UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

November 20, 2013

Ms. Diane Curran, Esq.
Harmon, Curran, Spielberg & Eisenberg, LLP
1726 M Street N.W., Suite 600
Washington, DC 20036

Dear Ms. Curran,

This letter responds to your October 2, 2013 letter (Enclosure 1) expressing concerns regarding the ACRS review of the NRC's Draft Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor (Spent Fuel Pool Study or SFPS). It also addresses your communication to Mr. Christopher Brown of the ACRS staff on October 9, 2013 (Enclosure 2), containing a letter to be forwarded to ACRS Member Dr. Dana Powers regarding the same subject.

We understand that the organizations that you represent did not believe that they had sufficient time to examine the SFPS and provide input to our July 2013 SFPS deliberations. However, we subsequently had the opportunity to hear your views as well as those of Dr. Robert Alvarez and Dr. Edwin Lyman during the 608th ACRS meeting held on October 2-5, 2013, and consider written comments prepared by Dr. Gordon Thompson.

In the communication that you sent to Mr. Christopher Brown, you requested that the letter contained therein be forwarded to Dr. Dana Powers. In that communication, you reiterated your request that the ACRS re-open the review of the SFPS. Additionally, you requested a meeting (or conference call) with Dr. Dana Powers, Dr. Gordon Thompson, and Mr. David Lochbaum to discuss the recommendations from the April 13, 2000 ACRS Letter Report on the draft technical study of spent fuel pool accident risk at decommissioning nuclear power plants, in relation to the SFPS. Dr. Dana Powers has reviewed your communications and was also present during the608th ACRS meeting.

We have considered your request that the ACRS re-open the review of the subject study based on Dr. Gordon Thompson's written comments, particularly those related to risks resulting from partial pool drain down events. We have concluded that these comments do not present new or unreviewed information regarding spent fuel pool risk, and do not warrant re-opening our review of the SFPS.

Dr. Dana Powers' comments on Dr. Thompson's review of the U. S. Nuclear Regulatory Commission's Draft Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a US Mark I Boiling Water Reactor) are provided in Enclosure 3.

Sincerely,

/RA/

J. Sam Armijo
Chairman

Enclosures:
As stated

REFERENCES

1. Draft Report, Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor, June, 2013, (ML13133A132).

2. Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor, October 2013, (ML13256A342).

3. ACRS Letter, Subject: Report on the Spent Fuel Pool Study, July 18, 2013, (ML13198A433).

4. ACRS Letter, Subject: Report on the Spent Fuel Pool Scoping Study, April 25, 2012, (ML12108A216).

5. ACRS Letter. Subject: Draft Final Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants, April 13, 2000, (ML003704532).

6. ACRS Letter. Subject: Draft Final Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants, November 8, 2000, (ML003769163).

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Enclosure 3

November 8, 2013

To: **J.S. Armijo**
From: D.A. Powers

SUBJECT: COMMENTS ON "COMMENTS ON THE US NUCLEAR REGULATORY COMMISSION'S DRAFT CONSEQUENCE STUDY OF A BEYOND-DESIGN-BASIS EARTHQUAKE AFFECTING THE SPENT FUEL POOL FOR A US MARK I BOILING WATER REACTOR" BY GORDON R. THOMPSON

I have examined the document "Comments on the US Nuclear Regulatory Commission's Draft Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a US Mark I Boiling Water Reactor" by Gordon R. Thompson and dated August 1, 2013. My comments on this document are presented here.

Dr. Thompson has examined very extensively the literature associated with accidents in spent fuel pools at operating nuclear power plants. His document is not an objective, critical review of this literature though it could have been. The author has chosen to punctuate the document with comments on the motivations and competence of the investigators responsible for literature that spans over three decades during which there were substantial evolutions in technical understanding of reactor accident phenomena. The ad hominem comments detract, of course, from what could have been a useful, technically objective critique of the current state of understanding of spent fuel pool fires.

Dr. Thompson raises several interesting points many of which are well recognized within the technical community concerned with reactor accident phenomena. I shall touch upon these points further in discussions below. I find one point that he seems to be making to be questionable. Dr. Thompson seems to feel a thorough phenomenological understanding is needed before any risk assessment is undertaken (See point III-7 in reviewed document). Suspending regulatory actions until thorough phenomenological understanding is available is not consistent with good engineering practice and would not serve well the assurance of adequate protection of the public health and safety. Accident initiation frequency, mitigation probability and accident progression can examined in parallel and, indeed, need to be investigated in parallel since findings in one area can affect investigations in another. I can think of no important reactor safety issue where a serial approach of developing a comprehensive phenomenological understanding prior to undertaking an analysis of event initiation and event mitigation has been pursued. To be sure, we have not attempted to develop a comprehensive phenomenological understanding of meteor impact on a nuclear power plant before concluding such an event is exceptionally improbable.

Dr. Thompson elects in his analysis to consider both natural events and hostile attack as initiators of spent fuel pool events. I shall confine my comments to accidents initiated by natural events or plant operations for the simple reason that I have no particular knowledge about the probability of attack on a spent fuel pool at a nuclear power plant. Dr. Thompson asserts (Section VI-12) that "The probability of an attack with a substantial likelihood of success is at

least equal to the probability of an earthquake that NRC does consider (i.e. 1 in 60000 years)." He does not provide a basis for this assertion. I'm not certain the usual concepts of probability are applicable to hostile attack. If such concepts are applicable, the Bayesian prior should be very small since to my knowledge there has been none in all the years of plant operations around the world. I do know that specialists in the field feel that hostile actions against nuclear power plants including spent fuel pools should be weighted by the difficulty of success. Since plants in the US are known to have the capacity to defend against a design basis threat, one might well conclude on this weighted basis that the chance of successful attack is below a threshold determined by the need for adequate protection of the public health and safety.

I proceed on the assumption that actions by site personnel and accident progression will be much the same whether an event is initiated by a natural event, plant operations, or hostile attack. That is, both accident progression and site personnel efforts to remediate a loss of spent fuel pool coolant inventory will have to be considered. I can well imagine hostile attacks in which these assumptions are not valid, but I am not capable of addressing these hypothetical, very extreme, security situations.

The natural event initiating draining of a spent fuel pool that is the focus of Dr. Thompson's analysis is, of course, a seismic event. Dr. Thompson does not explicitly quantify the probability of such a damaging event. He does appear to equate it with the probability of a seismic event capable of damaging the nuclear power plant itself. Certainly, this is a conservative position. It should be noted, however, that here have been several seismic events in recent years affecting boiling water nuclear power plants. In some cases, these events have produced ground motions that exceed the Safe Shutdown Earthquakes specified for the plants. In none of the cases has there been a pool draining event. Nevertheless, it would be imprudent to assume that a seismic event was incapable of rupturing a spent fuel pool in a way that lead to a loss of coolant inventory or loss of coolant feed. For the purposes of these comments, then, the equality suggested by Dr. Thompson is accepted.

Dr. Thompson devotes rather little attention to the issue of event mitigation. He does note the challenges encountered in assuring coolant to the Unit 4 spent fuel pool during the accident at Fukushima Daiichi. This light treatment of event mitigation leads, I think, to a misinterpretation of past analyses.

The "Worst" Accident

Dr. Thompson deplores the attention focused on events that lead to a complete loss of coolant inventory at the expense of attentions to events that cause only a partial loss of coolant inventory (See especially Section III of the report). Dr. Thompson raises this point because of a belief that it is more likely extensive damage to the fuel will occur in the partial drain event than in the complete drain event because of differences in circulation of gas over the fuel assemblies. Even using analyses presented by Dr. Thompson in his document, it is readily apparent that there is substantial time available for site personnel to recover from a partial drain event (See for example Section VII-13 in the report). That is, it is highly probable that site personnel will

identify a partial loss of coolant in a spent fuel pool and respond to replenish the coolant before any damage to the fuel occurs. An event that leads to prompt loss of all inventory, on the other hand, may develop so quickly that it cannot be diagnosed and remediated by the site personnel especially if damage has occurred to the nuclear power plant as well. I suspect, with rather substantial reasons, that the election for first analyses to focus on the complete drain event first was motivated by the consideration of not only the accident phenomena but also the probability that remedial action would be implemented successfully. Phenomenological analyses could well have suggested rather extensive automatic protections were needed for an event that developed too rapidly for effective remediation by site personnel.

The relative ease with which partial drain events can be mitigated and terminated needs to be recognized. Spent fuel pools are not pressurized systems. Consequently, rather simple water supply systems can be used to restore coolant. The simplicity of the needed systems contrasts with the rather robust systems needed to supply additional coolant to a pressurized reactor coolant system. Furthermore, rather small amounts of water are needed typically to maintain coolant inventory. Analyses typically show the leak size dictates the water supply rather than the decay heat load in the pool.

Natural Convection During Spent Fuel Events

Dr. Thompson's concerns with partial drain events arises primarily because the residual water will block the natural convection of cooling gas up through fuel assemblies that is possible in events that involve a complete loss of coolant inventory. In fact, there can still be natural convection of gases even in the partial drain event. The partial drain event will involve a low level hot layer below a layer of cool gas. This is a prescription for Bénard convection. The length scales for spent fuel pools are such that high Rayleigh numbers can be expected. Furthermore, the buoyancy of rising hot, low density gas into a layer of higher density, cool gas will give rise to Rayleigh-Taylor instability that can cause 'fingering' of the cooling gas down into the inter-assembly and inter-rack spaces. Channel boxes provide cooling 'fins' that can assist in the removal of heat from the assembly to this circulating gas. Natural convection of gas during the partial drain event still occurs. It is just more complicated than in the case of full drain events. Indeed, to my knowledge there has not been a detailed analysis of Bénard convection and Rayleigh-Taylor instability during a spent fuel pool accident. I am aware of proposals to conduct such analyses in France. Motivations to fund these proposals are limited, I suspect, by the slow development of partial drain events and the high probability that such events can be terminated by the restoration of coolant inventory.

Dense Rack Issues

Dr. Thompson calls attention to the decision to allow high density storage racks in spent fuel pools. He does not discuss the heat capacity effect of the higher density fuel storage nor does he address requirements to locate spent fuel assemblies with high rates of decay heat production within arrays of spent fuel assemblies that have very low rates of decay heat production. These requirements do not prevent the progression of an accident, but they do delay progression of an accident and provide more time for diagnosis of a loss of inventory and implementation of remediation measures.

Dr. Thompson asserts without reference that ignition of assemblies in low density racks would occur only in “very rare circumstances” (Section III-4). He seems to feel that ignition is only possible if there is some barrier to the cooling effects of natural circulation of gas. It is my impression that decay heat rates play a rather significant role in the propensity for fuel assemblies to oxidize catastrophically in the event of the loss of coolant either partially or completely. I do not share Dr. Thompson’s confidence that barring collapse of structures on spent fuel, low density racking is a panacea assuring safety of spent fuel pools.

Experimental Studies of Spent Fuel Pool Accidents

Dr. Thompson seems to be unfamiliar with experimental investigations of spent fuel pool phenomenology undertaken by NRC and OECD (Section III-25). I don’t really fault him for this since some of this work has not been openly published because of agreements among participants funding the work that delay making results available broadly to those who have not furnished resources. Neglect of these works does not detract from most of the points he makes. Because he is not aware of the work, he does not have some information that has been used to derive confidence in model predictions of spent fuel pool events.

What Studies Should Have Been Done

Much of Section IV of Dr. Thompson’s report is devoted to outlining an extensive study of accident phenomenology for spent fuel events. The intent seems to be to establish a very comprehensive understanding to a scientific certainty in this phenomenology. Dr. Thompson does not make clear why this should be done if, in fact, it can be shown that partial drain events are easily remediated with high confidence and that complete drain events are highly improbable. Nor does he provide a ranking of the use of resources for the purposes of studying spent fuel pools in preference to other safety issues. On the basis of results presented to ACRS thus far, it would appear that a systems engineering evaluation would suggest the best use of available resources would be to assure that mitigation of partial drain events was assured and that complete drain events were highly improbable. This would obviate the need for a detailed understanding of accident phenomenology. Should a decision be made to conduct confirmatory research, examination of the Dr. Thompson’s list of topics might be useful starting point in the identification of possible avenues of investigation.

Dr. Thompson does make an implied point that the collapse of structures and equipment into the pool may change our current understanding of accident phenomena and the time available for remediation of partial and complete drain events. I am not aware of studies of either analytic or experimental nature on this matter. We do know that a large amount of structural material collapsed into the Unit 3 spent fuel pool at Fukushima Daiichi. This did not lead to an event at the spent fuel pool, but there was also no significant loss of coolant inventory from this pool.

Again, I am aware of proposals to conduct further studies of spent fuel pool event phenomenology in Europe. I am not aware of the status of funding of the proposed work. I do know that some further consideration of studies by NRC is underway. Its progress is unknown to me. It is entirely possible that NRC will bolster its regulatory decisions based on expected initiation frequency, probability of successful mitigation and limited understanding of accident phenomena with some confirmatory research. I doubt that any program of confirmatory research would be as comprehensive as outlined by Dr. Thompson. Instead, a confirmatory research program would focus on critical issues most likely to alter the bases for regulatory decisions that could not be delayed until there was a comprehensive understanding.

Scope of NRC's Draft Consequence Study

Section V of Dr. Thompson's report complains of the narrow focus of the Draft Consequence Study on the issue of accelerated movement of spent fuel from the pools to dry casks. Dr. Thompson does not seem to be aware that the staff was responding to a particular question posed by the Commission with a very specific response date.

Section VI of Dr. Thompson's report opens with some criticism of the discontinuity between the Executive Summary and the main text. This is quite familiar to ACRS and I shall not further belabor it.

Dr. Thompson does not agree with the selection of example cases in the report. This, of course, is somewhat a matter of engineering judgment. It is not immediately apparent to me that alternatives would better serve the narrow purposes of the NRC's study which was a comparative risk analysis. Dr. Thompson does acknowledge in Section VI-6 that the two test cases selected by the staff were suitable for risk analysis. He asserts only that they are not adequate to address other issues or provide a more comprehensive understanding of phenomena. I suspect that the authors of the Consequence Study would concede this point.

Human Reliability Analysis

In section VI-17, Dr. Thompson casts aspersions on limited scope of the human reliability analysis done by the NRC. Human actions to mitigate partial drain events are crucial. The staff admits to having done a very limited analysis. Dr. Thompson does not note that the reliability estimates are rather conservative. He does not make clear why he feels these are not adequate bounds on what would make it challenging for plant personnel to identify and remediate an event that is readily detectable and takes hours to unfold. I do note that ACRS experts on human reliability critiqued the staff for being excessively conservative in their assessment of human reliability in spent fuel pool events. It is my experience, however, that reasonable men can differ in their assessments of human reliability. The report defends itself by using recognized methods of analysis and acknowledging limitations.

Use of MELCOR

In section VII of his report, Dr. Thompson questions the use of MELCOR for analysis of spent fuel pool accidents. To be sure, the MELCOR code was not developed for such analyses. It is, however, a flexible computational vehicle that could be adapted to the purposes of analysis of spent fuel pools and has been used to do so. MELCOR has been used to predict findings of NRC and OECD sponsored tests to investigate spent fuel pool phenomena.

Dr. Thompson notes that MELCOR assumes a cylindrical, axisymmetric computational geometry that is not precisely the configuration of fuel in a spent fuel pool. Of course, fuel within a reactor core is not precisely axisymmetric as modeled by MELCOR. Indeed every in-pile test that has been done of fuel degradation under accident conditions is not perfectly cylindrical – most configurations are square in cross-section in the fuel region. This treatment in MELCOR has consistently been found to be an adequate engineering approximation that improves with scale.

Dr. Thompson questions the adequacy of the radiation heat transfer modeling in MELCOR (SectionVII-4) which again has received quite a lot of attention within the community of accident analysis modelers. While simplified, the treatment is not simplistic and is usually found to be an adequate engineering approximation that balances the requirements of computational speed and predictive accuracy.

Dr. Thompson notes the inability of MELCOR to model the deformation of fuel rods and cladding during a thermal transient (Section VII-4). He asserts that such deformation could reduce heat transfer and promote cladding ignition without saying why. He does not consider comparisons of MELCOR predictions to CORA and QUENCH tests where deformation also occurred but MELCOR was still able to make adequate predictions of fuel behavior.

Reactor – Spent Fuel Linkage

Dr. Thompson criticizes the staff for neglect of the possibility of linkage between the reactor and the spent fuel pool such as during refueling operations. This is widely recognized as a critical plant evolution though to my knowledge no spent fuel pool accident has ever been initiated during such an evolution – perhaps because it commands close attention by the operating staff who are those most likely to be injured during such an event. The evolution occurs at a plant only for a very few days about once every 1.5 to 2 years. Such a small period of time certainly suggests unexpected accident events that cannot be promptly and effectively remediated are highly unlikely to make any significant contribution to risk. It is difficult for me to fault the staff for neglect of such apparently low contributors to risk in their limited scope study with tight time schedules.

Conclusion

Dr. Thompson certainly raises issues that merit consideration if any confirmatory research is undertaken on spent fuel pool accident phenomenology. I would certainly enjoy further discussions with Dr. Thompson to refine the issues he raises. But, I can find nothing in his report that directly calls into question the technical adequacy of the staff's Consequence Study given its rather limited scope. His points on the documentation of the work and the inconsistency between the main text and the Executive Summary echo points made by ACRS to the staff.