previous NRC estimates of the quantities of fission products released were high by likely an order of magnitude. Earlier NRC studies used large conservatisms, in generic calculations, with simplified modeling.

Further, the paper generally does not give credit for the likely intervention by operators to prevent uncovering the fuel or to provide emergency cooling to the spent fuel although it acknowledges some of the very long times available for loss of cooling events. Our ongoing analyses suggest that longer times than previously estimated are available for operators to intervene to restore water to ensure that the fuel remains cooled.

The National Research Council in its 2002 report, Making the Nation Safer: The Role of Science and Technology in Countering Terrorism, found: "The threat of terrorist attacks on spent fuel storage facilities, like reactors, is highly dependent on design characteristics. Moreover, spent fuel generates orders of magnitude less heat than an operating reactor, so that emergency cooling of the fuel in the case of an attack could probably be accomplished using 'low tech' measures that could be implemented without significant exposure of workers to radiation." The Commission agrees with this statement, and through its February 25, 2002 Order directed licensees to develop guidance and strategies to maintain or restore spent fuel pool cooling capabilities using existing or available resources.

Overestimation of Consequences and Societal Costs For Postulated Severe Event

The authors' analysis of land contamination for a postulated severe fuel damage event reflects a range of cesium-137 releases of 3.5-35 megaCuries, but the estimate of costs cited in the paper is taken from the 1997 BNL study which assumed a release of cesium-137 from 8-80 megaCuries. The BNL study was performed for a reactor site location that represents an extremely high surrounding population density and that is not representative of an industry average. However, the authors suggest that it is a characteristic site appropriate for broadly assessing the risk of their postulated severe event. The use of the BNL study's site characteristics, instead of a mean value considering all sites, biases the economic impacts and societal costs of the postulated worst-case fuel damage event by a factor of 5 - 10. Moreover, if a site-specific evaluation were performed, it would be necessary to address site-specific features which mitigate against pool damage and any large release, including location of the pool or fuel below grade and shielding of the pool by surrounding structures. When such mitigative site-specific features are taken into account, mean economic impacts and societal costs of the postulated severe fuel damage event would be further reduced.

Underestimation of Cost of Main Recommendation

The paper estimates the cost for removing the older fuel from pools and placing it in casks to be $3.5-7 billion. We have preliminarily concluded that the authors' estimate is low by at least a factor of two when considering the costs of spent fuel pool modifications, dry storage facility design and construction, dry storage cask procurement, and cask loading and transfer costs. Furthermore, the paper does not address the radiation doses to workers that would result from the removal, disposal, and replacement of the spent fuel pool racks nor the added risk from these manipulations.

Spent Fuel Pool Safety Facts

To reiterate before closing, the safety and security of spent fuel pools is ensured by a series of physical structures, operational measures and security barriers that are unprecedented in U.S. civilian infrastructure.

- Nuclear power reactor spent fuel pools are robust structures constructed of very thick steel-reinforced concrete walls with stainless steel liners located inside protected areas.

- Many of spent fuel pools are designed with the pool and fuel located below grade, many are shielded by other structures, and many have intervening walls that would obstruct an aircraft's or other object's impact.

- Spent fuel pools contain enormous quantities of water and the spent fuel in the spent fuel pool produces significantly less heat than in an operating reactor. As a result, for most events (i.e., loss of cooling or small leaks) plant operators would have significant amounts of time to correct the problem, or implement fixes needed to restore cooling.

- In addition to the water in the spent fuel pool, nuclear power plants possess many other sources of water that are readily available that could be made available as a backup supply to the spent fuel pool.

- Since September 11, 2001, additional measures have been taken to reduce the likelihood of a terrorist attack and to further improve capabilities of nuclear plants to resist and withstand an attack. These measures include specific enhancements associated with the protective strategies for ground attacks on spent fuel pools. Additionally the NRC has ordered licensee to develop guidance and strategies to maintain and restore spent fuel pool cooling using existing or available resources if cooling is lost for any reason.

- Access to spent fuel pools requires passage through multiple physical barriers which must be of sufficient strength to provide high assurance in the protection of public health and safety from radiological sabotage. An attempt to commit radiological sabotage at a spent fuel pool would result in a security response to neutralize the threat. Furthermore, the Federal government has taken numerous actions to prevent terrorist use of large aircraft over the past 18 months, thereby reducing the likelihood of an attack on all critical infrastructure from such threats.

- Currently analyses are underway utilizing updated realistically conservative methods. Insights from these more realistic analyses indicate that

  - the spent fuel stored in spent fuel pools is more easily cooled than predicted in earlier NRC studies,

  - the consequences of such an accident would be much less severe than previously estimated,

  - the radioactive release would be much smaller (by at least a factor of 10 for the scenarios analyzed), and the radioactive release would begin later than previously estimated

    - providing more time for implementing effective protective measures, e.g., evacuation of the EPZ,

    - resulting in reduced health effects, and

    - resulting in reduced land contamination.

Conclusion

In summary, we conclude that the authors' assessment of possible spent fuel pool accidents stemming from potential terrorist attacks does not address such events in a realistic manner. In many cases, the authors rely on studies that made overly conservative assumptions or were based on simplified and very conservative models. The use of these previous studies, most of them NRC or NRC contractor studies, provides overly conservative and misleading results when assessing potential spent fuel pool vulnerabilities to terrorist events. The overall effect of the combined conservatisms in the four major areas discussed cumulatively affect the paper's cost-benefit calculations for its central recommendation by orders of magnitude. Given all of this, NRC does not believe that the fundamental recommendation of this paper, namely that all spent fuel more than five years old be placed in dry casks through a crash 10-year program costing many billions of dollars, is at all justified. Spent fuel stored, in both wet and dry storage configurations, is safe and measures are in place to adequately protect the public.