Science and Global Security, 11:213–223, 2003

ISSN: 0892-9882 print
DOI: 10.1080/08929880390253987

Response by the Authors to the NRC Review of "Reducing the Hazards from Stored Spent Power-Reactor Fuel in the United States"

Robert Alvarez, Jan Beyea, Klaus Janberg, Jungmin Kang, Ed Lyman, Allison MacFarlane, Gordon Thompson, Frank von Hippel

SUMMARY AND OVERVIEW

Our study addressed the hazards associated with the dense-packed storage of spent fuel in pools next to U.S. nuclear-power reactors. Our concern was the possibility of a spent-fuel fire resulting in case of a sudden loss of coolant or cooling. We considered ways in which this hazard might be mitigated—especially by reducing the packing density.[1]

The summary in the conclusion of the NRC's critique of our article states that

> "The overall effect of the combined conservatisms in the four major areas discussed cumulatively affect the article's cost-benefit calculations for its central recommendations by orders of magnitude."

Specifically, the NRC claims that we have: 1) Exaggerated the probability of a spent-fuel-pool fire; 2) Overestimated the release of 30-year half-life cesium-137 (^{137}Cs); 3) Overestimated the damage from the release; and 4) Underestimated the costs of moving to dry-storage casks a large fraction of the older spent fuel currently in spent-fuel pools.

As will be shown below, however, the NRC's critique in each of those four areas evaporates upon detailed inspection: 1) On probabilities, it restates some of our observations as if we had said the opposite; 2) On ^{137}Cs releases from a spent-fuel fire, it has adopted the lower end of our uncertainty range by simply assuming that a fire would not spread from recently-discharged to older spent fuel; 3) On damage, it asserts that projections of the future population density around U.S. reactors used in a 1997 study done for it were unrealistically high without offering an alternative; and 4) On costs, it argues incorrectly that we have neglected certain costs of removing 80% of the spent fuel currently in spent-fuel pools and ignores lower-cost options that we urged it to examine as well.

More generally, the NRC rejects essentially all the studies of this issue that have been done for it over the last 25 years by its staff and by the national labs—studies with which our study is in essential agreement. It states that this rejection is based on a new study by its staff but that this study cannot be released for peer review because of "security classification issues."

But the substance of the NRC's critique of our analysis reveals the emptiness of its claim that its own analysis has to be classified. Is it justified—or even possible—to classify: 1) A model of whether or not a fire in dense-packed spent fuel would spread? 2) Projections of the future population densities around U.S. nuclear power plants? 3) Cost estimates for returning U.S. spent fuel pools to their design packing densities? Even in the area of generic studies of possible vulnerabilities, such as the ability of projectiles to penetrate reinforced concrete, we don't think that it is either desirable or feasible to roll back the clock and classify studies.

What should be classified is the vulnerabilities of specific plants. But there the NRC paradoxically criticizes us for our discretion in not doing "site specific studies."

Basically, the NRC's strident but vaporous critique reflects its determination not to require any costly upgrades in the current safety arrangements at U.S. nuclear power plants. As the NRC's own Inspector General recently observed[2]

> NRC appears to have informally established an unreasonably high burden of requiring absolute proof of a safety problem.

Indeed, the NRC has set up the same burden of absolute proof with regard to threats of terrorism, where no proof is possible until after the fact. It has repeatedly rejected consideration of the possibility of terrorist acts in its regulatory decisions, reciting over and over again the mantra[3] "the possibility of a terrorist attack . . . is speculative and simply too far removed from the natural or expected consequences of agency action [ellipsis in original]"

In the current threat environment, the nation must not give the economic interests of nuclear-plant operators priority over the safety of the American people. And the NRC cannot be allowed to use public fears of nuclear terrorism as an excuse to unnecessarily hide its analyses behind a curtain of secrecy. It should be required to subject these analyses to independent peer review with arrangements that protect sensitive information.

BACKGROUND

The NRC review of our article was in response to instructions from the Commissioners on April 11, 2003

"The Commission expects staff to respond promptly to published research in areas of concern to NRC which reflect questionable analysis and conclusions. In particular, staff should develop a brief critique which responds to the 'Alvarez report' and informs NRC stakeholders, and the general public, of how it deviates from NRC's own research conclusions."

On the same day that the review was issued, August 19, 2003, the authors received a response from Ashok Thadani, Director of the NRC's Office of Regulatory Research [RES], to our letter to him of April 21, 2003. In that letter, which had been provoked by the NRC's request, we stated that

"The 'questionable analysis' which the Commission attributes to us [the current authors] is, in fact, largely a technical review of 25 years of reports done for the NRC by its own staff and by the national laboratories. Now, you [Mr. Thadani] are being asked by the Commission to inform 'NRC stakeholders, and the general public' how our findings and implicitly those in 25 years of reports done for the Commission '[deviate] from NRC's own [new] research conclusions,' without your new analysis even being published."

"We believe that you will agree that what you are being asked to do does not conform to the standard procedures by which technical debate is kept open and honest. Those procedures require that, before the NRC issues a critique of our paper, it must publish the RES analyses on which the Commission requests you to base the critique. Only in that way will we and other independent experts be able to compare RES's new analysis with those done for NRC during the previous

> 25 years and understand the differences. With this letter, we request that you do so."

Mr. Thadani responded that

> "In your letter you also requested that we publish the new spent fuel analyses before issuing a critique of your paper. Because of the current threat environment and heightened government and public interest, we believe it is important to prepare an unclassified critique of your article . . . Thus, although our usual practice is to have our research peer-reviewed before it is published, in this case it was important to make some of the results publicly available before the peer review.
>
> "We recognize the importance of making the analyses publicly available to the extent possible considering security classification issues, and we will strive to do so in a timely manner. We intend to conduct a peer review of the analyses by qualified non-NRC persons who have done work in this field and possess the appropriate security clearances. Following the peer review we will prepare a non-classified summary of the analyses."

In fact, as we will show below, classified information has little relevance to the NRC's comments on our article. And the NRC's claims about the conclusions of its own analyses are just as vague in obviously unclassified areas, such as cost and radioactive releases from a spent-fuel fires, as in areas such as the vulnerabilities of spent-fuel pool systems about which both the NRC and we must be discreet.

Below we organize our response under the same headings used in the NRC review.

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

The NRC review comments that

> "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.' . . . The authors deduce that if there is a 0.7 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."

The NRC then complains

> "but they do not provide any basis for these probabilities."

In fact, the NRC quotes us selectively and misleadingly. Our paper states that

> "Since the probabilities of specific acts of malevolence cannot be estimated in advance, the NRC and Congress will have to make a judgment of the probability that should be used in cost-benefit analyses. The most costly measures we propose would be justified using the NRC's cost-benefit approach if the probability of an accident or attack on a U.S. spent-fuel pool resulting in a complete release of its ^{137}Cs inventory were judged to be 0.7 percent in a 30-year period. *This is the upper end of the range of probabilities estimated by the NRC staff for spent-fuel fires caused by accidents alone.* For a release of one tenth of the ^{137}Cs inventory, the break-even probability would rise to about 5 percent in 30 years" [italics in the original].

In the associated footnote, we note that the 2001 NRC staff report, *Technical study of spent fuel pool accident risk at decommissioning nuclear power plants* (NUREG-1738) estimated a probability for a spent-fuel fire as $0.6 - 2.4 \times 10^{-6}$ per pool per year. Multiplying by 103 pools, this corresponds to a probability of 0.2–0.7 percent in 30 years. Thus the NRC's estimate of the risk of a spent-fuel pool fire caused by accident *alone* would justify the consideration of significant safety improvements. The NRC and Congress must judge how much the urgency is increased by the additional unquantifiable risk of terrorism.

With regard to our discussion of specific possible means by which terrorists might cause a spent-fuel-pool fire: loss of cooling and boil off; drainage by opening of valves or seals; fire; fuel-air or other type of explosion; and puncture by an airplane engine turbine shaft, dropped cask or shaped charge, the NRC comments on only two: puncture by an airplane turbine shaft and a jet-fuel fire. In its comments, the NRC claims that in those cases it has arrived at different conclusions than we did but, in fact, the differences are not apparent to us.

Puncture by an Airplane Turbine Shaft

As the NRC points out

> "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 . . . analyses which rely on these assumptions, as does the subject study. . . are not reflecting the actual structural capabilities of power reactor spent fuel pools."

In fact, contrary to the NRC's statement, our article makes the same point: "It is possible that a spent-fuel pool, with its content of water mixed with dense fuel assemblies, might resist penetration more like an infinitely thick slab," which we note would significantly reduce the penetration. We conclude, however, that, if a large aircraft were traveling at the speed of the one that crashed into the World Trade Center South Tower (590 miles/hr), penetration "cannot be ruled out." We note that, despite its claims for the improved models whose development it has sponsored (are generic models now classified?) the NRC does not dispute our conclusion.

Jet-Fuel Fire

The NRC review states that

> "a means cited in the article 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 vaporize 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."

This is a tendentious and tortured misinterpretation of the two sentences in our article on the subject. We believe that any fair-minded reader would understand that these sentences, which we copy below, simply say that a jet fuel fire would likely not evaporate a significant amount of water

> "The burning of 30 cubic meters of kerosene—about one third as much as can be carried by the type of aircraft which struck the World Trade Center on September 11, 2001—would release about 10^{12} joules of heat—enough to evaporate 500 tons of water. However, under most circumstances, only a relatively small fraction of the heat would go into the pool."

We take the opportunity to urge here that the NRC should analyze data from spent-fuel-pool accidents worldwide. We note specifically that an overheating accident in a spent fuel pool—perhaps the most serious to date—occurred on April 12, 2003 at Hungary's PAKS-2 nuclear power plant in the course of an operation in which freshly discharged fuel was being cleaned. A large fraction of the volatile fission products in the fuel were released but were fortunately mostly trapped in the pool water.[4] The lessons for the U.S. are not immediately clear but for the NRC to act as if the event did not happen is irresponsible.

Overestimation of Radiation Release

The NRC review states that

> "preliminary analysis indicates that previous NRC estimates of the quantities of fission products released were high by likely an order of magnitude."

The NRC notes that we followed a 1997 study done for the NRC by Brookhaven National Laboratory (BNL), a *safety and regulatory assessment of generic BWR and PWR permanently shutdown nuclear power plants* (NUREG/CR-4982), which estimated spent-fuel fire consequences for ten and hundred percent releases to the atmosphere of the ^{137}Cs in the pool. The NRC claims that the 75 percent release assumed in its own 2001 staff report (NUREG-1738) was simply a conservative assumption.

In fact, the BNL report and our own discuss at some length the factors that would determine the release fraction. The most important determinants would be the fraction of the spent fuel that burned and the fraction of the released ^{137}Cs plated out in the spent-fuel building. The phenomena of fire spread and building plate out are quite complicated, have not yet been modeled by anyone, and the range of uncertainty for any serious analysis would be large. We are skeptical that the NRC staff has enough firepower on its own to do such an analysis.

Which "previous NRC estimates" are being referred to in the statement above? Our guess is primarily the 2001 staff estimate of 75 percent release. And mathematically "high by an order of magnitude" means that previous estimates were high by a factor of about ten. We note that 7.5 percent is close to the 10-percent-release bottom end of the BNL range estimate. This presumably is based on an NRC best-case assumption that a spent-fuel fire starting in recently discharged fuel would not spread into older, colder fuel. It would be interesting to learn whether this assumption is based on more than classified wishful thinking.

Overestimation of Consequences and Societal Costs for Postulated Severe Event

The NRC review states that

> "The authors' analysis of land contamination for a postulated severe 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."

Here again, the NRC misrepresents our article. We quoted the BNL results and then went on to state that its findings were "consistent with our own calculations using the [NRC's] MACCS2 code." We then described the results of our own calculations for releases of 3.5 and 35 megaCuries of ^{137}Cs. The assumptions used are standard. The NRC recommended value of $4 million per cancer death is the most important. We used the cancer dose-risk coefficient recommended by the most recent review by U.N. Committee on Sources and Effects of Atomic Radiation and EPA evacuation criteria. All this, the NRC reviewers have chosen to ignore.

With regard to population density, the BNL report apparently projected future population growth around U.S. nuclear-power plants. In order to minimize transmission costs, these plants, which were mostly sited in the 1970s, are typically located near urban areas. Those urban areas have been spreading and are expected to continue to spread. The BNL report therefore assumed that the average population density in the 30 mile zones around reactors will rise to about 1000 people per square mile—approximately the population densities of Massachusetts or New Jersey. In its stylized population distribution, the BNL group assumed further a city with a population of 10 million centered 40 miles away from the plant and finally, an average population density beyond 50 miles of 200 people per square mile—about twice the average population density of the 48 contiguous states. This reflects again the fact that nuclear power plants are mostly located in the more densely populated Eastern, Midwest and Pacific states. Our own calculations assumed a uniform population density of 650 people per square mile—intermediate between the near and distant population densities used by BNL. Of course, we would be interested in what assumptions the NRC used in making its own projections of the average population density profile around U.S. nuclear power plants 20 years or so in the future—if these assumptions are not classified.

A note giving additional details of our economic calculations will appear at the Princeton website of *Science & Global Security* by the time this appears in print.[5]

Underestimating the Cost of Main Recommendation

The NRC review states that

"The article estimates the cost for removing the older fuel from pools and placing it in casks to be $3.7–7 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."

Why so vague? Surely the NRC's own cost estimates are not classified! Our own uncertainty range is a factor of two. Does the NRC consider the middle of our range low by a factor of two? Why does the NRC want to attribute to the cost of our proposal the design and construction of dry storage facilities when, as our paper points out, most reactor owners are constructing such facilities anyway because, even with dense-packing, their pools will soon be full? Why also does the NRC choose to focus on the highest cost proposal we make and ignore our suggestion that it examine the potential value of an intermediate, less costly

> "arrangement where one fifth of the fuel assemblies are removed in a pattern in which each of the remaining fuel assemblies has one side next to an empty space."

This alternative would require the removal of only about one fourth as much fuel, and would cost about one fourth as much as would going back to the original design density for these pools.

CONCLUSION

The record is clear: the NRC allowed the nuclear power industry to choose the least-cost default option to store a burgeoning inventory of spent reactor fuel in pools that were originally designed for a density one fifth that now prevalent in dense-racked pools. Even with the highly optimistic assumption that a geological repository will be open by 2010, large amounts of densely compacted spent fuel will remain in potentially vulnerable pools for decades.

We are disappointed by the NRC's unwillingness to even engage in a serious discussion of the excellent analyses that have been done for it by the national labs of the safety and security issues stemming from this situation—or of the policy proposals that follow naturally from these analyses.

Even the most costly proposal discussed in our paper is hardly radical or unproven. Germany recognized the risks associated with densely compacted spent fuel pools 25 years ago and now uses dry, hardened storage. In 1993, the Department of Energy decided to dry store almost all of its spent fuel and is currently in the process of implementing that decision.

The NRC's misleading characterization and denigration of our work and that of the national laboratories is not appropriate for a regulatory agency with its great responsibilities for public health and safety. We return to the recent observation by the Commission's own Inspector General

> "NRC appears to have informally established an unreasonably high burden of requiring absolute proof of a safety problem."

How does the NRC culture work to informally require absolute proof of a safety problem? Based on our experience with the spent fuel issue, we have noted a pattern of "asymmetrical analysis." When a study suggests there is no problem, it is accepted and rarely questioned. On the other hand, when an analysis suggests a safety problem exists, it is challenged and redone again and again indefinitely or until, as in the present case, the staff finally decides that the problem is not so serious after all.

Since September 11, 2001, it has become impossible for outsiders to even question this process because of a wall of secrecy. In the present case, our review of the NRC's comments suggests that this secrecy hides more lack of analysis than sensitive analysis.

Given the huge amounts of radioactive material in spent fuel pools and the real danger of terrorist attacks against nuclear power facilities, the NRC should not be allowed to escape scrutiny of its own analyses by invoking "security classification issues." In recent licensing cases, citizen groups and state officials have requested evidentiary hearings to examine the hazard posed by potential acts of malice at spent-fuel-storage facilities and the options for reducing that hazard. Well-established procedures would allow these hearings to function without the disclosure of sensitive information. Dr. Thadani's proposal to arrange for a

> peer review of the [NRC staff] analyses by qualified non-NRC persons who have done work in this field and possess the appropriate security clearances

is no substitute for truly independent peer review.

The public and Congress should hold the NRC to a higher standard.

NOTES AND REFERENCES

1. "Reducing the hazards from stored spent power-reactor fuel in the United States," by Robert Alvarez, Jan Beyea, Klaus Janberg, Jungmin Kang, Ed Lyman, Allison MacFarlane, Gordon Thompson, and Frank von Hippel, *Science & Global Security* 11 (2003), pp. 1–51.

2. *NRC's regulation of Davis-Besse regarding damage to the reactor vessel head* (Inspector General's Report, Dec. 30, 2002, http://www.nrc.gov/reading-rm/doc-collections/insp-gen/2003/02-03s.pdf, p. 23).

3. NRC quotation and reiteration of four previous rejections of petitions by citizens groups and state governments that it consider the possibility of terrorism in spent-fuel-pool storage licensing decisions, "In the Matter of Pacific Gas & Electric Co. (Diablo Canyon Power Plant Independent Spent Fuel Storage Installation)" (NRC Memorandum and Order, January 23, 2003, http://www.nrc.gov/reading-rm/doc-collections/commission/orders/2003/2003-01cli.html).

4. "Radiation release from PAKS-2 traced to fuel cleaning system," *Nucleonics Week*, April 17, 2003; "Extensive ex-core fuel damage found at PAKS; rated at INES 3," *Nucleonics Week*, April 24, 2003.

5. http://www.princeton.edu/~globsec/publications/SciGloSec.shtml