Assessment of Radioactive Material Release during the Accident at the Sodium Reactor Experiment

by

R. Denning

OHIO STATE UNIVERSITY

Background

- During Run 14 of the Sodium Reactor Experiment program, severe fuel damage occurred resulting in a release of radioactive material.
- Three panel members were requested to review evidence from the accident and provide their interpretation of events.

Personal Background

- Since 1973, I have developed methods to predict severe accident behavior, the release of radioactive material and the risk of accidents in nuclear power plants
  - Technical lead for severe accident analysis in WASH-1400, first assessment of nuclear power plant risk
  - Major contributor to NRC's Severe Accident Research Program
  - Consultant to Three Mile Island Special Inquiry Group
  - Member of the NAS committee to review the safety of DOE reactors following the Chernobyl accident
  - Member of DOE's Advisory Committee on Nuclear Facility Safety
  - Member of NRC's Advisory Committee on Reactor Safeguards
- Currently Professor of Nuclear Engineering, OSU
  - Teach courses on reactor safety and risk assessment
  - Over past two years developing realistic methods for the assessment of fission product release in sodium cooled fast reactor accidents in a DOE funded project

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Presentation Objectives

- To the stakeholders in the vicinity of the site, the real question is how much radioactive material was released and what are the potential health impacts.
- Prior to my review, I hadn't realized that there were dramatically different interpretations of the accident.
- The evidence indicates that the view of the accident portrayed by D. Lochbaum and J. Beyea does not have technical merit.
- There have been some excellent technical reviews of the accident.
- I will try to explain in lay terms, why I am confident that the release to the environment from the accident was minor.

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Barriers to the Release of Radioactive Material

- One of the safety principles that was followed in the design of SRE was the use of multiple barriers to the release of radioactive material and exposure of the public
  - Fuel pin cladding
  - Reactor primary system (vessel and piping)
  - Containment building
    - SRE used a confinement approach involving low leakage design with internal pressure less than external pressure so all leakage is from outside to inside
    - Controlled venting and filtering of any radioactive material released

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Release of Radionuclides from Over-Heated and Molten Fuel

- Principal radionuclides of interest
  - Radioactive noble gases (xenon and krypton)
  - Radioactive iodine isotopes (primarily I-131)
  - Radioactive cesium isotopes (primarily Cs-137)
- For the SRE fuel, melting begins as a mixture of uranium and iron from the cladding at a temperature that is lower than the melting point of uranium.
  - When the melting occurs, noble gases will be released (noble gases react with almost nothing)
  - In contrast, the release of iodine and cesium atoms will be very small

Release of Iodine from Uranium Fuel

- Elemental iodine has a low boiling point.
  - When the fuel melts, some radioactive iodine would be released if it existed in the fuel in elemental form.
  - However, the iodine reacts chemically with uranium to form a chemical compound UI_3, which does not have a low boiling point (see excellent review by Krsul)
    - This is the principal reason why the release of iodine in the accident was small.
- Concern for radioactive iodine primarily arose from the Windscale Accident in England. In that accident, there was a large release of iodine but the chemistry was entirely different from the conditions at SRE.
  - Although the fuel was metallic uranium, it was being oxidized by air flowing through the burning graphite.

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Release of Iodine from Uranium Fuel (Cont)

- In modern commercial reactors, fuel is in the form of an oxide rather than a metal.
  - Although this fuel melts at a lower temperature than the melting point of pure uranium dioxide (by forming a mixture with zirconium cladding), this melting temperature is much higher than the melting temperature of metallic uranium fuel.
  - Small differences in temperature have a very large effect on the release rates of fission products.
  - Under the chemical conditions of the oxide fuel, nearly 100 percent of the iodine would be released from molten fuel in a core uncovery accident.
- Mr. Lochbaum was familiar with severe accident behavior in modern commercial (oxide fueled) reactors.
  - This is why he so dramatically over-estimated the release from fuel in the SRE accident.

Release of Cesium from Uranium Fuel

- Elemental cesium also has a low boiling point but higher than that of iodine. However, the amount of cesium actually released as vapor from molten uranium fuel is reduced by two key effects:
  - When there is a contaminant (cesium) in solution in another material (uranium), the vaporization of the contaminant is reduced by the relative ratio of the number of contaminant atoms to solvent atoms. There were 10,000 uranium atoms in the core for each cesium-137 atom.
  - Uranium is an exceptionally good solvent – Retains cesium a factor of 100 better than an ideal solution.
  - Thus, very little cesium would be expected to be released from the molten fuel.
- In contrast, for commercial reactors, in a hypothetical core uncovery accident nearly 100 percent of cesium would be expected to be released from molten fuel.

Release of Radionuclides from Sodium

- Radionuclides released from the fuel must pass through the sodium pool to reach the gas space above the pool.
- The radioactive noble gases, krypton and xenon, have very low solubility in sodium and will pass through the sodium pool as bubbles.
- Any iodine released to the sodium pool will react to form sodium iodide, which will remain in the sodium pool.

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Release of Radionuclides from Sodium (cont)

- Cesium that is released to the sodium pool will go into solution in the pool.
  - As with uranium, the concentration of the cesium in the sodium has a major effect on the amount of release to the gas space.
  - There are 400 million sodium atoms for each Cesium-137 atom released to the pool in the SRE accident.
  - In addition, sodium is a good solvent for cesium (but not as good as uranium)
- Cesium will react with either carbon or oxygen, which were major contaminants in the sodium.
  - Based on the effectiveness of cold trapping on the removal of radioactivity from the pool, it is most likely that the cesium reacted with oxygen to form cesium oxide.

Conclusions Regarding the Release of Radionuclides

- Based on our technical understanding, the release of iodine and cesium to the cover gas region should have been very small.
- The various reports from Atomics International following the accident indicate high confidence that there was no cesium or iodine in the cover gas. In the material that I reviewed, I found only limited measurements that directly addressed the question.
  - Nevertheless, based on the total curies released from the waste tanks, an upper bound to the release can be established of approximately 1/1000th of the core inventory.
- Dr. Beyea's subjective assessment of the magnitude of the release was based on the supposition that an elaborate cover-up was undertaken by plant personnel.
  - There is no evidence to support this supposition.
- The noble gases in the cover gas region were collected in waste tanks by standard procedures and, after decay, released over a two-month period through a stack.

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Projected Health Effects

- In Dr. Beyea's report, he predicts the possibility of potentially large numbers of latent cancer fatalities (associated with his larger release estimates).
- As identified by J. Frazier in his report, Dr. Beyea's results arise from the summation of very low doses of radiation to very large numbers of people up to 62 miles from the site (this is called population dose).
- The model used to convert the population dose to expected cancers was developed based on data obtained from people exposed to very large doses of radiation.
- The use of this model for low doses is very controversial. As indicated by J. Frazier, the Health Physics Society recommends against the use of this model for doses below 5 rem to an individual.
- I independently performed a very conservative calculation of radiation exposure to individuals using the maximum release values for iodine and cesium estimated by Lochbaum. Even under these assumptions, the maximum dose to any offsite individual would be less than 5 rem.

Projected Health Effects – Final Comment

- To the public living near the Santa Susana site that may be concerned about their health, it doesn’t matter whether Dr. Beyea is right or wrong about the estimation of the probability of potential cancers from small doses or even whether Mr. Lochbaum is correct about the possibility of a large release of iodine and cesium.
- Your personal risk, your family’s risk, the risk to your neighbors from this accident is negligibly small relative to your risk of incurring cancer from other causes.