REPORT ON

CONSIDERATION OF CORE MELTDOWN

AS A DESIGN BASIS REQUIREMENT

AND ALTERNATE COURSES OF ACTION TO

CONCLUDE REVIEW OF FNP APPLICATION

March 24, 1975

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I. STATEMENT OF THE PROBLEM

A. Staff Use of Probability Assessments

Radiological safety assessments performed by the Commission staff pursuant to its responsibility in the licensing of power reactor facilities have to date consistently required that the design of the facility be such that no credible single event or sequence of events be capable of resulting in unacceptable consequences to the public. Although our regulations do not define the term unacceptable consequences, we have for safety assessment purposes generally interpreted them to be doses substantially in excess of the guideline values specified in 10 CFR 100. Similarly, the term credible is not defined in our regulations. However, our past licensing actions have indicated that the likelihood for an accident resulting in consequences substantially in excess of the guideline values specified in 10 CFR 100 should be in the order of one chance in one million per year per reactor. In summary, our practice has been to require that a reactor plant be designed so that the probability of having an accident occur that would result in consequences substantially in excess of the guideline doses specified in 10 CFR 100 would be no greater than about 10^{-6} per year per reactor.

Since the consequences of a gross core meltdown in a power reactor plant will, for all designs approved to date, clearly result in calculated doses far in excess of the 10 CFR 100 guideline values, it is clear that in the past we implicitly concluded that the probability for a gross core meltdown in each approved reactor plant was less than 10^{-6} per year. The staff has in the past made estimates of probabilities for specific events and combinations of events and, on the basis of the results of those quantitative estimates, determined whether or not the event or combination of events need be considered as a design basis for the reactor plant. The following are examples of instances wherein the staff has made quantitative probability assessments to determine whether or not a postulated event need be considered in the design of the plant.

1. <u>Reactor Pressure Vessel Failure</u>

The staff concluded on the basis of a generic evaluation that the probability for failure of a reactor pressure vessel is less than 10^{-7} per year per vessel and, therefore, that such an event need not be considered as a design basis for a light water reactor power plant. This evaluation is described in WASH-1318, Analysis of Pressure Vessel Statistics from Fossil-Fueled Power Plant Service and Assessment of Reactor Vessel Reliability in Nuclear Power Plant Service (dated May 1974).

2. Aircraft Impact

The probability for a plane to impact a nuclear plant is quantitatively assessed in each case where the location of an airport or of aircraft landing and/or takeoff patterns are such that the probability for an aircraft crash at the site is of concern. Quantitative assessments of aircraft impact probabilities have been made for numerous applications, including those for the following facilities:

(a) Three Mile Island
(b) Zion
(c) Shoreham
(d) Seabrook
(e) Douglas Point

The calculated probability in each case was used to determine whether or not and to what extent aircraft impact needed to be considered in the design of the facility. These evaluations are documented in the records of these applications.

3. Explosions

For sites where shipments of explosive materials create a potential safety problem, the staff has assessed the probability for such explosions and determined the extent to which they needed to be considered in the design bases for the specific plants involved. Specific applications for which this has been done include Brunswick and Byron-Braidwood. Documentation for these evaluations is provided in the applicable record.

4. Reactor Scram

The probability for reactor scram upon demand has been assessed by the staff on a quantitative basis. This assessment is described in WASH-1270, Anticipated Transients Without Scram for Water-Cooled Power Reactors (dated September 1973), and forms the basis for our current position on ATWS and the need to improve the reliability of the reactor scram system in future plants.

In addition to the above, a careful search of the records will provide other cases where the staff has made quantitative probability assessments which served as the basis for licensing action. In general, however, whether or not an event or combination of events needed to be considered in the safety assessment of a reactor plant was determined on the basis of a qualitative probability estimate. If the estimated value was clearly less than about 10^{-7}, it was neglected; if it was significantly greater than about 10^{-7}, design changes were required either to reduce the probability to an acceptably low value or to alter the plant so that it would be able to withstand the event in an acceptable manner; that is, lead to consequences within the dose guidelines established in 10 CFR 100. The entire structure of our safety evaluations has from the on-set of the regulatory program been based on estimates of the likelihood for the occurrence of specific events. While several of these assessments have been quantitative most have been made on the basis of undocumented qualitative group judgments. In any event, for each case we evaluate, we as a staff convince ourselves that the probability for experiencing an accident in the nuclear power plant that would result in dose consequences significantly in excess of 10 CFR 100 is so low that it need not be considered as a design basis. In part, since a gross core meltdown accident would lead to consequences well above the guideline limits, we also consistently conclude that the probability for a core meltdown in a licensed facility is less than 10^{-6} per year.

B. Recent Considerations

The occurrence of two events during the past year or so has, as a result of their combined impact, led the staff to reexamine its position with regard to consideration of core meltdown. The first event was the proposed use of nuclear power plants installed on floating platforms located miles offshore at ocean sites. On the basis of preliminary consideration, we were convinced that the probability for a core meltdown accident for a floating nuclear plant (FNP) would differ little from that for a land-based unit. On this basis, we have consistently refrained from formally requiring the FNP applicant to consider core meltdown as a design basis event or to investigate the consequences of a meltdown.

The Advisory Committee on Reactor Safeguards (Committee or ACRS) has been involved in the review of the FNP since its initial proposal. From the onset, the ACRS has voiced its concern that core meltdown should be considered for the FNP concept. Without any support from the staff, the Committee has encouraged the applicants involved in the FNP proposal to investigate the consequences of a core meltdown at an offshore ocean site and to consider the potential for mitigating those consequences by use of special design provisions such as a core catcher. The Committee has maintained a consistently strong position with respect to the need to consider the core meltdown situation for a FNP.

The second event was the issuance of the draft version for public comment of WASH-1400, An Assessment of Accident Risks in U. S. Commercial Nuclear Power Plants (dated August 1974). This draft report indicates that the average probability for a core meltdown is 60 times greater than the 10^{-6} per year value discussed previously. The draft report was reviewed by a Regulatory staff Task Force during the latter part of 1974. One of the conclusions of the Task Force was that the core meltdown probability predicted by the Study Group that issued the WASH-1400 document was too high by a factor of at least ten.

C. The Problem

The problem faced by the staff can be separated into the following items:

1. Is the evidence provided in WASH-1400, in conjunction with the concerns expressed by the ACRS with respect to the FNP concept, sufficient to support a staff conclusion that FNP core meltdown consequences should be evaluated in detail?

2. If the answer to 1 above is positive, then should similar evaluations be made for land-based nuclear plants?

II. PROPOSED POSITIONS

Several alternative courses of action are being considered by the staff in order to bring our ongoing review of the FNP proposal to a conclusion. These are described below.

A. Consideration of Core Meltdown in Safety Evaluations

While no special in-depth investigations have been conducted by the Office of Nuclear Reactor Regulation with respect to probabilities for accidents leading to core meltdown, we do have a reasonable knowledge of the WASH-1400 draft report and of the reasoning behind the core meltdown concerns of the ACRS. Further, we have a good understanding of the basic design differences between a land-based and a floating nuclear plant and can reasonably assess how these design differences and siting differences can, in a general way, affect the probability for core meltdown and the consequences of such a meltdown. On the basis of this knowledge, we have reached the following conclusions with respect to the question as to whether sufficient evidence is now available to justify detailed evaluation of core meltdown consequences.

1. It is likely that rigorous evaluation of all pertinent information, including the WASH-1400 draft report and the comments made by the Regulatory staff Task Force on the draft report, would lead to a significant reduction in the core meltdown probabilities given in the WASH-1400 draft report.
2. On the basis of the WASH-1400 analyses, there are reasonably clear-cut design and operating and maintenance procedural changes that can be made for nuclear plants to further reduce the probability for core meltdown. These include eliminating the potential for single equipment failures that could lead to system failures, minimizing dependence upon operators to perform emergency functions, and careful scheduling of maintenance.
3. The probability for core meltdown in an approved floating nuclear plant will not differ significantly from that for a land-based plant.

4. The acute or immediate radiological consequences to individuals of a core meltdown in a floating nuclear plant located at an ocean site some miles from land will not differ greatly from those for a land-based plant. In the event of a core meltdown in an ice condenser containment, such as is proposed for the floating nuclear plant, the most probable mode of initial containment failure for either a land-based plant or a floating nuclear plant will be due to overpressurization rather than melt-through of the containment base. It is likely that the atmospheric releases will control the extent of the acute consequences. The doses to people from such releases will, on the average, be less for a floating nuclear plant since it will be located some miles from any populated land areas. The acute consequences to individuals from the release of the molten core to the ground under the land-based plant and to the ocean under the floating nuclear plant will be less than those associated with the atmospheric releases. Preliminary analyses by the floating nuclear plant applicant have indicated that for that concept, releases to the sea would not result in any fatalities, while the atmospheric releases could lead to several fatalities. While we have not as yet reviewed those analyses in any depth, qualitative assessments of the potential acute consequences for either

the land-based or floating nuclear plant indicate that post-accident control measures will limit the acute consequences from the water or ground release pathways to a secondary order of concern compared with the acute consequences from the atmospheric release pathway.

5. The longer-term, or environmental, consequences of a gross core meltdown in a land-based plant compared with the consequences of the same event in a floating nuclear plant are likely to differ to a greater extent. Even for these consequences, however, the difference may not be as wide as might initially be surmised. One of the most significant differences between the floating nuclear plant and most land-based plants would be the loss of control of radioactive material that melted through the plant. For most land-based plants, the release of radioactivity to the ground water could be controlled to a significant extent by the use of perimeter wells and flow barriers. For the ocean-sited floating plant, dispersion of radioactive material to the ocean could be immediate and would not appear to be amenable to practical control. A similar problem could, however, exist for some land-based plants where the molten core could possibly enter a near-surface aquifer before preventive measures could be taken,

and contaminate the water used for a wide and populated area. In addition, land-based plants located near the ocean shore, a lake shore, or river bank are likely to contaminate those waters in due time via the diffusion of long-lived radionuclides. It is difficult to see how the extent of contamination of water bodies could be as great for a land-based plant, but it should be recognized that the water bodies could serve as sources of drinking water or for food irrigation purposes.

Another obvious environmental difference results from the fact that dispersion to the ocean will contaminate large areas of "international waters" and result in potential food chain doses to residents of countries other than our own that would be difficult to estimate with any degree of accuracy at the present time.

6. The practical design of core catchers or other devices which would mitigate the course of events of a grossly melted reactor core is beyond present-day technology.

B. Alternative Courses of Action to Conclude Review of FNP Application

The following alternative courses of action are available to the staff to conclude its review of the FNP application:

Alternative 1

Maintain the position that the probability for gross core meltdown is low enough that it need not be a design basis event for any light water reactor plant. On this principle take the following steps:

1. Issue our SER within a few months holding to our position on the low probability for gross core meltdown and indicating in the SER that this is a basis for our favorable findings. Attempt to convince the ACRS, on the basis of qualitative arguments, that the probability for and consequences of a gross core meltdown for an ocean-sited nuclear power plant do not differ greatly from those for land-based plants.
2. Proceed with our present plans with respect to environmental impact statements; i.e., to issue the FNP generic DES with little change in our position on class 9 accidents realizing the potential for DES recirculation.*
3. Have the Office of Nuclear Regulatory Research extend the WASH-1400 study to floating nuclear plants on a generic basis without any ties, schedular or otherwise, to the processing of the FNP license applications presently before NRC. Current plans call for extension of WASH-1400 to the

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*Letter dated 2/21/75, A. Giambusso to E. Case, "Accident Analysis for Generic DES - Offshore Power Systems (OPS)

LMFBR, HTGR, and FNP (nuclear powered merchant ships should be included in the FNP assessment for completeness). We estimate that this effort will be complete in two to three years.

Alternative 2

Proceed as in Alternative 1 except that we would conclude in our SER that the manufacturing license should be restricted to a limited number of ocean-sited units (say two to four). Indicate to OPS that its application could be more readily extended to a larger number of units if the itional units were located at protected, non-ocean sites, such as a sealed lagoon. In such locations, the consequences of a gross core meltdown could qualitatively be shown to be not significantly different from those for a land-based plant.

Alternative 3

Proceed as in Alternative 1 except that while we would issue our SER within a few months holding to our position on the low probability for gross core meltdown, we would indicate that because of the persistent ACRS concerns about the consequences of a gross core meltdown, we are requiring the applicant to perform additional analyses of the acute consequences to confirm that their magnitude will not differ greatly from those calculated for land-based plants of similar design. The applicant would be requested to provide these analyses to the staff and ACRS during the course of the review. The staff would review and comment on these analyses to the ACRS, but they would not be used as a basis for the staff recommendation in the SER regarding issuance of the manufacturing license. This would probably require an extension of six to nine months in our schedule.

Alternative 4

Expand the scope of our review to include the consideration of the probability and the consequences (both acute and long-term) of a gross core meltdown. Proceed in the following manner:

1. Issue our SER within a few months but withhold our final conclusions pending the completion of our assessment of the gross core meltdown event. This will permit the applicant, the staff, the Coast Guard, and the ACRS to resolve any outstanding issues on the basic design while the degraded accident concerns are being addressed on a different time scale.

2. Within the Office of Nuclear Reactor Regulation, develop a program of six to nine months' duration to investigate and compare core meltdown for the floating nuclear plant located at a fixed ocean site and a land-based plant located at a few typical sites. Specific areas to be compared are (a) core melt probability, (b) radiological (acute) consequences, and (c) environmental (long term) consequences. RL (LWR-1)

would assume responsibility for item (a), TP for item (b), and RL (EP) for item (c). The applicant would be requested to provide additional information in all these areas. This program would aim toward issuance of a supplement to the SER late this year.

3. Have the Office of Nuclear Regulatory Research undertake a short-term evaluation of core melt for floating nuclear plants. The program should be limited to consideration of a floating nuclear plant at an ocean location and should consist of an investigation of about six months' duration to bound the consequences of ocean dispersion of the radioactivity released from a melted reactor core deposited within the proposed breakwater for the Atlantic Generating Plant. This would provide needed validation for our short-term assessment described in (2) above and for the concurrent investigation that is to be conducted by the applicants. It is our present understanding that such a study would require about six months to perform but could not be completed until about a year to a year and a half from now because of other priority work assignments and manpower limitations.

4. Have the Office of Nuclear Regulatory Research extend WASH-1400 to cover floating nuclear plants as specified in Alternatives 1, 2, and 3 above.

5. Issue our generic DES as soon as practical but withhold our final conclusions pending the completion of an environmental assessment of the core meltdown event. This will permit the identification and possible resolution of any problems that develop with respect to our basic assessment while the degraded accident assessment is being performed on a longer time scale. The schedule could be directed toward issuance of an amended DES, if needed, by about the end of the year; that is, in concert with the planned SER Supplement addressing the probabilities of core meltdown events and the safety related consequences of such meltdowns.

6. The DES for the manufacturing license was issued in July of last year. The comments are to be incorporated into the FES for the generic review which would be expected to be issued some four months after the DES for the generic review; on this basis, the FES might be expected to be issued in the fall of this year unless an amendment is needed in which case it would be in the spring of next year.

This alternative would permit the basic SER and DES (generic) to be issued within a month or two, the first SER Supplement to be issued near the end of the year in concert with an amended DES (generic), if needed, both of which would address the degraded accident event in appropriate perspective. The final SER Supplement (following a final ACRS meeting and favorable letter) and the FES (generic) might be expected to issue in the spring of 1976 should an amended FES be required. The hearing could commence, and sometime during the hearing, the results of the short-term investigation by the Office of Nuclear Regulatory Research should be available. The results of the long-term review could be issued before issuance of the manufacturing license is needed (no sooner than 1978) and should be issued in time for our review of the final design.

Alternative 5

Have the Office of Nuclear Regulatory Research undertake a comprehensive, detailed, long-term study and comparison of the probabilities and consequences of core melt in land-based and offshore floating nuclear plants. This would involve an in-depth study of both acute and long-term consequences of core melt for offshore plants, and also an extension of WASH-1400 to investigate the long-term, environmental core melt consequences for land-based plants. This effort would require three to five years to complete and would involve both theoretical and experimental effort to achieve the desired result. Issuance of a manufacturing license would be delayed until the study is complete.

Alternative 6

Inform the FNP applicant that NRC cannot, in the next several years, issue a manufacturing license for offshore sited floating plants. This decision would be based on the need for much more information about the consequences of core melt than is presently available and the fact that the necessary information cannot be obtained without a major, in-depth study of the problem (such as is described in Alternative 5).

Point out to the applicant that if his application is limited to plants located at protected, non-ocean sites, such as a sealed lagoon, the probability and consequences of core melt could easily be shown to be comparable to land-based plants. If the FNP application were so limited, the NRC review could proceed without the major delay described above.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

APR 11 1975

Edson G. Case, Acting Director
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CORE MELT CONSIDERATIONS AND ALTERNATIVE PROCEDURES FOR PROCESSING THE FLOATING NUCLEAR POWER PLANT APPLICATIONS

In response to your memorandum of March 31, 1975, we have the following comments:

1. It is suggested that much of the discussion on pages 1-8, related to staff usage of probabilistic techniques and to probabilities of core melt accidents is not useful in this document. The issue with FNP's appears to be not as much related to accident probabilities as it is to whether accidents in FNP's can have markedly different consequences than land based reactors.

2. Page 9. It appears inappropriate to speculate that the acute consequences of a potential core meltdown in an FNP would not differ greatly from those of a land based plant. Atmospheric dispersion over water is quite poor and the distance that the plume travels over water before contacting land may not cause significant dilution of the plume concentration.

   There are two other significant factors to consider:

   a) On the one hand, the possibility of steam explosions and sea water-fuel chemical reactions when melt-through occurs may result in <u>increased</u> release of radioactivity from the fuel.

   b) On the other hand, it is not apparent that the most likely potential containment failure mode for an FNP will be due to over pressurization rather than melt-through. There are potential significant advantages in <u>decreasing</u> the amount of fission products released to the atmosphere by absorption in water by assuring that the most likely path for containment failures would be melt-through. In a MkI BWR containment, $P \times V = 5 \times 10^7$; in an FNP it is about 4×10^7. In a BWR MkI, the timing for failure by over-pressurization versus melt-through is a close race. Although the PV product appears to be almost the same for an FNP, the bottom concrete thickness is significantly less (~3' vs. ~12'). Small adjustments in design could make bottom melt-through the more likely failure mode, if it is not so already.

3. One of the key issues for FNP's is whether the consequences of potential core melt-through can be significantly different in terms of dispersion of non-volatiles in the ocean. It would seem that this question could not be answered well without conducting about a one year R&D program.

4. One way to go ahead now with FNP's would be to have the first few plants surrounded by an impermeable barrier (or be placed in a sealed lagoon) that would obviate the need to consider the ocean dispersion of radioactivity. This course would make enough time readily available to permit resolution of the issues surrounding FNP's constructed without such barriers.

5. If the alternative presented in paragraph 4 above is not feasible, we would favor your alternative 4 as the best way to proceed.

for Saul Levine

Herbert J. C. Kouts, Director
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