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UNITED STATES ATOMIC ENERGY COMMISSION

DIVISION OF REACTOR LICENSING

REPORT TO ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

IN THE MATTER OF

CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.

INDIAN POINT NUCLEAR GENERATING UNIT NO. 2

REPORT NO. 4

Note by the Director, Division of Reactor Licensing:

The attached report has been prepared by the Division of Reactor Licensing for consideration by the Advisory Committee on Reactor Safeguards at its Special August 1966 meeting.

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Introduction

As a result of discussions during the July ACRS meeting related to the consequences of core melt-through and adequacy of emergency core cooling, the applicant has proposed several facility modifications which would further mitigate the potential consequences of postulated loss-of-coolant accidents. These modifications and the applicant's evaluation of their potential performance were submitted in the Fourth and Fifth Supplements, dated July 25 and July 28, 1966, respectively, to the Preliminary Safety Analysis Report for Indian Point Nuclear Generating Unit No. 2.

The Staff's analysis of the conformance of the proposed facility to the "General Criteria for Nuclear Power Plants" and other related safety problems is contained in our July report (No. 3) to the Committee. This report considers only the emergency core cooling modifications and the reactor pit crucible proposed in the Fourth and Fifth Supplements. We have also evaluated the proposed modifications in relation to applicable portions of the revised draft of "General Design Criteria" dated July 25, 1966, copies of which have been provided to the ACRS.

Discussion

A. Safety Injection System Modifications

A Safety Injection System (SIS) is provided for this facility to limit core damage following postulated loss-of-coolant accidents resulting from a complete spectrum of primary coolant pipe rupture sizes. The system contains both high-head and low-head pumps that deliver borated water from the refueling water storage tank (320,000 gallons) to each of the cold- and hot-leg pipes of the reactor vessel, respectively. The SIS is automatically initiated following a loss-of-coolant accident by coincident two of three signals for both low pressurizer level and pressure. In addition, manual actuation of systems or components can be initiated from the control room. For the Indian Point II reactor, the following emergency core flooding pumps are provided:

a) Three high-head safety injection pumps - 400 gpm @ 2500 ft.

b) Two low-head safety injection pumps - 3000 gpm @ 280 ft.

c) Two residual heat removal pumps - 3000 gpm @ 280 ft.

The applicant has proposed several piping modifications to improve the reliability of this system; however, the number and capacity of the pumps has not been changed. The piping arrangement of the modified system is shown in Figure 3-1 of the Fourth Supplement and provides the following improvements:

a) The piping header on the injection side of the high-head SI pumps is now divided into two headers. Each header delivers its water into two of the reactor vessel cold-leg pipes. As before, these headers are protected by the polar crane support wall from possible missiles generated by failure of the primary system.

b) The injection header for the low-head SI pumps (and residual heat removal pumps) has also been divided into two headers. Each header delivers its water into <u>all four</u> of the reactor vessel hot-leg pipes, and is also missile protected. By dividing the headers as indicated, the flooding capability of either the high-head or low-head SI system is not lost in the unlikely event of a single header failure under accident conditions.

c) Additional piping has been provided to connect the discharge from the low-head system to the suction header of the high-head SI pumps. This connection enables long-term reactor cooling to be maintained even if both low-head headers should fail, and also permits recirculation with the high-head pumps for small primary system failures in which the reactor coolant pressure remains above the delivery head of the low-head pumps.

d) The suction of the low-head SI pumps has been connected to the refueling water storage tank. The connection enables these pumps to be operated continuously for both the injection and recirculation phases, thereby limiting the required number of operator actions to align the system for the long-term recirculation phase.

The pumps of the Safety Injection System can be operated by the three emergency diesels if outside power is lost. Table 3-2 of the Fourth Supplement lists all of the engineered safeguards that can be powered assuming two or three diesel generators in operation. For the SIS, 3 high-head SI pumps, 1 low-head SI pump, and 1 residual heat removal pump can be operated from three diesels. If only two diesels are assumed to operate, 2 high-head SI pumps, 1 low-head SI pump, and 1 residual heat removal pump can be operated.

The applicant has also considered the forces that the safety injection pipes must withstand during the blowdown phase. This analysis is provided in Section 9 of the Third Supplement and indicates that the pipes can withstand the maximum forces expected. In addition, the pipes and headers are braced so that a single piping failure will not cause failure of the associated header.

The quality standards for selection, installation, and periodic testing of the pumps, pipes, valves, motors, power supplies, and control circuits for the Safety Injection System are provided in some detail in Section 1 of the Fifth Supplement. We believe that adherence to these standards should provide a system of high quality with reasonable assurance that it will perform in the manner specified.

B. Evaluation of Safety Injection System

To provide a basis for the evaluation of the modified SIS, the Staff has chosen to demonstrate the system's conformance to applicable sections of the revised draft of "General Design Criteria for Nuclear Power Plant Construction Permits" dated July 25, 1966. The applicable portions of these criteria are as follows:

CRITERION 7 (Category A) ENGINEERED SAFEGUARDS

Safeguards shall be engineered into the facility to back up safety features provided by the core design and the core and coolant boundary protective systems. Such safeguards shall be designed on the basis that:

2. Temperatures that could endanger the capability of the reactor vessel to function as a postaccident core enclosure and coolant container are to be prevented.

3. Fuel temperatures from decay heat and from chemical reaction that could cause or materially augment the release of fission products from the core are to be limited both in extent and consequences.

The SIS is provided to limit potential core damage following primary system piping failures of all sizes. The three high-head SI pumps are designed for small breaks in which the reactor pressure remains relatively high for long periods. This system can recirculate water (with the aid of any low-head pump) from the containment sump, if necessary. For large piping failures, two low-head SI pumps are provided. Either low-head SI pump has sufficient capacity to prevent major damage or melting of the core, and can refill the reactor vessel to the top of the fuel in about seven minutes. For this condition, the applicant has calculated that a 5% zirconium-water reaction will occur.

The low-head SI system also provides long-term core cooling and may be required to function for about one year after a major accident. These pumps are located within the containment building so that it will not be necessary to circulate radioactive water outside the containment during the recirculation phase.

However, since one of these low-head pumps must function to maintain containment integrity, a redundant set of low-head pumps (termed the residual heat removal pumps) have also been provided. These pumps are located in an accessible area of the auxiliary building. They would normally be used only during the injection phase, but could be operated during recirculation if both internal low-head SI pumps were to fail.

We believe that Criterion 7-2 and 3 are satisfied.

CRITERION 9 (Category A(RELIABILITY OF SAFEGUARDS

In determining the suitability of a facility for a proposed site, the degree of permissible reliance upon and acceptance of the inherent and engineered safety afforded by the systems, materials and components, and the associated engineered safeguards to be built into the facility will be influenced by their known or their demonstrated performance capability and reliability and the extent to which the operability of such systems, materials, components, and engineered safeguards can be tested and inspected where appropriate during the life of the plant. Therefore, all engineered safeguards shall be designed to provide high functional reliability and ready testability.

1. With respect to functional reliability, redundancy as appropriate shall be provided where importance of the safety function requires. Reliability principles embodied shall include the following:

   a. Where active heat dissipation systems are needed to prevent under accident conditions loss of containment vessel integrity or meltdown of the core, at least two independent systems must be provided, preferably of different principles.

Two independent systems are provided to prevent core meltdown for both large and small failures of the primary system. For large piping failures, these systems are the two low-head safety injection pumps and the two residual heat removal pumps. As discussed previously, the low-head SI pumps are located within the containment and the residual heat removal pumps are in the auxiliary building. Both sets of pumps feed into separate headers that direct borated water to all four hot-leg pipes of the reactor vessel. The operation of one pump in either system is sufficient to preclude core melting in the event of a large piping break; however, a 5% zirconium-water reaction was calculated to occur.

The two independent systems provided to prevent core melting following a small piping break are the high-head SI pumps and the low-head SI pumps. The high-head pumps are provided primarily to preclude any core damage resulting from this kind of failure. In addition, the low-head SI pumps (or residual heat removal pumps) would probably prevent significant core meltdown following a small break. For this case, the low-head pumps could not inject water into the vessel until the vessel pressure dropped below about 150 psig. During the period before the low-head pumps could function and assuming that all high-head pumps are inoperable, we believe the core would be cooled by the water-steam mixture in the vessel which must be present to maintain its pressure above 150 psig. The applicant will be prepared to discuss this item orally at the special meeting.

It should be noted that all of the above systems share a common water supply (refueling water storage tank) and delivery pipe from this source to the suction header for the pumps. We accept this feature because it is completely passive, is located away from the containment and thus would not be vulnerable to damage initiated within the containment, and is a Class 1 structure. All safety injection headers are multiple, inject into all eight reactor vessel piping legs, and do not rely upon components within the reactor vessel in order to perform their functions; therefore, we do not believe that it is necessary for these systems to be of different principles in order to provide sufficient reliability.

Based on the foregoing, and since both independent systems are redundant in active components, we believe that Criterion 9-1a is satisfied.

CRITERION 9 (Category A) RELIABILITY OF SAFEGUARDS

In determining the suitability of a facility for a proposed site, the degree of permissible reliance upon and acceptance of the inherent and engineered safety afforded by the systems, materials and components, and the associated engineered safeguards to be built into the facility will be influenced by their known or their demonstrated performance capability and reliability and the extent to which the operability of such systems, materials, components, and engineered safeguards can be tested and inspected where appropriate during the life of the plant. Therefore, all engineered safeguards shall be designed to provide high functional reliability and ready testability.

2. Testability provisions shall include those required for demonstrating operability to the extent practicable.

   b. Emergency core cooling system shall be designed so that:

      (1) Physical inspection of all components, including reactor vessel internals and water injection nozzles in closed loop piping, can be accomplished.

      (2) Active components, such as pumps and valves, can be tested periodically for operability and required functional performance.

      (3) A capability is provided to test periodically the delivery capability at a position as close to the core as is practical.

      (4) A capability is provided to test under conditions as close to design as practical the full operational sequence that would bring the systems into action, including the transfer to alternate power sources.

The initial and periodic testing capability of the Safety Injection System is discussed in Section 1 (parts 8 and 9) of the Fifth Supplement. Conformance with the above criteria is as follows:

1) All pumps, valves, heat exchangers, pipes, and headers of the SIS are installed at locations that are visible and available for inspection during periods of reactor shutdown. No components of these systems are installed within the reactor vessel; therefore, physical inspection of components within the containment

can be accomplished during shutdown. Those portions of the SIS outside the containment are always available for inspection.

2) All systems of the SIS are provided with minimum flow recirculation test lines. Thus, the pumps and valves in each system to be tested any time during operation if the reactor pressure is above 1500 psig. Since this pressure is above the cutoff head of the pumps, no flow will enter the reactor and operation will not be disturbed. Each system can be manually actuated from the control room by tripping the main actuation relays. Proper valve operation is noted by position indicating lights in the control room, and pump operation is determined by the discharge header pressure and pump motor ammeters.

3) The delivery capability to the reactor vessel can be tested during periods of reactor shutdown. The water delivered to the primary system is determined by manually initiating each system and noting the rising water level in the pressurizer. In addition, the residual heat removal system is normally operated during all shutdowns requiring reactor cooldown and depressurization. This operation tests the pumps, valves, and heat exchangers associated with this system.

4) Testing of the full operational sequence of the SIS, including the transfer to the diesel generators, is provided in the design of this system. To initiate this test, the pressurizer level and pressure are adjusted below the respective trip points. Also, the breakers supplying outside power to the 480 volt buses can be tripped manually to initiate operation of the three emergency diesels. The high- and low-head SI pumps and the residual heat removal pumps should start automatically in the proper sequence. All valves should also operate automatically and system delivery would be noted by the pressurizer

water level. The test would be terminated manually in the control room.

Based on the above testing and inspection capability, we believe that Criterion 9-2b is satisfied.

C. Reactor Pit Crucible

To mitigate the consequences of a core meltdown, the applicant proposes a MgO refractory lined steel crucible located near the bottom of the reactor cavity into which the core would fall should melting of the pressure vessel bottom occur. The applicant states that (1) the crucible design will be based on extensive analysis with adequate design margins, (2) crucible systems of this principle are well known in the metal casting industry, and (3) exact experimental heat transfer data under these conditions with these materials are not available.

We have evaluated the information submitted and note the following:

1. The applicant has presented a limited amount of material and without some of the detail necessary for a definitive evaluation of even the basic concept.
2. Rather limited heat transfer models and arguments are used.
3. The limiting or significant parameters are not noted.

Our review of the material presented consisted of using the applicant's proposed heat transfer model and noting its limitations and important parameters. Our conclusions are:

1. An evaluation of the concept requires further information regarding the fundamental heat transfer mechanisms (which may not be easily obtainable).
2. The model presented is highly sensitive to the amount of heat transfer downward through the bottom of the crucible. As the heat flux increases, the steel temperature increases and the amount of remaining

refractory material decreases (MgO above 3900F is assumed to float to the top of the melt). The applicant's simplified approach for evaluating this quantity leaves much to be desired.

3. The applicant does not state, nor do we know, the limiting thickness of refractory material necessary or the limiting steel temperatures before failure of the crucible can be assumed.

Figures 1 and 2 summarize the applicant's model and the results of our independent calculations using the model. Figure 1 presents the basic model with necessary explanatory information. Figure 2A shows the thickness of refractory remaining and the maximum steel temperature (at MgO-steel interface) as a function of downward heat flux. Figure 2B shows the downward heat flux as a function of percent of full power (decay heat rate) and the parameter "k." This parameter is the assumed conductivity of liquid UO_2 which is used in the simple conduction model for estimating downward heat transfer. As we increase the value of "k," we are essentially assuming added heat transfer mechanisms in the downward direction (due, for example, to convection currents). With the information we presently have available, it is difficult to predict the value of "k" which should be used in a simple conduction model. The applicant proposes to use a maximum value of 5.2 Btu/ft-hr-F which is two times their presently accepted value for conductivity in solid UO_2 at the melting point. Considering the model assumes liquid UO_2 with convection currents, this value does not appear to be unduly conservative.

In summary, we do not believe that the applicant has presented sufficient detail or analysis to demonstrate that the reactor pit crucible will function in the manner anticipated. However, we believe that installation of the crucible will not reduce the safety of the facility.

Figure 1

Steady State Conduction Model

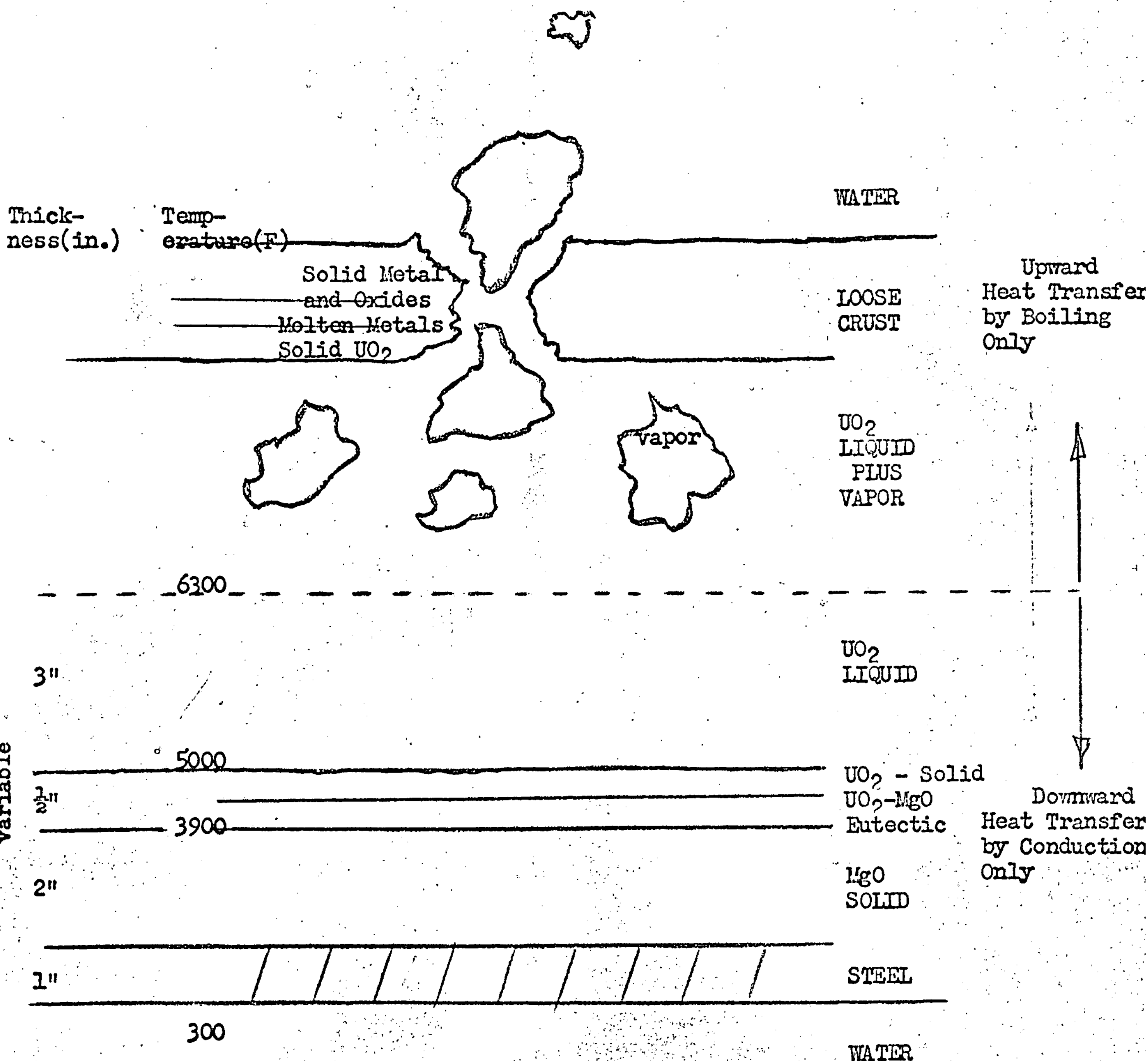


Figure 2A
Steel Temperatures and Refractory Thickness

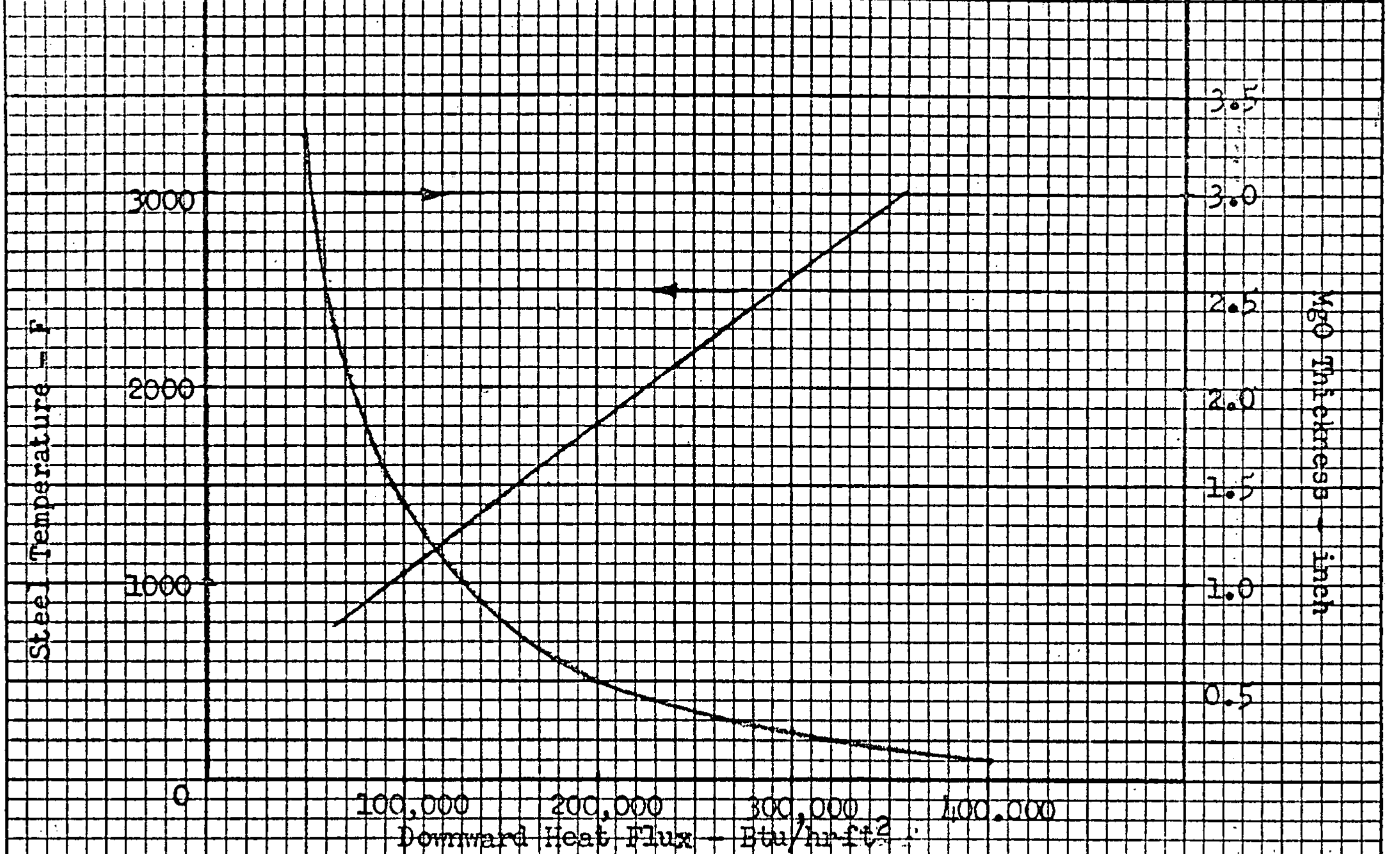
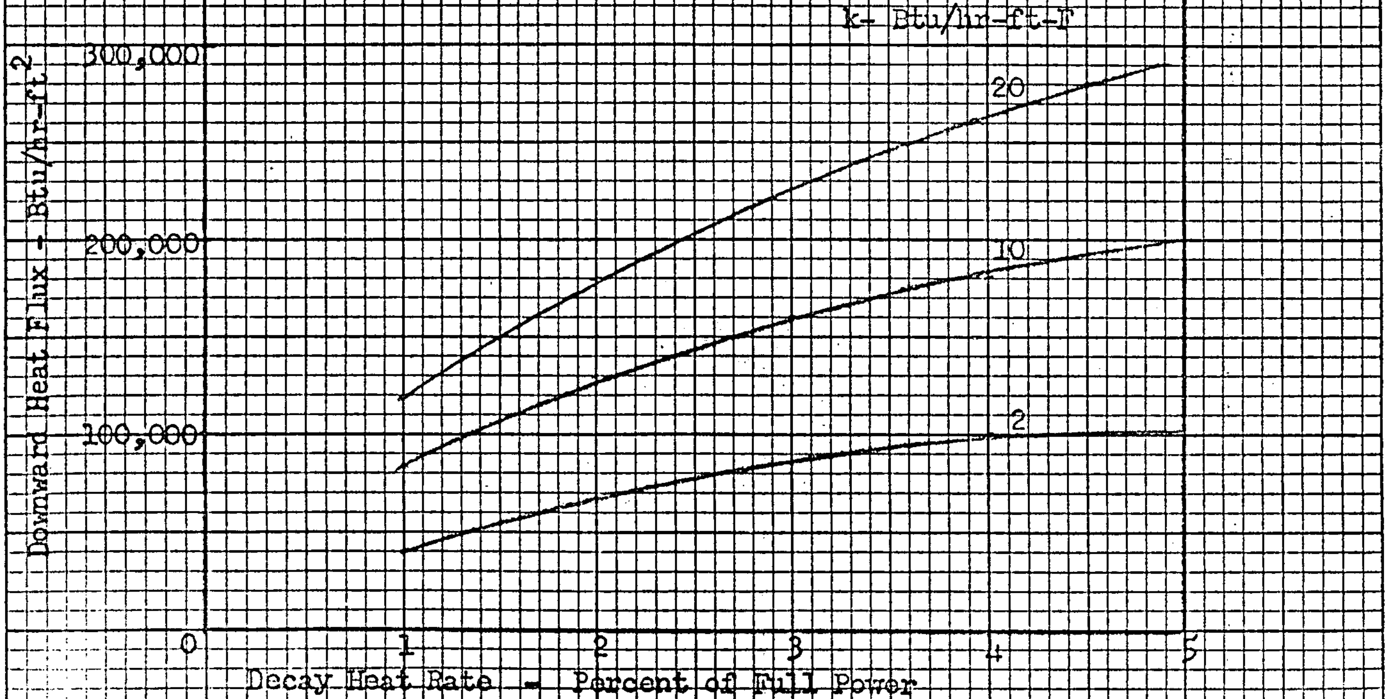


Figure 2B
Effect of Assumed Liquid UO_2 Conductivity on Heat Flux



Conclusion

We believe that the proposed emergency core cooling system for Indian Point II provides sufficient capacity, redundancy and reliability to preclude significant core damage and protect containment integrity in the event of credible loss-of-coolant accidents. We intend to follow the detailed design of the emergency core cooling system closely during the construction phase of this facility in order to insure that the system will perform its necessary functions under accident conditions.

We also believe that the reactor pit crucible should be considered as only a backup to the emergency core cooling system, and that sufficient evidence has not been presented by the applicant to demonstrate its effectiveness under the assumed accident conditions. However, the installation of this device does not detract from the safety provided by the containment and its associated engineered safeguards.