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Prof. David D. Jackson
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Mr. Ralph Hutchison, Director
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Dear Mr. Hutchison

You have asked me to review the National Nuclear Security Administration's ("NNSA") discussion of seismic risks at the Y-12 National Security Complex, particularly in association with NNSA's 2020 issuance of a Draft Supplement Analysis for the Site-Wide Environmental Impact Statement for the Y-12 National Security Complex (DOE/EIS-0387-SA-02) ("2018 SA"). I have reviewed the 2018 SA, as well as related documents including NNSA's prior Supplement Analysis from 2016, NNSA's 2011 Site-Wide Environmental Impact Statement, the data and models represented in the 2008 and 2014 United States Geological Survey's ("USGS") seismic hazard maps, Judge Reeve's Memorandum Opinion and Order, the NNSA 2020 Draft Supplement Analysis, as well as more recent seismic hazard maps and underlying data from the USGS. In my professional opinion, NNSA has conducted no rigorous seismic hazard evaluation associated with its activities at the Y-12 National Security Complex. A more thorough consideration of seismic risks is essential in light of the hazardous and nationally important work done at this Complex.

I am a geophysicist with extensive experience considering seismic issues, in particular with regard to probabilistic seismic hazard analysis, statistical data analysis, earthquake forecasting and prediction, and the consideration of likely damage from earthquakes. I earned my Bachelor of Science degree in geophysics from the California Institute of Technology in 1965 and my Ph.D. in geophysics from the Massachusetts Institute of Technology in 1969. I served as a professor of geophysics at the University of California Los Angeles from 1969 until 2011, when I became a Distinguished Professor Emeritus and a consultant in seismology, statistics, and natural hazards. In my decades of experience, I have authored or co-authored hundreds of articles in peer-reviewed scientific publications covering probabilistic forecasting of earthquakes, simulation and modeling of earthquakes, the testing of earthquake likelihood models, seismic hazards, and probabilistic hypothesis testing. I led numerous professional organizations, serving as President of the Seismology Section of the American Geophysical Union and Science Director of the Southern California Earthquake Center. I served on a research panel for the National Academy of Sciences, advised the Governor of California by serving on the California Earthquake Prediction Evaluation Council. I served on the National Earthquake Prediction Evaluation Council, an advisory committee to the USGS created by Congress in 1980 to provide expert input and recommendations regarding the best means to issue timely warnings of potential geological disasters.

I have reviewed the relevant documents associated with NNSA's analysis of seismic risks at the Y-12 National Security Complex, and I find the agency's analysis to be badly lacking. In my expert opinion, NNSA's review is not an adequate scientifically based review of seismic risks. The agency's review is defective in numerous regards. It falls far short of relevant professional and scientific standards, offers a simplistic analysis of risks that fails to disclose or properly analyze critical underlying data, fails to consider adequately some highly relevant new data from the USGS, fails to employ a modern set of tools for analyzing seismic risks, chooses an arbitrary measurement of risk, and fails to respond in any coherent manner to new information furnished by the USGS and the Defense Nuclear Facilities Safety Board ("DNFSB").

A rigorous scientific evaluation of seismic risks considers numerous features of earthquakes, including some or all "intensity measures" like:

a. PGA, peak ground acceleration at different probabilities;
b. PGV, peak ground velocity at different probabilities;
c. maximum ground displacement at different probabilities
d. spectral acceleration at various wave frequencies that can affect different structures in different ways;
e. spectral velocity as a function of frequency
f. ground settling, ground tilt, and permanent ground displacement,
g. Modified Mercalli Intensity,
h. duration of shaking
i. secondary risks such as fire, soil liquefaction, landslides,
j. potential for dam failure, drainage blocking, or other hydrologic changes
k. potential for raising dust or possibly unhealthy fine-grained sediments

Those measures depend on the location, size, and other characteristics of future earthquakes, and the rock and soil conditions at any particular site. Large earthquakes may occur where none have been known to happen before, or where no "capable fault" can be identified before. Each of these intensity measures is important and merits thorough analysis in some cases. These measures are highly correlated, but their differences are important because they affect structures in different ways, and a single measure is not adequate for complicated or critical facilities. Except for PGA and spectral acceleration, NNSA's review considers these issues superficially if at all.

NNSA's Deficient Consideration of USGS Seismic Hazard Reports

USGS estimates probable earthquake locations, magnitudes, sizes and occurrence rates throughout the USA. It then combines the effects of all such earthquakes to estimate the rate at which a selected intensity measure would likely exceed a given value at each point on the map. Reported intensity measures include peak ground acceleration (PGA), and frequency dependent spectral acceleration estimated by separating the frequency components of likely ground shaking. Frequency content matters because structures and their underlying soil have resonant frequencies at which they are more likely to suffer damage. NNSA's treatment of the USGS hazard reports is defective because NNSA considered them only in the most simplistic manner.

First, they describe Probabilistic Seismic Hazard Analysis (PSHA) as if it describes just a single scalar intensity measure of probable ground shaking exceedance, (acceleration at 2% probability in 50 years), and that a structure should be safe enough if it was designed to survive that measure of shaking. That approach may be adequate for common structures whose behavior is easily modeled and for which occasional failures can be tolerated. Larger structures are harder to model, and tolerance for failures of crucial structures is much lower. For them, other intensity measures, the spectral response of probable shaking, and the spectral response of target structures must be considered. The NNSA Draft SA makes glancing references to such effects but shows no relevant data. Another problem with this simplistic assumption for existing structures is that actual structures may not conform to the design specification. Physical experiments and/or theoretical engineering calculations may be required to confirm that actual properties are up to the design specifications.

Second, NNSA has not articulated a standard for acceptable risk. The "2 percent over 50 years" standard is an arbitrary one that seismologists have in the past used to communicate with engineers, who often assume that a 2 percent risk is acceptable for most buildings and that many buildings have a 50-year lifespan. These assumptions are not appropriate for the existing buildings 9204-2E and 9215 at Y-12 because they are already about 50 and house extremely hazardous processes and materials that are critical to the NNSA's Enriched Uranium Program. Under these circumstances, a more conservative standard than the "2 percent over 50 year" would be more appropriate. The underlying USGS data show risks of significantly larger earthquake shaking than that which NNSA has superficially considered. Indeed, the underlying data shows that, while much larger earthquakes are less likely, very strong shaking at Y-12 is a real possibility and merits much more rigorous consideration.

Again, the hazardous nature of the work done at Y-12, the importance of this work, and the vulnerability of the aging buildings warrant more careful analysis and consideration of less frequent but much larger shaking than that reported for 2% in 50 years.

Following recent dramatic increases in earthquake occurrence in the Central and Eastern Unites States, USGS has since issued three updated sets of seismic hazard estimates in 2016, 2017, and 2018 that in my opinion are relevant to the risks at Y-12 and should be considered by NNSA. However, NNSA appears unaware of these publicly available estimates and maps. Of particular significance, the 2018 seismic hazard calculations indicate even greater hazard than that represented in the 2014 map. In particular, my review of the data indicates that, even within the “2 percent in 50 years” probability standard (which, again, is not the only standard NNSA should consider), the peak ground acceleration in the area of Y-12 could reach 0.6g. This is far greater than the levels that the aging buildings at Y-12 could likely withstand.

In my professional opinion, the hazardous and important nature of activities at Y-12, and the fact that these buildings are old, decaying, and not constructed according to modern standards (an issue described in greater detail below), warrant consideration of risks that are less likely but far more disastrous.

The recently updated USGS seismic hazard estimates are important and constitute new information that NNSA should carefully consider. In my professional opinion NNSA has fallen far short of a professional, scientific consideration of the issues by neglecting the recent USGS studies.

NNSA’s Inappropriate Focus on “Capable Faults”

Neither the 2018 SA nor the NNSA’s earlier 2016 SA acknowledge important new seismological observations showing that earthquakes— even very large ones—can and do occur in areas where no prior large earthquakes have been known to occur. Instead, the 2016 and 2018 SAs appear to carry over the analysis in NNSA’s 2011 Environmental Impact Statement, which focused principally on “capable faults,” arbitrarily defined as having surface movement within the past 35,000 years or movement of a recurring nature within the past 500,000 years. However, it is increasingly evident that large earthquakes can occur in the absence of such a fault. For example, in 2011 a disastrous earthquake (magnitude 6.1) occurred in Christchurch, New Zealand in a location where there were no capable faults within 20 kilometers. That earthquake caused serious damage to the city and indeed the entire country of New Zealand. Similarly, in 2012 a record-breaking magnitude 8.6 earthquake in the Pacific Ocean west of Sumatra struck where there was no capable fault, in spite of extensive sub-sea geological studies there. The recent Ridgecrest earthquake in California (2019, magnitude 7.1) and the Tonopah Nevada earthquake (2020, magnitude 6.5) both occurred away from previously discovered faults, even though the areas had been examined thoroughly by expert geologists.

Treatment of so-called capable faults is inconsistent in the Draft SA which references the 2011 SWEIS. Section 4.5.3 states that the nearest capable fault is 300 miles to the west of Y-12, yet an 1886 earthquake in Giles County VA was felt in Oak Ridge, 255 miles away. Independently, Hatcher et al. (2013) published Paleoseismic evidence that earthquakes of likely magnitude 6.5 occurred near Dandridge, TN, 55 miles from Oak Ridge. Warrell et al (2017) followed up with a more complete study, with evidence that three such earthquakes with magnitude of about 6 have occurred there in the last few thousand to tens of thousands of years.

It is a fact that large earthquakes commonly occur in areas where no capable fault is known. In my opinion, NNSA must give greater consideration to the possibility of a large earthquake in the vicinity of Y-12, because a focus on “capable faults” is inappropriate in light of the new seismological information. To ignore the empirical evidence in favor of an arbitrary definition and outdated observations is unjustifiable.

NNSA's Inadequate Consideration of Secondary Hazards

The risks associated with an earthquake are not limited to the immediate shaking of the ground. Secondary hazards from earthquakes include liquefaction, in which seismic shaking causes soil to lose cohesion, which can undermine building foundations or roads; landslides; fires caused by damage to electrical components and containers of flammable fluids; access and safety constraints on emergency response; and the risk that effects on one building could carry over to nearby buildings. Fires caused by the great San Francisco Earthquake of 1906 killed far more people than the earthquake shaking itself. The fires were especially serious because the earthquake disrupted water supply needed for fire suppression. The Fukushima Daiichi Nuclear Power Plant suffered fires and meltdown of three nuclear reactors largely because of secondary failures, including water and electrical failures, from the massive Tohoku, Japan earthquake and tsunami of 2011. There is of course no tsunami threat at Oak Ridge, but the lesson of cascading failures still applies.

Floods and fires are common side effects of strong earthquakes. While the Draft SA document and references describe plans for dealing with predictable consequences, the Fukushima and other recent events show that unanticipated failures still happen. For example, earthquake rates in the USGS PSHA reports do not consider aftershocks. Most are relatively small, but occasional ones can damage structures weakened by a main shock. Covid-19 doesn't cause structural damage, but it too serves as a reminder that some risks exceed our expectations.

In my professional opinion, NNSA's consideration of secondary effects from an earthquake is seriously inadequate.

NNSA's Failure to Conduct a Modern Analysis of The Risk Associated with Using Existing Buildings

Since the construction of the existing buildings at Y-12 during the Manhattan Project and the Cold War, building standards and the techniques used to evaluate risks have changed very significantly. As a result of more sophisticated abilities to model and evaluate risks, building standards have become far more rigorous and now require certain structural elements that allow buildings to better withstand the forces associated with an earthquake. Building codes require that structures be built to withstand prescribed shaking characteristics, depending on the size and intended use of the structures. The actual implementation depends in part on engineering calculations for how each structure would respond to that shaking. Recent experience and more sophisticated calculations show that many of the old designs would not in fact meet the standards for which they were designed. NNSA now acknowledges that the existing buildings 9204-2E and 9215at Y-12 would not satisfy modern building standards

Here the NNSA's reliance solely on probabilistic hazard analysis (e.g. the "2 percent in 50 years" standard) is far too simple. Older buildings and contents could fail for many reasons not covered by the PGA standard. Modern analysis of seismic risk entails the use of sophisticated computer models that simulate many hundreds of potential earthquakes and their likely effects on a structure. Designers then use the output from these models to amend the design of a building to ensure that it is best capable of withstanding the forces associated with an earthquake. These analysis methods would be far more effective at modeling the likely impacts on the existing buildings from earthquakes of various sizes, locations, and other characteristics.

Although design of these buildings could not be changed, cost efficient modifications and alternate usage modes might significantly reduce risks. In my opinion, the failure to use these modern tools in planning upgrades to the existing buildings is a significant deficiency in NNSA's analysis.

NNSA has now made a somewhat vague commitment to implement modern non-linear methods in designing the new UPF building, but not for the existing buildings targeted for new uses. Linear analysis is an overly simplified method wrongfully assuming that the deformation that a building undergoes during an earthquake scales in a linear fashion with the force of that earthquake. NNSA mentions correctly that in some cases nonlinear behavior may absorb energy and reduce stresses. However, the "some cases" clause is crucial. Linear modeling fails to capture the progressive failure that occurs in long duration, even moderate, shaking in which each cycle weakens the structure. In reality, building components have varying levels of ability to resist the forces associated with an earthquake. For example, different types of welds or rivets are more or less capable of withstanding different types of forces; a structural component that may be very capable of resisting compression may be very weak under tension. As a result, the various components of a building may experience failure when faced with different levels of force; even a weak earthquake may damage or destroy weaker building components. This is also one reason why long period deformation, duration of shaking, and other intensity measures may be as important as PGA. Once certain portions of a building's structure fail, the other components likely face greater stress potentially leading to collapse of the entire building. Modern, non-linear analysis can take this type of progressive degradation into account, no doubt one important reason why the DNFSB stressed that NNSA should undertake non-linear analysis if it intends to continue using existing aging buildings. NNSA's failure to follow DNFSB's recommendation to use modern analytical techniques is another egregious defect in its consideration of seismic risk.

Indeed, the critical difference between NNSA's assumptions about linear risks and modern non-linear analysis illustrates the importance of the fact that the existing buildings at Y-12 do not meet modern seismic standards. These seismic standards must be updated precisely because non-linear analysis and other modern modeling techniques can identify structural upgrades that allow buildings to better withstand earthquake forces. The fact that the buildings at Y-12 have not been updated to meet modern standards—

and in all likelihood *cannot be upgraded to meet these standards*—is not merely a failure on paper to meet a building code. The structures themselves lack the features that modern engineering analysis shows to be necessary to withstand earthquake shaking.

Lack of evidence for Site-Specific Hazard Studies

Most publicly available USGS hazard reports rely on global and regional seismic data, geologic mapping of large faults with substantial recent slip rates, and in some cases surface deformation observed with GPS or other geodetic techniques. They are meant for planning decision by ordinary residents, public leaders, insurance rate setting, and routine uses that do not demand exceptional detail. For critical or otherwise special "targets", site specific explorations using more precise geological, geophysical, geodetic, seismological, hydrological, topographic, soil stability, and other techniques are appropriate and often necessary. That is surely the case at the Y-12 site.

While there is frequent reference in the Draft SA and earlier documents to site specific studies and some of its tools, there is little detail and virtually no relevant data describing these studies in the Draft SA.

Mention of "site specific" is often coupled with a reference to Chapter 4 of the 2011 SWEIS, and a 2003 "Update of the Seismic Hazard at the Department of Energy National Nuclear Security Administration Y-12 National Security Complex".

In Section 4.5.3 of the 2011 SWEIS there is one low-resolution geology map; one schematic diagram of soil type with depth; and a list of a few earthquakes described by year, nearest town or possible major fault name, and estimated Modified Mercalli Intensity at Oak Ridge. I hoped to find at least an earthquake catalog with date, latitude, longitude, depth, and magnitude, some borehole logs or cone penetrometer data for boreholes near the site, and an estimate of "Vs30", a measure of the shaking amplification by soils at the site. The document had no discussion of how the "site specific" studies or results were used to refine any intensity measure or performance standards for the involved buildings.

The 2003 "Update" document is by far the most detailed. While it does have many of the details mentioned in the previous paragraph, it is relatively old now, and missing the kind of technical detail, resolution, and precision available now.

In my professional opinion, NNSA has not provided any sufficient documentation of a professionally adequate, rigorous site-specific study for either the UPF or the existing buildings. This is an important deficiency because genuinely rigorous site-specific analysis can provide much greater information about the risks that facilities face and what measures may possibly be taken to reduce such risks.

State of documentation

Although NNSA states that it is currently preparing additional seismic studies, including updating earthquake sources, maximum earthquake magnitudes, frequency of earthquake occurrences, historical earthquake databases, and related uncertainties, the fact that NNSA has chosen not to disclose any material information about these new studies is extremely troubling. Independent experts like myself cannot evaluate the seriousness of the risk and NNSA's decision to proceed with construction before these studies are completed. In my expert opinion, NNSA must disclose the methods, scope, research plans, and results of these studies *before the agency decides to continue to use aging, vulnerable buildings.* Committing to use these vulnerable facilities before quantifying their vulnerability given their planned use highly risky and fails to fulfill the requirements of the National Environmental Policy Act.

My concern about NNSA's decide-first, analyze-later approach is especially acute given the fact that the agency has already had years to prepare a professional, rigorous seismic analysis. My understanding is that NNSA has effectively been committed to the ongoing use of existing buildings since 2014 and that the Oak Ridge Environmental Peace Alliance brought the issue of seismic risks to NNSA's attention that same year, specifically identifying the 2014 USGS seismic hazard maps as scientific information that the agency should consider. Given that history, it is clear that NNSA has had at least six years to prepare a rigorous assessment of the seismic risks associated with the ongoing use of aging buildings—which is more than enough time, in my professional opinion—yet has failed to do so.

The agency's delay in producing any scientifically defensible analysis of seismic risks is also especially troubling because in June 2018—nearly two years ago—I specifically brought to NNSA's attention many of the same issues I am now forced to reiterate in these comments. In June 2018, I prepared for the Oak Ridge Environmental Peace Alliance comments on a similar draft Supplement Analysis that the agency released in 2018. Those comments explained that the analysis the agency used at that time was deficient for many of the same reasons that the agency's analysis still remains deficient. For example, I identified the failure to use modern, non-linear analysis as a serious deficiency; that deficiency continues today. I also explained that NNSA's analysis at the time was simplistic and badly lacking because the agency failed to take into account current scientific information about how serious shaking can occur even in the absence of known, "capable faults"—another failing that continues to render the agency's analysis inadequate today. NNSA's failure to consider these issues in any scientifically defensible way—despite having two years to do so since I raised them in detailed comments—is very troubling.

Finally, roughly eight months ago, a federal court ordered NNSA to produce "an unbounded accident analysis of earthquake consequences at the Y-12 site, performed using updated seismic hazard analyses that incorporate the 2014 USGS seismic hazard map." In that ruling, the court specifically cited my comments on the agency's 2018 SA and noted that "NNSA did not really dispute most of [my] comments, but rather indicated that it was taking the more sophisticated data Dr. Jackson mentioned into account as part of the site-specific analysis it was preparing."

In my professional opinion, the draft SA that NNSA has produced falls far short of the scientifically sound seismic analysis that is necessary under these circumstances. For example, the court ordered the agency to produce "updated seismic hazard analyses," but NNSA's draft SA states very clearly that it has not done so; instead, NNSA states that for the existing buildings on which the agency intends to continue to rely, "updated [probabilistic seismic hazard analysis is] anticipated by the end of 2020 and the updated facility evaluations [are anticipated] by the end of 2021." Further, NNSA states that the "updated [probabilistic seismic hazard analysis will incorporate the 2014 USGS seismic hazard maps." Because the agency clearly states that it has not generated updated probabilistic seismic hazard analysis for existing buildings that takes the 2014 USGS maps into consideration (much less the subsequent USGS evidence that shows an even greater level of seismic risk), in my professional opinion, NNSA has not met the plain requirements of the court's order and has failed to generate any analysis of seismic risks that comports with professional standards.

Conclusion

NNSA's analysis of seismic risks is not well-founded scientifically. It suffers from numerous analytical defects, ignores or downplays important data, obfuscates the importance of the fact that existing buildings do not meet modern standards, and fails to employ modern tools for seismic risk analysis. NNSA has given only very cursory attention to important new information the agency obtained since 2011, including the USGS seismic hazard maps and input from the DNFSB. Moreover, NNSA has ignored altogether the most critical underlying data from the USGS's updated seismic hazard reports and has failed to even consider the USGS's 2016, 2017, and 2018 updated seismic hazard reports. As a result, in my professional opinion, NNSA's analysis is patently deficient, and a more thorough consideration of the seismic risks associated with the ongoing use of aging, vulnerable buildings at the Y-12 Complex is necessary, particularly in light of the hazardous and important work done at these facilities.

Most troubling is the situation of the existing buildings 9204-2E and 9215, which NNSA confidently assumes can be safely used, despite the fact that they do not presently meet modern seismic standards. Page 11 of the Draft SA contains the following text:

"As discussed in Section 2.1.3.1, the 2014 USGS seismic hazard/maps were incorporated into ASCE 7 in 2016. Subsequently, an informal comparison of the ASCE 7- 2016 seismic hazard with the Y-12 2003 site-specific seismic hazard shows that the Y-12 2003 site-specific seismic response spectrum is more conservative in some frequency ranges, while the ASCE 7-2016 seismic response spectrum is more conservative in others. These differences merit more formal review, which is currently underway, and described below (CNS 2020a). "

Seventeen years after the most detailed sites-specific study, its implications for the safety of the existing ELF is still in doubt. Engineering studies of the ELF buildings are also incomplete at this time. In my opinion completion of engineering and seismological studies should be a prerequisite to an informed assessment of environmental consequences.

Sincerely,

David D. Jackson

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