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Severe Accidents and Regulation
by
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OPENING REMARKS
Cooperative Severe Accident Research Program
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Good morning ladies and gentlemen. It is a pleasure to address this meeting of our international partners in the cooperative research program on severe accidents. During the past decade there have been major changes in the membership of this program as major changes in the perception of severe accidents. We at NRC are delighted with the increased interest and participation in the program. We are not so delighted with our collective awakening to the effects of severe accidents emerging from the program, but these realities must be accepted. Many of us can remember, in the early years after the accident at Three Mile Island, how it was believed -- or hoped -- that only minor damage had occurred to the core. Then we saw television pictures revealing the void in the upper core region. More recently specimens have been recovered exhibiting damage to the lower head of the vessel indicating a rather serious progression of events. Our view of the potential damage from credible severe accidents has changed forever, and at NRC some changes in our regulatory process are being made accordingly.

I would like to take a few moments this morning to review with you how the NRC addresses accidents in its regulatory process, to recall some of the history of our severe accident program, and then to talk about some regulatory changes involving severe accidents that are on the horizon. These changes, in my opinion, will increase our dependence on your severe accident work even more than now. From the outstanding work you have done during your first decade, I am sure we can count on you to provide the support that will be needed in the future.

Let's start by reviewing current regulatory practices. NRC's requirements for coping with abnormal reactor events can be put into three categories: those for Anticipated Operational Occurrences, those for Design-Basis Accidents, and those for Severe Accidents. Anticipated Operational Occurrences are events that are expected to happen one or more times during the 40-year lifetime of a given plant. Design-Basis Accidents are more serious events that individually are not expected to occur during the plant lifetime, but collectively could be expected to occur at least once during the plant lifetime. And Severe Accidents are very serious events that we hope will never happen.

Generally speaking, our requirements for these events have been as follows: Plants should be able to ride out Anticipated Operational Occurrences with no fuel damage, and be returned to operation. Design-Basis Accidents may result in limited damage to the fuel -- no melting though -- but radioactive releases from the plant to the environment must be very small. For Severe Accidents, until the present time, only a few direct requirements such as emergency planning were in place; as in the aviation industry, most of the regulatory requirements have dealt with avoiding a serious accident rather than coping with one.

TURNING POINT 1 -- LESSONS LEARNED FROM TMI-2

Of course the TMI-2 accident in 1979 fundamentally altered the perception of severe accidents. Shortly after the accident, changes started to be made at the NRC, and very likely the end of these changes has not yet been reached. It will be useful to think of several turning points in NRC's regulatory activities following TMI-2, so let me start with the first one. This came in 1980, when the NRC required nuclear plant operators to make a rather large number of backfits (more than 6,400 separate action items) to deal with lessons learned from the TMI accident. By and large, these were improvements in dealing with Design-Basis Accidents to avoid another severe accident, rather than requirements intended to cope with a severe accident should another one occur. The Commission took its first step in addressing some aspects of severe accidents as a direct result of the TMI-2 accident and promulgated a rule (10 CFR 50.44) dealing with the generation of large quantities of hydrogen in the three types of BWRs and in Ice Condenser PWRs, which were thought to be the most vulnerable to the threat of hydrogen combustion (because of their size and pressure capability).

Several changes were made at NRC, however, dealing directly with severe accidents. One occurred rather spontaneously, and this was a shift in our research program to the study of more severe phenomena. In particular the Fuels Systems Research Branch and the Containment Systems Research Branch moved quickly from LOCA-related studies to studies involving molten core material. These two branches were later combined to form the

Accident Evaluation Branch, which manages our severe accident research today.

A more coordinated change in NRC's research program came about in 1980 as a result of a cooperative effort to study the TMI accident. An agreement was reached between the TMI operator, General Public Utilities, the Electric Power Research Institute, the NRC, and the Department of Energy to distribute among themselves various activities related to accident follow-up. NRC's role was to conduct a general severe accident research program; DOE was to extract specimens and study the accident itself; GPU was to facilitate the overall study during its recovery operation; and EPRI was to provide management and coordination. Documents were issued under the acronym GEND, formed from the initials of the four participants.

Rounding out these early changes, NRC published an Advanced Notice of Proposed Rulemaking on October 2, 1980, announcing that it was planning to create new regulations to deal specifically with severe accidents. In direct response to this announcement, the industry organized the Industry Degraded Core Rulemaking program, or IDCOR, to provide an industry perspective for any rulemaking activities that might ensue. The Notice of Proposed Rulemaking was later withdrawn, however, and I'll come back to that subject in a little bit.

TURNING POINT 2 -- ACCIDENT SOURCE TERM PROGRAM

The second turning point regarding severe accidents came in 1983 and had to do with source terms. The "source term," as we use this expression, is a measure of airborne radioactivity in the containment that could be released to the atmosphere if the containment leaked. After the TMI accident, three scientists from Los Alamos and Oak Ridge National Laboratories had written a letter to NRC's Chairman stating, in effect, that the TMI accident had proven that the source term being used by the NRC was much too large. This letter was typical of many comments the NRC had received after the accident. It was claimed -- later to be disproved -- that the NRC's 20-year-old source term gave iodine releases that were too high by a hundred or a thousand times so that the risk of severe accidents was much less than commonly believed.

The NRC's response to these comments -- and it was the response that was the turning point -- was to launch a major research program addressing severe accident source terms. To accomplish this, a special program office was formed, reporting at a high level. It was called the Accident Source Term Program Office and its mission was to reassess the entire technical basis for estimating source terms. As it turns out, an assessment of source terms requires an understanding of wide-ranging severe accident phenomena, so this source-term project became a defacto

severe-accident project. At about the time this project was initiated, the NRC also completed a formal plan for its severe accident research program, and that plan was published as NUREG-0900 in January 1983.

For three years this source term work went on, incorporating substantial results from the ongoing research program and interacting extensively with the industry's IDCOR group in a series of large, public meetings. Since there was little direct action going on related to the proposed rulemaking, IDCOR found its opportunity to confront the NRC on the source term issue. The IDCOR-NRC relation was adversarial; at the end of each meeting, IDCOR and NRC would sit down and make a list of all the points on which they disagreed. But this interaction was very constructive in bringing important weaknesses in severe accident technology into sharp focus. Final results of the NRC's source term reevaluation were published in 1986 as NUREG-0956, after undergoing peer review by a special committee of the American Physical Society and a period of public comment.

NUREG-0956 concluded that there was no extremely small source term as had been claimed. Ironically, as this report was in final review, the Chernobyl accident occurred. The report's conclusion was never challenged.

Other results from the source term study were, perhaps, more important than this single conclusion. Paramount among these was the development of a coupled set of analytical models to describe a host of severe accident phenomena, all of which come into play in determining the source term. This set of models was called the Source Term Code Package, and with it the NRC for the first time had the ability to make reasonably credible estimates of severe accident behavior in individual nuclear power plants. This code, as you all know, has now been replaced by the MELCOR code.

The NRC's severe accident research plan had been updated once during the course of the source term reassessment (NUREG-0900 Rev. 1). However, at the conclusion of the source term work, a major revision of that research plan was undertaken to home-in on the weaknesses in technology that had been identified during the IDCOR interaction and the peer review. That revision of the research plan was drafted, it was reviewed by another external panel of international experts (headed by Herb Kouts of Brookhaven with conclusions published as NUREG/CR-4883), and the revision was supported by a series of "Uncertainty Papers" (published as NUREG-1265). That revision of the severe accident research plan was not adopted, though, because a third turning point had occurred and events overtook it.

TURNING POINT 3 -- SEVERE ACCIDENT POLICY STATEMENT

The third turning point was the issuance of a severe accident policy statement by the Commission in July of 1985. Before summarizing the policy statement and its implementation, let me digress momentarily and talk about probabilistic risk assessments, or PRAs.

Using analytical models of severe accident phenomena, like those embodied in the Source Term Code Package or MELCOR, it is now possible to perform plant-specific PRAs with reasonable confidence as to radioactive releases. Crudely speaking, a PRA consists of the following: (1) Estimates of the probabilities of failures of components, leading to a large number of possible sequences of core damage events; (2) Analyses of the behavior of the nuclear plant for these possible event sequences (this is where the new analytical models come in); (3) Radiological consequences of these hypothetical event sequences (i.e., deaths, illnesses, and land contamination); and (4) a summing up of the consequences, appropriately weighted by the probabilities, to get the overall probabilities of deaths, illnesses, etc., per year for that plant.

By the time the Commission's severe accident policy was published, the NRC was well along with formulating the study of five selected operating reactors using the Source Term Code Package. This monumental study, known by its report number NUREG-1150, was completed at a later time, but the value of such studies had already become apparent. Thus PRAs figured prominently in the severe accident policy statement.

The policy statement can be roughly summarized as follows:

1. Licensed operating reactors are safe enough, given that the TMI backfits have been made.

2. However, each operator of a licensed operating reactor should perform a disciplined, PRA-based study to search for hidden vulnerabilities to severe accidents and to address any that might be found.

3. New reactor applications must be accompanied by a PRA with its severe accident analysis, and the PRA would be taken into account by the NRC in its review.

Subsequent to issuance of the severe accident policy statement, a number of separate programs on severe accidents were being pursued by the NRC. So in 1988, the NRC coordinated these programs with an "Integration Plan for Closure of Severe Accident Issues" (SECY-88-147). That plan consisted of six main elements:

1. Individual Plant Examinations
2. Containment Performance Improvements
3. Improved Plant Operations

4. Severe Accident Research
5. External Events
6. Accident Management

Most of these elements involved specific activities related to current operating reactors, and those activities had schedules for completion. Completing those activities became known as "closure" of the severe accident "issues." It was decided that the severe accident research program would be restructured to support closure of the other main elements of the plan rather than retaining its structure of addressing weaknesses and uncertainties in the technology.

Thus in mid 1989, a fourth version of the research plan was issued as the "Revised Severe Accident Research Program Plan," NUREG-1365, to cover a three-year period of FY 1990-1992. That period has recently ended, and an updated version of the research plan, the "Severe Accident Research Program Plan Update," NUREG-1365 Rev. 1, has just been issued. This brings us to the current time. The newest version of the research plan has returned to a

phenomenologically oriented structure of the earlier plans, and these major phenomena are:

1. Core Melt Progression
2. Reactor Vessel Penetration
3. High Pressure Melt Ejection
4. Core Concrete Interactions
5. Steam Explosions
6. Hydrogen Combustion
7. Containment Failure, and
8. Fission Product Release and Transport

I will not try to list or describe the severe accident research projects that are exploring these phenomena, because you are much more familiar with them than I am. However, in addition to these research projects, the NRC does have a program for severe accident issue resolution. Organizationally, NRC has a Severe Accident Issues Branch to assimilate severe accident research results and utilize them to address severe accident issues. This work is also done in NRC's office of Research, although strictly speaking this work is not research -- it's more related to regulatory standards work that is also the responsibility of our Research office. Currently, this branch is performing the reviews of the Individual Plant Examinations (IPEs) for operating reactors, required by the Severe Accident Policy Statement of 1985. This branch is also handling rulemaking activities on source terms and severe accidents, a subject I will return to presently.

THE NEXT TURNING POINT

A major event is on the horizon that may be the next turning point in our regulatory work on severe accidents. This turning point would be the promulgation of new Federal regulations to account for severe accidents in the design, siting, and operation of nuclear power plants. In a way, the Commission is revisiting the aborted effort of 1980, but we are now in possession of a decade of severe accident research that should allow the development of plant performance criteria.

While there are several related efforts under way -- the decoupling of siting criteria from plant design criteria, the implementation of new source terms, and the implementation of performance criteria for plant features related to source terms -- the event that could be pivotal is the adoption of a new rule to specify criteria for plant performance under severe accident conditions. These criteria would apply largely to the design bases for containment severe accident loadings, so I will refer to them as containment criteria for severe accidents.

Your severe accident research has enabled us to consider requirements on containment strength in a realistic way. This ability and several other activities have led up to the present threshold. One was the staff's review of the EPRI Advanced Light Water Reactor Requirements Document. This review was one of several reviews the staff has been performing on advanced reactor designs, which brought focus to a number of policy issues. In all of these reviews, severe accident phenomena are being addressed. The staff has chosen in the individual design reviews to address severe accident phenomena by specifying those features which the designs should incorporate to prevent or mitigate the phenomena. The severe accident requirements for the evolutionary as well as passive reactor designs are being provided for Commission approval prior to implementation and are being documented in draft Safety Evaluation Reports (SERs) for the evolutionary and passive designs and the EPRI requirements document. Another very important activity was an independent study of containment design criteria made by the NRC's Advisory Committee on Reactor Safeguards. From this unusual study, the ACRS recommended that the Commission promulgate revisions to Part 50 of our regulations, and in particular they recommended revisions to Appendix A, which contains our General Design Criteria.

As a result of these factors, the NRC published an Advance Notice of Proposed Rulemaking on September 28, 1992, to solicit public comments on several possible methods of codifying severe accident containment criteria. Three alternatives were described, but they all had two features in common: one was the maintenance of containment integrity for a specified period of time (like 24 hours), and the other was a delineation of the risk-significant severe accident phenomena to be considered, namely:

1. Hydrogen Combustion
2. High Pressure Melt Ejection
3. Molten Core Concrete Interactions
4. Containment Overpressure and Overtemperature
5. Steam Explosions, and
6. Containment Bypass

Alternative 1, called the "Hardware Oriented Rule," was the most prescriptive. Alternative 2, called the "Phenomena Oriented Rule," was a less-prescriptive version of Alternative 1. Alternative 3 would modify the General Design Criteria as recommended by the ACRS. The staff seems to prefer Alternative 1, which would lead to a more standardized resolution of severe accident issues and might require less extensive analysis by the applicant, thus making licensing review easier.

The period for public comment on the Notice has just ended and comment letters have been received. The industry has opposed any such regulation, but the thrust of the ACRS recommendation to strengthen containment capability under severe accidents appears to be compelling. Currently, the Commission plans to publish a proposed rule for additional comment in about one year, and to publish a final rule about a year later.

Promulgating a rule like this is very serious business, not unlike implementation of the emergency-core-cooling-system, or ECCS, acceptance criteria two decades ago. While the impact of such rulemaking on the severe accident research program is unknown at this time, if history is a guide, there will be much confirmatory work that could go on for a long time. This is where your severe accident research program will be of so much value, and I wish you well in your efforts to help us all to understand these complex phenomena.