April 25, 1980

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TO: D. Okrent

FROM: I. Catton

SUBJECT: Breach of Containment by a Core Melt

REFERENCE: Letter from Ivan Catton to David Okrent dated 6 March 1980

The question posed is whether or not it is feasible and practical to design a containment that can withstand a core melt. It is my opinion that to do so is both feasible and practical. Of course there will be a number or hurdles to overcome in arriving at a design. I will attempt to substantiate my opinion in the following paragraphs by first addressing existing plants and then give my ideas about new plants.

Before discussing LWRs, however, I would like to call your attention to previous work in this area for LMFBR's. Designs for core catchers were proposed for FFTF and CRBR. A number of crucible materials were evaluated and both passive (time delay) and active systems were considered. The German reactor SNR 300 will have an actively cooled crucible using depleted UO_2 as a sacrificial material. Several ideas for core retention have come out of efforts of the GE advanced reactor group. A firm in Germany was found that would make standard size bricks out of depleted UO_2 for what I remember to be a reasonable cost. The depleted UO_2 was needed to absorb the thermal shock from the melt and protect the active cooling system. The designs were not fully evaluated but had potential for being successful. When one considers that the fuel melt from an LMFBR has an energy density that is an order of magnitude greater than an LWR one sees that the design of a core catcher for a LWR will be less difficult.

A number of aspects of a core melt accident were discussed in the above referenced letter, which dealt with Indian Point and Zion. They are repeated here in part.

1. Steam explosions will probably not occur in-vessel if the pressure is above 7-10 bars. Even if a steam explosion were to occur in-vessel, recent SANDIA work shows that there is little chance of a missle that could penetrate the containment. The only missile that might be of concern was the control rod drive. Some plants have missile shields for this already and plants without could install one. An ex-vessel steam explosion will only occur if water is in the reactor cavity before the vessel is penetrated or enters shortly thereafter (before the molten pool solidifies and while gas is still being generated by concrete decomposition). The ex-vessel steam explosion will probably not do much damage and it appears that acceleration of missiles that will penetrate the containment is unlikely. Further confirmation of this opinion is needed to assure that damaging the shield wall, moving the vessel or some other aspect will not lead to containment penetration. High steam generation rate will occur if water precedes the melt and the resultant high steam generation rate needs to be a factor considered in seeking mitigation measures.

ATTACHMENT 1

2. In-vessel core coolability is presently not well enough understood to fully describe the core meltdown process. Programs presently underway in Germany and the US may yield sufficient information at some time in the future to describe the process. At this time one can only bound the problem and must assume that penetration of the vessel occurs early in the worst way. It should be mentioned that it is not really clear what the worst way is. For example a jet of fuel resulting from a hole in the bottom of the vessel might erode a hole in the base mat with subsequent erosion of the hole being greater than if the entire vessel lower dome failed dumping all the molten fuel at one time.

3. Ex-vessel core debris coolability will depend strongly on whether or not water is in the cavity. If water is in the cavity in sufficient quantity before the vessel is penetrated, the core debris will be quenched as it enters. A sufficient quantity of water is a pool deep enough to prevent erosion of the base mat. It is not clear how deep this is. SANDIA programs underway, however, could help answer this question. If a reflux path is available the core debris will probably not dry out and re-melt. This opinion is based on past work at TREAT, UCLA, ANL and SANDIA that shows that $\varepsilon = 0.45$ is a reasonable void fraction and that an average particle size of 500 μm is to be expected. For $\varepsilon = .45$ and 500 μm particle sizes the entire core and a great deal of steel (125 tons of fuel and steel) will remain cool·ble.

If vessel penetration occurs when no water is in the reactor cavity, a great deal of penetration of the base mat may occur. The amount of penetration occurring during the period when the core debris is molten is predictable. Once it freezes a complicated process occurs and the amount of penetration is not predictable. Again, studies are underway in Germany (their strong interest results because they do not allow water into the reactor cavity) that will answer this question within the next couple of years. Use of a liner in the cavity could buy time for plant personnel to get water into the cavity.

The debris could enter the dry cavity and become particulates. The gas flow from the decomposing concrete might block water added later from entering the bed. It is not known whether the cooling by the gases from the decomposing gases will be sufficient to preclude re-melting. This sequence needs further study if it cannot be shown that water will always pr ede the melt.

To summarize, in existing plants where water precedes the melt in sufficient quantities and can be resupplied, penetration of the base mat will most likely not occur. Under these conditions an ex-vessel steam explosion will probably take place with the possibility of a great deal of steam generation that must be accommodated. The possibility of damage of the biological shield or shifting of NSSS components leading to containment damage needs to be further assessed. When water is not available, the chances of base mat penetration are much greater. The conclusion is that a water supply needs to be assured. A cavity liner of depleted UO_2, Al_2O_3, MgO or some similar refractory or sacrificial material should be considered.

A containment building could be designed based on present information to preclude molten core penetration. A conceptual design that has redundant cooling capability as well could include the following features:

1. Concrete that minimizes gas generation on decomposition and has the best possible refractory characteristics.

2. Several courses of depleted UO_2 bricks actively cooled at the concrete-UO_2 brick interface similar to the SNR 300 core catcher. The heat sink could be an existing plant system.

3. A steel liner to protect the UO_2 bricks.

4. A cavity flooding capability and a method of refluxing to insure that the cavity stays flooded.

Such a system requires very little new technology and depends on no new research. It should also be relatively inexpensive.