LMFBR Safety Research

A View From Outside

by

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The Atomic Energy Commission (AEC) is proposing that the Liquid Metal Fast Breeder Reactor (LMFBR) should be the backbone of our electrical energy economy after the turn of the century, following commercial introduction in 1987. The AEC's 1973 Cost-Benefit Analysis of the breeder program projects 2200-Gwe of LMFBR capacity by 2020, i.e., 1100 central station LMFBR power plants, each 2000-Mwe in capacity.[1] Each reactor would contain some 6 to 8 metric tons of plutonium.[2] A principal effort of LMFBR safety research over the past two decades has been to assess the explosive potential of this reactor. Two recent evaluations of the potential radiological consequences following a hypothetical core disruptive accident (HCDA) at the Fast Flux Test Facility (FFTF) assumed, for purposes of

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1/ U.S. AEC, DRAFT, Environmental Statement, Liquid Metal Fast Breeder Reactor Program, Vol. III, WASH-1535 (March 1974), p. 10-17.

2/ Assumes specific inventory 2 to 27 kg fissile/Mwe [WASH-1184, p.40] and 70 percent of the total Pu is fissile.

evaluating the containment design, fuel release fractions, from the primary to the secondary containment, of the order of 10^{-2} and 10^{-4}. The larger of the two estimates, 10^{-2}, corresponds to an AEC Directorate of Licensing (DL) assumption.[3] While the smaller, 10^{-4}, corresponds roughly to an AEC Division of Reactor Research and Development (RRD) assumption.[4] In its assessment of the FFTF secondary containment design, DL made two sets of calculations. One set is based on a single containment model which assumes that the head cavity region is not sealed and inerted and that the head lifts and gross venting occurs through the head cavity region into the reactor containment building.[5] Using this model 0.1 percent of the activity released to the secondary containment is ultimately released to the environment.[6] The other set, based on a double containment model assumed that either the seals between the reactor vessel and the head cavity region remained functional or that the reactor head seals failed but that the head cavity region is sealed and inerted.[7] This assumption gives a release fraction from

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3/ U.S. AEC, Directorate of Licensing, "Safety Evaluation of the Fast Flux Test Facility," Project No. 448 (Oct 31, 1972), pp. 115-116.

4/ "Fast Flux Test Facility Design Safety Assessment," HEDL-TME 72-92 (July 1972), prepared by Hanford Engineering Development Laboratory for the AEC, p. 3.6-13.

5/ U.S. AEC, Directorate of Licensing, Op. cit., p. 109.

6/ Ireland, Richard, Director, Fast Reactor Safety Branch, U.S. AEC-DL, Private communication, April 26, 1974.

7/ U.S. AEC Directorate of Licensing, Op. cit., p. 109.

the secondary containment to the environment of an order of magnitude lower, i.e., 10^{-4}.[8]

Applying DL's release fractions, 10^{-2} to the secondary containment and 10^{-3} from the secondary containment to the environment, to the larger 2000-Mwe LMFBRs yields releases to the environment of the order of 70 gm of plutonium. This release corresponds to about 15 curies of plutonium (Pu-238, Pu-239, and Pu-240) alpha activity. Including the transuranics, curium-242, curium-244, and americium-241 increases the alpha activity release to 50 curies.

The AEC has estimated for a point source, approximately 10^{-5} of the alpha activity released is ultimately inhaled by man.[9] Roughly half of this is inhaled directly (within two years) and half after resuspension.[10] Dr. Arthur R. Tamplin and I have made a study of the lung cancer risk associated with the inhalation of hot particles, that is, insoluble alpha-emitters in particulate form.[11] This study has been used to support a petition by the Natural Resources Defense Council to the AEC and EPA to lower the existing radiation protection standards where hot particles are concerned.[12]

8/ Ireland, Richard, Op. cit.

9/ U.S. AEC, DRAFT, Op. cit., Vol. II, Part 2, p. 4.7-6.

10/ Ibid, p. 4.G-36.

11/ Tamplin, Arthur R. and Thomas B. Cochran, "Radiation Standards for Hot Particles," Natural Resources Defense Council (February 1974).

12/ NRDC, "Petition to Amend Radiation Protection Standards As They Apply to Hot Particles," Before the EPA and AEC, Natural Resources Defense Council, 14 Feb. 1974.

We believe that for radiation protection purposes, one should assume a lung burden of one hot particle carries a lung cancer risk of one in 2000. Assuming that 10 percent of the inhaled actinides represent hot particles retained in the deep respiratory tissue, an average hot particle activity of 0.25 pCi, and our hot particle risk assumption, then an accident with a release fraction of 10^{-5} (10^{-2} to secondary containment and 10^{-3} secondary to the environment) could result in 100,000 lung cancers. Use of the primary containment release fraction assumed by RRD for the FFTF, i.e., 10^{-4}, together with DL double containment model, i.e., 10^{-4} from the secondary to the environment, gives one hundred lung cancers. There are order-of-magnitude uncertainties in either direction in several of the other assumptions used to make this estimate. The fraction of activity released that is ultimately inhaled is particularly uncertain due to variations in meteorological conditions, and the wide range observed in the resuspension factor.

The AEC in the Draft Environmental Impact Statement (EIS) of the LMFBR Program estimates that per 1000 Mwe-yr roughly 1 mCi transuranic alpha activity will be released through normal routine operation of the LMFBR fuel cycle. Ninety-five percent of this activity will be airborne.[13] These releases are assumed to be insoluble particulates having an activity median aerodynamic diameter of 0.3 microns. The AEC's projected cumulative LMFBR generation through 2020 is 23,000 Gwe-yr with an additional 26,000 Gwe-yr

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13/ U.S. AEC, DRAFT, Op. cit., Vol. II, Part 2, p. 4.G-2. This estimate includes Pu-238, Pu-239, Pu-240, Am-241, Cm-242, and Cm-244, and commited after 2020.[14] Using these figures the LMFBR fuel cycle is projected routinely to release ultimately on the order of 50 curies of alpha activity. With the hot particle assumptions above this gives a long term commitment of 100,000 lung cancers due to transuranics. This estimate is roughly 10,000 times higher than the AEC's estimate of the lung cancer commitment in the Draft EIS and 5,000 times higher than the AEC estimate of the total cancer commitment.[15] Here again there are order-of-magnitude uncertainties in either direction in the assumptions used to make this estimate.

Our estimates are what some of you would refer to as scoping calculations. What do they tell us? First, they clearly demonstrate a need for the fast reactor safety community to quickly come to grips with the hot particle risk issue. The available biological evidence suggests to us that the toxicity of plutonium is such that this industry with its present design objectives is totally unacceptable, with respect to both routine and accidental releases of plutonium and other actinides.

With respect to the narrow question of reactor safety, a question that is often raised is what level of safety is required, or "how safe is safe enough," or what constitutes, in the words of the ACRS, reasonable assurance that fast reactors can be operated without undue risk to the health and safety of the public? Let me start by saying I do not believe you can demonstrate that a

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14/ U.S. AEC, DRAFT, Op. cit., Vol. III, p. 9.1-56.

15/ U.S. AEC, DRAFT, Op. cit., Vol. II, Part 2, p. 4.7-9 for AEC estimate.

power-flow mismatch coupled with failure to scram has vanishingly small probability, i.e., has a remote chance of occurring. The human factor elements including, for example, sabotage, operator, construction or maintenance error preclude such certainty, in my view. I do not believe you can demonstrate otherwise with fault tree analysis or any of the analytical approaches currently being suggested by PMC, among others, in its proposed approach to licensing the Clinch River Breeder Reactor. William Bryan, a reliability and safety analyst for the Apollo and NERVA programs, ably attests to this view in his testimony before the Subcommittee on State Energy Policy of the California State Assembly.[16] Bryan believes that the AEC is up to 10 years behind as far as implementing aerospace reliability and safety techniques, and as a substitute to good analysis the AEC is pushing phony reliability and safety numbers to assure us of just the opposite. Bryan notes that NASA went through the exercise of generating estimates of vehicle reliability, but abandoned this approach as being unrealistic. Estimates of this type are useful if used as a relative merit when comparing alternate designs. They are also beneficial in identifying system weaknesses and identifying areas needing further research and development. However, they are meaningless as an absolute measure of reliability, or risk.

Nor can you demonstrate that the primary containment release fraction will be less than 10^{-4} or even 10^{-2}, without

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16/ Hearings of the Subcommittee on State Energy Policy, Committee on Planning, Land Use, and Energy, California State Assembly, February 1, 1974.

demonstrating that fault propagation cannot lead to loss of an inplace coolable geometry of the core. You have to resolve the questions related to fuel pin and sub-assembly failure propagation. It is my understanding that to do this you would have to demonstrate among other things that vapor explosions cannot occur in large LMFBRs which in turn inplies an understanding of superheat and coherency under a wide variety of accident conditions. The number of fuel pins which are needed to represent accurately sub-assembly or whole core behavior in in-pile safety experiments is still an open question. As Henry Kendall, an MIT nuclear physicist, warns, "mathematical models cannot be used reliably to span large gaps in engineering knowledge, owing to the very great uncertainties that accumulate in long and unverified chains of inference."

What constitutes a "good" or adequate understanding of these phenomena (fault propagation) is of course subjective. To some of you, it implies as good a basic understanding of the phenomena as is possible under the constraints of time and budget. Less than full understanding, it is argued, permits setting upper bounds on the consequences of hypothetical accidents. To others there is no substitute for experimental evidence gained in real time on the real thing. Bounding the accident at something less than what is theoretically possible, of course, involves subjective technical judgments which are arguable. Even within the fast reactor research community there is no general agreement with respect to these technical judgments. Furthermore, the present institutions which are supposed to be resolving these technical issues appear to be incapable of making objective assessments. In short, the institutional structure is such that the fast reactor safety community lacks credibility.

Until last year, the fast reactor research programs in the United States were for the most part managed out of a single office in what has been described as an autocratic manner. Critical safety documents were censored and suppressed. Monthly progress reports of ANL-Reactor Analysis and Safety Division were unavailable to consultants to the AEC-Regulatory. A director of LMFBR safety research at Argonne National Laboratory was dismissed shortly after completion of a postburst analysis of a loss-of-flow accident which he authorized. He was subsequently hired by the AEC Directorate of Licensing. This is not a program that instills public confidence. Fortunately, within the past six months there have been signs of improvement. For example, under the new regime there is more delegation of authority and requests for documents are being honored with only the usual bureaucratic delays.

Nevertheless, even today you have a situation where the principal objective of LMFBR safety research is not assessing the hazards of the LMFBR. Rather it is getting the FFTF "licensed." The FFTF FSAR is being prepared by the Hanford Engineering Development Laboratory (HEDL), which in turn is managed for the AEC by Westinghouse. Westinghouse was responsible for the FFTF design and through HEDL is responsible for its development. In addition, Westinghouse is prime contractor for the proposed Clinch River Breeder Reactor.

With respect to FFTF FSAR, the approach appears to be taking the form of preparing an adversary position for presentation to Regulatory rather than preparing an objective assessment of the FFTF hazards. The approach is prove the unprovable, don't discuss unfavorable cases, don't document model limitations and uncertainties in assumptions; then settle with Regulatory and the ACRS for what you can get. This message comes across loud and clear in the HEDL safety analysis reports, in technical papers presented at ANS meetings, and in the halls outside meetings such as this one. Again, this is hardly what you would call an R&D program that instills public confidence.

In summary, on the basis of our assessment of the biological hazard of plutonium, the LMFBR program with its present design objectives is unacceptable. With respect to the narrow issue of reactor safety, you simply cannot permit under any circumstances one part in 100,000 of the reactor fuel inventory to be released to the environment as an aerosol. In this respect, sabotage is a credible scenario and should be considered not only as a potential HCDA initiating event, but as a potential means of breaching the secondary containment. To have an acceptable design it must be demonstrated at a minimum that conceivable faults can not lead to the loss of an inplace coolable geometry. The fast reactor community is a long way from doing this. I doubt that it can be done under any circumstances and there is not even a credible program for making an objective assessment. They are negotiating safety rather than determining the hazard through careful, thorough, objective analysis.