PDR 4/27/82
CT-1413

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Nuclear Engineering

28 December 1981

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REACTOR SAFEGUARDS, U.S.N.R.C.
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Professor Max Carbon
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Dear Max,

My recent conversations with you and Carson Mark were stimulated by the forthcoming safety review of the Clinch River breeder reactor and by my belief that the problem of the "Hypothetical Core Disruption Accident" (HCDA), the "Maximum Credible Accident," the "Explosion Accident," the "Bethe-Tait Accident," or however designated, can now be solved or at least settled in the sense of not offering an undue risk to the health and safety of the public. I believe that analytical tools now exist that are much superior to those used for the FFTF (and for earlier reactor designs) and that our understanding of the necessary phenomenology also is greatly improved. Certainly, knowledge is not complete nor are computer programs perfect, but both are adequate for the purpose. The present political climate also seems favorable, and the appropriate reactor to examine first is the CRBR.

Thus, I believe that the time has arrived, both technically and politically, for a comprehensive review of the matter and that the proper (and best) forum for this review is the Advisory Committee on Reactor Safeguards with the assistance of its appropriate subcommittees. I suggest that an ad hoc and especial task force of, say, 8 to 12 nationally recognized experts in the appropriate specialties (physics, nuclear engineering, metallury, neutronics, explosives, hydrodynamics, chemistry, or whatever may be necessary) who are independent of the developmental and regulatory agencies be chosen. They should work closely and actively with the ACRS, the NRC, the DOE, and the several investigative groups (e.g. national laboratories, reactor vendors and safety specialists in the U.K., France, and Germany) that have been studying this and related problems for many years.

A fresh look and an intensive effort of some months would be needed probably beginning when the several computational centers (ANL, Los Alamos, GE) have completed or are well along in their analysis of the present core proposed for the CRBR. Precedents exist in the history of the ACRS for such a specialized and intensive effort, for example the pressure vessel study completed in 1974.

To put my proposal in perspective, allow me to set down my perception of the political situation and some general thoughts on the

LMFBR and comment on what I see as its technical advantages and disadvantages. The reasons for this special study at this time are part and parcel of these several factors and discussion.

Political Situation

Both the Executive Branch of the government and the Congress are now in favor of constructing the Clinch River Plant and proceeding with additional developmental plants. I have been told that the Department of Energy has formally requested permission from the NRC to commence construction, but I do not expect that the NRC has yet responded nor should it do so without adequate consideration. However, the NRC has reacted to the President's statement of a few weeks ago by reactivating a review organization within its licensing division and by reviewing its own fast reactor research efforts (a report by L. S. Tong's Special Review Group was posted to you under separate cover). Thus, I believe that this administration is determined to begin construction of the CRBR project; support for efforts to solve its licensing problems, therefore, should be forthcoming.

Advantages of the LMFBR

The sodium-cooled reactor is an interesting creation that has a number of safety advantages. A few of the obvious advantages are as follows:

1. The primary system operates at low pressure--only high enough to move the sodium through the system.

2. The coolant is noncorrosive to materials and components designed for its environment. EBR-II experience is showing some remarkable results from components that have been in sodium for nearly a generation.

3. The coolant operates far below its boiling temperature.

4. The large volume of sodium provides an enormous heat sink.

5. The coolant's heat transfer characteristics are excellent. These characteristics--the operating temperature, the heat sink, and the high heat transfer rate--have not been investigated systematically or exploited fully, but it is clear that a significant power transient involving a large temperature rise could be accommodated without damage to the core.

6. The coefficient of expansion of the coolant is large enough that convective cooling can be designed into the system. The advantages of this property of sodium have not been fully exploited in existing designs.

7. The coolant, sodium, is a marvelous getter for iodine, which is, by far, the most dangerous of the fission products. This property is a safety factor of great significance.

Prima facie, it appears that if the reactivity control and decay heat removal systems operate reasonably effectively, nothing much can go wrong. Indeed, on a second look, this still seems to be the case; even if the latter system works only poorly or not at all, a long time, depending upon design, should be available to take action before the health and safety of the public is threatened.

Some persons regard other factors as good reasons for continuing the development of this reactor concept. These factors include such matters as the following.

1. The fuel is U-238, which is in abundant supply and inexpensive per se. Given a successful design or designs, the price of energy (electricity, hydrogen) from this source should be constant except for inflation of the economy for other reasons. For the first time, one can truly speak of a "lid" on the price of power and energy.

2. The limited amount of U-235 in the world would not be consumed in a few generations as will be the case if only U-235 burners are used. U-235 is, after all, the only naturally occurring fissionable isotope, and, like seed corn, we should be niggardly about using it.

3. The supply of uranium already above ground is sufficiently large that mining operations would not be needed for this reactor concept for generations, perhaps a century. This reduction of mining requirements is, of course, a safety matter of significance.

4. Most of the excess plutonium would be in use in reactors and hence inaccessible to terrorists. A chemical processing plant and fuel production plant may well be easier to safeguard than a large number of spent fuel storage pools (sometimes referred to as latent plutonium mines). Additionally, the sodium-cooled reactor can be regarded as a plutonium burner, and hence actually reduces the amount of plutonium in the world and truly lessens the terrorist threat.

5. The breeder reactor is the only sure thing we have for future generations. If we (our generation) are so selfish as to burn all the fossil fuels and U-235, the least we can do for our children and grandchildren is to provide them with the technology to produce an abundant and assured supply of energy. Whether or not they use it is their choice; our task is to create the capability.

Disadvantages of the LMFBR

Disadvantages exist, and the last of these get to the crux of my proposal to you and Carson. Some of the difficulties or problems include the following.

1. The optimum design of the sodium-cooled, plutonium-fueled power plant must be at least a couple of decades away, commercialization and accumulation of experience certainly is a matter of decades. Things take longer now than they did 30 years ago, and introduction of this concept probably will be more time consuming than was the case with the LWR. Its expense is greater than can be afforded by a single corporation, and the first few plants must be funded by the federal government or, perhaps, by a small tax on the entire electric utility industry.

2. The coolant is liquid sodium; large amounts have been handled successfully, but generally, the utility industry is unfamiliar with handling the necessary very large amounts.

3. The coolant is flammable in air and reacts violently with water.

4. The sodium captures neutrons and becomes radioactive with a half-life of about 15 hours. Given the fallibility of mankind, one must assume that sooner or later serious sodium fires will occur and that some of these will be fires with radioactive sodium. Fortunately, because of containment or confinement, such a fire need not pose a threat to the health and safety of the public.

5. The sodium-water steam generator is a difficult device to design and construct so that no leaks, even pinhole size, exist. Success has been achieved (e.g., EBR-II), but the task is not easy or inexpensive, and difficulties have been encountered (e.g., PFR in the UK, BN-350 in the Soviet Union). Fortunately, this area of the plant is not radioactive so that additional hazard is not present.

6. The neutronic and reactivity characteristics of the fast neutron core are such that the voiding of sodium coolant from some parts of the core will increase reactivity and thus reactor power. A reactivity control or scram system must work, should a situation develop that involves boiling of sodium in a significant fraction of the core.

7. The core of the fast neutron reactor is not in its most reactive configuration. Should some accident or incident cause the core or some fraction of the core to be driven into a smaller volume by even a small amount, its reactivity and the reactor power level would increase. Again, the reactivity or shut-down controls must work properly, to avoid damage to the core.

Item 7 is the origin of the reactivity accident that is associated with the fast neutron reactor. Indeed, in the early 1950s, during the design of the Dounreay Fast Reactor, some people were willing to postulate spherical implosions of that little core. The resulting calculations naturally predicted explosive energy releases of the order of tons of high explosive equivalent, given such an unrealistic and imaginary situation. In order to resolve this apparent dilemma, in 1957 Bethe and Tait assumed a gravity induced collapse of a voided and molten (but in-place) core and showed that even with these assumptions, the explosive energy could not be more than the equivalent of 160 kg of HE.* The Bethe-Tait result was accepted, even though it was unrealistic, as an upper limit for the Dounreay Reactor and was satisfactory then because it showed that containment of an explosion of this magnitude was quite feasible. Unfortunately, the precedent of assuming a very unlikely or even a near-impossible situation for a worst-case analysis was set and has plagued all subsequent LMFBR proposals and designs and discussions, both technical and popular. Indeed, the fuel-melting accident in the Fermi Plant was caused by a hastily installed safeguard to protect against the threat of accumulation of molten fuel and a possible "Bethe-Tait" accident.

Since the time of the Dounreay calculation, the history of analysis of this and related hypothetical accidents (for various reactors) has been to insert more realism and less arbitrariness into the initial assumptions and calculational technique. The result has been a fairly steady reduction of the estimate of the possible magnitude of the "explosion" or "energetics" as it is sometimes called.

A good many fast reactor designers, analysts, and technical specialists believe that the day of the "explosion" accident concept has come and gone; however, this belief is sometimes based on physical intuition and engineering experience rather than a rigorous investigation and analysis. I place myself in the group of those who think about the problem and have this opinion, but I have worked in this field; hence my proposal in the beginning of this letter is founded on a background of experience and quantitative studies. I believe that a rigorous examination of the facts of the case will show no "energetics" for the Clinch River Plant and, further, will at least be strongly indicative for future, larger LMFBRs.

Conclusions

The possible reward is potentially very great as I discussed above; the reactivity accident is about the only conceptual accident characteristic of the LMFBR that would be of significance to the health

*Modern, but still conservative, calculations of the Bethe-Tait model show about the same number of fissions but no explosive energy. Note that the energy equivalent of 1 kg HE is 4.2 megajoules.

and safety of the public. If this proposed study leads to a positive result, it will certainly suggest that the LMFBR may be unique in regard to its public health and safety characteristics.

In conclusion, I repeat my recommendation for an ad hoc, pre-eminent advisory review panel to assist the ACRS in this part of its consideration of the Clinch River Plant. The tools and knowledge are available, and the political climate (and hence funding) is favorable to such a special effort. The ACRS provides the proper forum and commands sufficient respect worldwide to collect the best talent available in the United States and abroad. The task is worthy of our best efforts. Please be assured that I am available to cooperate with you and the Committee on this matter at any time.

Sincerely,

Bill Stratton

William R. Stratton

WRS:hmb

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