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The Importance of Forensic Research in the Nuclear Power Industry -- What the OECD Three Mile Island Reactor Vessel Investigation Means to the Future of Commercial Nuclear Power

PRESENTED BY
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THREE MILE ISLAND
VESSEL INVESTIGATION PROJECT
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Good morning, ladies and gentlemen. I am very pleased to join you today at this Open Forum for the presentation of the significant results of the OECD Three Mile Island reactor vessel investigation project which, after almost five years, has essentially been concluded.

I wish to acknowledge the active participation and attendance at this Forum of members of the OECD Program Committee, including the Chairman of the Management Board, Dr. M. Banaschik; the Program Review Group Chairman, Dr. J. Hudson of AEA Technology; the OECD Nuclear Energy Authority Secretary for the TMI-Vessel Investigation Project, Dr. Alex Miller; the NRC Project Manager for the Program, Dr. Alan Rubin; and our good friend, Mr. Klaus Stadie, Deputy Director, OECD Nuclear Energy Authority (NEA).

I am also pleased to see many colleagues here, including Eric Beckjord, Director of NRC's Office of Nuclear Regulatory Research, and Chairman of our first session, and other speakers of this session including Professor Norman Rasmussen of the Massachusetts Institute of Technology; Mr. Edward Kintner, formerly of General Public Utilities; and Mr. Walter Pasedag of the U.S. Department of Energy.

In my brief remarks this morning, I will try to illustrate the importance of forensic research to the international nuclear power program. Webster's dictionary defines the adjective "forensic" in terms of its Latin derivative -- forensis-- meaning "public", and the Latin usage -- forensis forum -- meaning "public forum". Thus "forensic" is defined by Webster as "belonging to, used in, or suitable to courts of judicature or to public discussion and debate." I trust this particular forum is of the latter variety, and not the former.

Thus I welcome all of you as public examiners as you report on your respective investigations of this latest example of the power of forensic science -- the examination of the TMI reactor vessel, and what it can tell us, after all these years, of the fateful events of March 28, 1979 at Three Mile Island.

Many of us can remember, in the early years after the accident at Three Mile Island, how we believed -- or maybe even hoped -- that only minor damage had occurred to the core. Then, some time later, we saw television pictures of the void in the upper core region. Subsequently, we recovered specimens exhibiting damage to the lower head of the vessel indicating a rather serious progression of events. I need not tell this forum that our understanding of the potential damage from credible reactor severe accidents was changed forever by TMI, and that significant changes in all international regulatory processes were a consequence.

I would like to review with you how profoundly the nuclear regulatory agenda in the U.S. and -- I believe the entire Western world -- was affected by the TMI accident, by recalling some of the history of the NRC's severe accident research program.

LESSONS LEARNED FROM TMI -- PART I

As many of you know, for severe accidents, until the present time, only a few direct requirements such as emergency planning were in place. Like the civil aviation industry, most of our regulatory requirements dealt with avoiding a serious accident rather than coping with one. Then, TMI occurred, and our preconceptions about our degree of attainment of engineering perfection in nuclear technology changed forever.

In particular, TMI-2 altered our perception of the likelihood of severe accidents and their precursors. Shortly after the accident, changes began at the NRC. We have yet to see the end of these changes. There have been a number of twists and turns in NRC's regulatory research activities following TMI-2, some to the consternation of the licensee community. Let me try to sort out a few of the major lessons learned and their impacts on licensees.

The first major impacts on licensees occurred in 1980 following formal reports by the two independent federal commissions appointed to investigate the causes of the TMI accident and to offer recommendations to the President and the Congress. As a result, NRC required its nuclear power licensees to make a rather large number of backfits (more than 6,400 separate action items) to respond to the lessons learned from the 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. For example, the Commission promulgated a rule (10 CFR 50.44) dealing with the generation of large quantities of hydrogen in BWRs and in Ice Condenser PWRs, which were thought to be the designs most vulnerable to the threat of hydrogen combustion and resulting overpressure because of their smaller size and somewhat limited pressure capability.

Another change at the time, within the NRC, dealt directly with severe accidents -- a shift in NRC's research program to broaden the study of severe accident phenomena. In particular, the Fuels Systems Branch and Containment Systems Branch began to focus on studies involving molten core materials as opposed to LOCA-related studies. These two Branches were later merged to form the Accident Evaluation Branch which manages NRC's severe accident research today.

Another change in NRC's research program occurred in 1980 when an agreement was reached between the TMI licensee, General Public Utilities, the Electric Power Research Institute, the Department of Energy, and the NRC to share various activities related to the accident evaluation and follow-up. NRC's role was to conduct a general severe accident research program; DOE's role was to extract specimens and study the accident itself; GPU's role was to facilitate the overall study during its recovery operation; and EPRI was to provide management expertise and coordination.

NRC also published an Advanced Notice of Proposed Rulemaking (ANPR) in October 1980, announcing that it was planning to create new regulations to deal specifically with severe accidents. The Licensee community in response organized the Industry Degraded Core Rulemaking program, or IDCOR, to provide an industry perspective and expertise for rulemaking activities that were expected to ensue. The ANPR was later withdrawn.

LESSONS LEARNED FROM TMI -- PART II

A second major turning point regarding severe accidents occurred in 1983 in response to attempts to quantify the TMI source term -- and had to do with severe accident source terms. As many of you know, the "source term" is a measure of airborne radioactivity in the containment that could be released to the environs as a result of containment leakage or failure.

This initiative was the result of three scientists at Los Alamos and Oak Ridge National Laboratories having written the NRC's

Chairman in 1982 stating, in effect, that the TMI accident had proven that the source term being used by the NRC for accident evaluation was far too large. It was claimed -- later to be disproved -- that the NRC's 20-year old source term yielded iodine releases that were too high by a hundred or a thousand times, and that the risk of severe accidents was much less than commonly believed.

The NRC's response to the letter -- and other letters at the time which expressed similar sentiments -- was to initiate a major research program on the severe accident source terms. The mission of the special program office, the Accident Source Term Program Office, was to reassess the entire technical basis for estimating source terms. This effort required an understanding of wide-ranging severe accident phenomena, so the accident source-term project became a "de facto" severe accident project. In January 1983, the NRC also published the formal plan for its severe accident research program as NUREG-0900.

Source term research progressed for about three years incorporating substantial results from this ongoing research program and the industry's IDCOR group which were discussed in a series of public meetings. There was, however, little direct NRC activity related to rulemaking, leading the IDCOR group to confront the NRC on the source term issue. While the IDCOR-NRC relationship at the time was adversarial from a technical perspective, the interactions were constructive in bringing important weaknesses in the severe accident state of art into sharp focus. The 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 receipt of public comments.

NUREG-0956 concluded that an extremely small source term did not exist under accident conditions as had been claimed. Events however subsequently overtook the debate -- the Chernobyl accident occurred. The report's conclusions thereafter were never challenged. One of the more important results of the source term study 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. With this set of models, termed the Source Term Code Package (STCP), the NRC had the ability, for the first time, to develop rather credible estimates of severe accident behavior in individual nuclear power plants. The STCP model has since been replaced by a more comprehensive code termed MELCOR.

At the conclusion of the source term work in 1986, a major revision of the research plan was undertaken to refocus regulatory research attention on weaknesses in the technology that had been identified through the IDCOR interchanges and the peer review by the American Physical Society. An updated draft accident research plan was reviewed by a panel of international experts, and their conclusions published as NUREG/CR-4883 together with a series of "Uncertainty Papers". The revised plan was never adopted however since a third turning point in severe accident research occurred -- an event not anticipated -- which overshadowed the conclusions of the study.

LESSONS LEARNED FROM TMI -- PART III

This third turning point was the issuance of a Severe Accident Policy Statement by the Commission in July 1985. The policy statement broke with the previous "deterministic tradition" of the agency -- staff and previous Commissions alike -- by embracing a new methodology, "probabilistic risk assessment". The new formalism would henceforth be a requirement for new reactor licensing applications.

As many of you know, probabilistic risk analysis involves a sequential process of:

(1) estimation of the probabilities of failures of components, resulting in a large number of possible sequences of core damage events;

(2) analyses of the behavior of the plant for these possible event sequences with the aid of analytical models;

(3) calculation of radiological consequences of these hypothetical event sequences (i.e., fatalities, illnesses, and land contamination); and

(4) a summation of all consequences, appropriately weighted by the probabilities, to yield the overall probabilities of deaths, illnesses, etc., per year for that plant.

The Commission's Severe Accident Policy Statement made three points:

- Licensed operating reactors, with the TMI-mandated backfits incorporated, were safe enough;

- The state-of-art of nuclear safety however was still sufficiently uncertain that each power reactor licensee should conduct a disciplined, systematic study to search for hidden vulnerabilities to severe accidents. Any vulnerabilities that might be found were to be addressed;

- All new reactor applications were to be accompanied by a PRA with its severe accident analysis. The PRA was to be taken into account by the NRC in its review.

By the time the Commission's severe accident policy was published, the NRC's update of Professor Rasmussen's well known WASH-1400 report, a study of five selected operating reactors using the Source Term Code Package, was well underway. This monumental study, was finally completed after extensive international peer review and published as NUREG-1150. By the date of its publication, the ubiquitous insights and other benefits of probabilistic risk assessment had already captivated the technical and regulatory communities.

Following issuance of the policy statement, a plan to integrate the numerous separate programs related to severe accidents was developed for the completion or "closure" of these various activities. The NRC's research plan, to reach closure on these issues was issued in mid-1989 as the "Revised Severe Accident Research Program Plan" (NUREG-1365).

As required by the Commission's Severe Accident Policy Statement of 1985, the NRC is now reviewing the 63 Individual Plant Examinations (IPEs) submitted thus far, and the agency will review the Individual Plant External Event Examinations (IPEEEs) upon completion of the IPE reviews.

The current, up-dated version of the research plan has returned to a more phenomenologically oriented structure reminiscent of earlier plans. The major phenomena include research programs on:

Core melt progression,

Pressure vessel breech and high pressure melt ejection,

Core-concrete interactions,

Fuel-coolant interactions and debris coolability,

Hydrogen transport and combustion,

Containment failure, and, of course,

Fission product release and transport.

Perhaps one might ask what does all of this history have to do with the TMI Vessel Investigation Project (VIP), and why is the TMI Vessel Investigation Project important to the U.S. regulatory, licensee, and reactor equipment supply communities? One should note that the first two major phenomena in the NRC's research program are directly linked to the principal topic of this Open Forum -- the structural integrity of the TMI reactor vessel during and after the Western world's first and only reactor severe accident at a licensed commercial LWR.

Let me recap briefly both what we knew before the TMI-VIP, and did not know prior to this research program. What we did know was:

- There was extensive oxidation of fuel cladding, fuel damage, and release of fission products;
- At least 45% of the core (62 metric tons) had melted;
- Molten core materials had relocated and frozen in lower core regions forming metallic core blockage;
- After approximately 4 hours following scram, molten core material broke through the crust at the side of the core and approximately 19 metric tons of molten ceramic material relocated to the lower plenum of the reactor vessel itself; and
- After an unknown but presumably brief period, the capability for heat removal from this molten ceramic material was restored and a stable situation established.

What we did not know was:

- The possibility of one or more localized hot spots in the lower vessel plenum, where they might be and how large they might be;
- The vessel temperature at any hot spot, and the temperature distributions through the vessel wall -- could the ferrite to austenite transition temperature have been exceeded in the vessel wall;
- If the transition temperature had been exceeded, for how long, and what would have been the controlling failure mode of the vessel if heat removal had not occurred;
- What was the margin of structural integrity in the reactor vessel during the period of presumed contact of the molten core debris and vessel wall;
- What were the likely heat transfer processes between the molten core debris and surrounding water within the plenum; what were the likely vessel hot-spot heatup and subsequent cooldown rates;
- What could the "companion samples" taken of solidified debris in the vessel plenum tell us about decay heat levels in the lower head;

- To what extent were the vessel instrument penetrations ablated or melted; did the ceramic melt intrude into the penetrations; if so, could such intrusions have led to loss of structural integrity of the penetrations; could loss of weld integrity have led to their ejection (vessel failure);

I leave it to the experts of the TMI Vessel Investigation Project assembled here to provide the answers to these questions based on their forensic science. It is my understanding however that answers to most of these questions are in hand as a result of this Project.

For these reasons, the OECD-NEA TMI-Vessel Investigation Project program in my opinion can be called an unqualified success. The Project now has developed a good indication of actual metal peak temperature and time at temperature, core debris decay cooling rates, and vessel instrumentation penetration temperatures. These data have enabled the Vessel Investigation Project to develop measures of the TMI pressure vessel's structural margins to failure. The results of the VIP data and analyses may even suggest that reactor pressure vessels have additional capability to maintain their integrity during some severe accidents beyond that considered in current severe accident analyses and codes.

Knowledge of how to predict breach of a pressure vessel during a significant severe accident would obviously be of value. Confirmation that challenges to the containment structure, under some severe accident conditions, could be reduced would result in reduced source terms and could also increase public acceptance of commercial nuclear power plants.

Therefore, I look forward to the productive exchanges and interactions of this <u>forensic forum</u>. I hope that over these next three days, as your experimental data and findings are presented and the major conclusions are provided and debated, the results will help to guide future severe accident regulatory research agendas. The ultimate challenge will be to apply the research findings so as to reduce the probability of severe accidents in the reactors of the future.

I wish you a most successful conference. Thank you for your attention.