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# CONSOLIDATED EDISON COMPANY OF NEW YORK. INC.

# INDIAN POINT NUCLEAR GENERATING UNIT NO. 2

## FIFTH SUPPLEMENT TO:

## PRELIMINARY SAFETY ANALYSIS REPORT

REGULATORY DOCKET FILE COPY

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# INTRODUCTION

This amendment contains an expanded description of the reliability of emergency core cooling and a description of the Reactor Pit Crucible.

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RELIABILITY OF CORE COOLING

## 1.0 INTRODUCTION

A description of revisions made to the Safety Injection Systems was given in the Fourth Supplement to the PSAR. The following paragraphs contain more detailed information on the reliability of the systems to accomplish their function of core cooling. Design objectives and design criteria are presented along with a description of the systems features and how they meet these objectives and criteria. The core protection provided is described. Components of the systems such as pumps, valves, piping, motors and heat exchangers as well as instrumentation and control and electrical power supplies are described along with the steps taken to assure that reliable, high quality components are obtained for use in the systems.

Also discussed are the fabrication and erection techniques used to assure that the systems are installed and built to the highest standards in accordance with the final designs and specifications. The checks and tests and acceptance criteria to be followed during the initial checkout of the systems to demonstrate that the systems will function as designed are covered. In addition, periodic tests and maintenance programs to assure that a high degree of reliability and operability are available in the systems throughout the life of the plant are discussed.

## 2.0 SAFETY INJECTION SYSTEMS DESIGN OBJECTIVES

The Safety Injection Systems are designed to provide the post-accident emergency and long-term core cooling functions for Reactor Coolant System piping ruptures up to and including the double-ended severance of a reactor coolant pipe. Two specific objectives are imposed on the systems design:

a) For all piping break sizes up to and including a rupture equivalent to complete severance of the largest line connected to the Reactor Coolant System (or an equivalent size reactor coolant pipe rupture), the systems will prevent fuel clad melting and limit to a negligible amount any metal-water reaction.

b) For all piping break sizes up to and including the double-ended severance of a main reactor coolant pipe, the systems will limit core temperatures to the extent that the resulting energy releases to the reactor containment (flashing water and the products of metal-water reaction), when considered in conjunction with the containment cooling systems, will not result in the containment pressure exceeding the design pressure.

The Safety Injection Systems are designed reliably to meet these performance objectives with allowances for partial system operation. The specific measures taken to achieve a high degree of reliability and ensure that the post-accident emergency and long-term core cooling functions will be accomplished are summarized in this report.

e) Response of the injection systems must be automatic, with appropriate allowances for delays in actuation of circuitry and active components. (The injection systems are automatically actuated by coincidence of low pressurizer water level and low pressurizer pressure. In addition, manual actuation of the entire injection system and individual components can be accomplished from the control room. Delays in reaching the programmed trip points and in actuation of components are conservatively established on the basis that only emergency on-site power will be available.

f) Redundancy of instrumentation, components and systems must be incorporated, to assure that postulated malfunctions will not impair the ability of the systems to meet the design objectives. (System effectiveness will exist in the event of loss of normal station auxiliary power coincident with the loss of coolant, and will be tolerant of failures of a single component or instrument channel to respond actively in each system. In addition, gross core meltdown is protected against even if partial system failure is postulated which is more extensive than that derived from single fault analysis).

g) Provisions for periodic tests must be capable of demonstrating, with due credit for manufacturer's performance tests and preoperational test results, the state of readiness and functioning capability of the injection systems. (The systems, including their power supplies, are designed to permit complete demonstration of readiness and functioning capability when the reactor is operating at power or at a hot shutdown. In addition, extensive shop performance testing of characteristics and preoperational functional testing will be carried out. Consolidated Edison personnel or its representatives will participate in witnessing and evaluating tests related to engineered safeguards components, equipment and systems).

## 3.0 SYSTEMS RELIABILITY CRITERIA

To meet the systems design objectives, the following reliability criteria have been established:

a) Borated cooling water is to be supplied to the core through separated and redundant flow paths; (Eight points of injection are provided; one into each reactor coolant loop hot leg and one into each reactor coolant loop cold leg).

b) Loss of injection water through a severed reactor coolant loop or safety injection branch line must be considered. (For the double-ended severance of a reactor coolant loop, loss of all safety injection water delivered to that loop is assumed. For rupture of an injection branch line between the loop and check valve, spilling is established according to Reactor Coolant System pressure).

c) Natural phenomena characteristic of the site must be considered. (All associated components, piping, structures, power supplies, etc. are designed to Class I seismic criteria).

d) Layout and structural design must specifically protect the injection paths leading to unborken reactor coolant loops against damage as a result of the maximum reactor coolant pipe rupture. (Single injection lines penetrate the missile barrier, with injection headers in the missile-protected area. Individual injection lines are connected to the injection header, pass through the barrier and then connect to the loops. Maximum practical separation of the individual injection lines is provided. Movement of the injection line associated with a rupture of a reactor coolant loop is accommodated by line flexibility and by the design of the pipe supports such that no damage beyond the missile barrier is possible).

## 4.0 SYSTEM MECHANICAL COMPONENTS

### 4.1 PUMPS

#### 4.1.1 HIGH HEAD SAFETY INJECTION, LOW HEAD SAFETY INJECTION, AND RESIDUAL HEAT REMOVAL PUMPS

Pumps will all be constructed of austenitic stainless steel or materials of equal corrosion resistance. The pressure containing parts of each pump will be static castings conforming to ASTM A-351 Grade CF8 or CF8M. Stainless steel forgings will be procured per ASTM A-182 Grade F304 or F316, and stainless plate will be constructed of ASTM A-240, Type 304 or 316. All bolting material will conform to ASTM A-193. Materials such as weld-deposited Stellite or Colmonoy will be used at points of close running clearances in the pumps to prevent galling and to assure continued performance ability in high velocity areas subject to erosion.

All pressure containing parts of the pumps will be chemically and physically analyzed and the results will be checked to ensure conformance with the applicable ASTM specification. In addition, all pressure containing parts of the pump will be liquid penetrant inspected in accordance with Appendix VIII of Section VIII of the ASME Boiler and Pressure Vessel Code. The acceptance standard for the liquid penetrant test will be ASA B31.1, Code for Pressure Piping, Case N-9.

The pump design is reviewed with special attention to the reliability and maintenance aspects of the working components. Specific areas include evaluation of the shaft seal and bearing design to determine that adequate allowances have been made for shaft deflection and clearances between stationary parts.

Should welding of one pressure containing part to another be necessary, a welding procedure will be submitted for review and approval. This procedure must include evidence of qualification necessary for compliance with Section IX of the ASME Boiler and Pressure Vessel Code Welding Qualifications. This requirement will also apply to any repair welding performed on pressure containing parts.

In addition to the above requirements, these welds must be radiographed in accordance with Paragraph UW-51 of Section VIII of the ASME Boiler and Pressure Vessel Code, and subsequently liquid penetrant inspected in accordance with Appendix VIII of Section VIII of the ASME Code. The acceptance standard for the liquid penetrant test will be ASA B31.1, Case N-9.

The pressure-containing parts of the pump will be assembled and hydrostatically tested in accordance with Paragraph UG-99 of Section VIII of the ASME Code with the additional requirement that the test pressure shall be held for 30 minutes. This test will be witnessed by qualified Westinghouse personnel, and any leakage is cause for rejection.

Each pump will be given a complete shop performance test in accordance with Hydraulic Institute Standards. The pump will be run at design flow and head, shut-off head and three additional points to verify performance characteristics. When NPSH is critical, this value will be established at design flow by means of adjusting suction pressure.

4.1.2 COMPONENT COOLING PUMPS

The three component cooling pumps will be constructed of grey cast iron with carbon steel shafts. The pumps are of the manufacturer's standard design which are based on years of experience. The pump will be hydrostatically tested at the manufacturer's shop and performance tested in the field to verify conformance with the manufacturer's published data.

4.1.3 SERVICE WATER PUMPS

Six pumps, identical in size, capacity, and head, will supply river water to the service water system. Three pumps will be headered into each of the two independent, full size supply lines. Each one of the electric motor drives for the pumps will be connected to a bus supplied by a diesel-generator unit. In case of loss of station power, at least two of the service water pumps will continue operation on the diesel power source.

The pumps will be of the vertical, wet-pit, turbine type, an industry standard. This type pump has been universally and successfully used by utilities and heavy industries for a long period of time. The design specifications will require the highest quality construction and corrosion resistant materials available in accordance with industry standards.

The pump impeller will be hydraulically balanced to remove part of the thrust normally imposed on the motor drive. Properly executed certificates of chemical and physical properites of all materials used in the construction of the pump will be available to the purchaser.

Pump motor drives will be vertical, solid shaft type, NEMA type II with Class "B" insulation and space heaters; squirrel cage induction suitable for across-the-line starting with anti-friction radial and thrust bearings.

The vendor's list to be used in the procurement of the pumps will limit the bidders to those with the best reputation for designing and building high quality vertical pumps.

During pump fabrication, periodic visits by the purchaser's inspector to the vendor's shops will insure adherence to the specifications and the maintenance of high standard quality control. After fabrication, the pumps will be hydrostatically tested in the shop for strength, capacity, and head from wide open discharge to shut-off head conditions.

After installation, each pump will again be operationally tested as part of the pre-criticality systems tests. During plant operation, the service water system and all its components will be uniquely adaptable to regular maintenance and testing, since only one service water supply line and its associated three pumps is required for normal operation. All components--pumps, valves, piping and instrumentation-of each service water supply line can therefore be conveniently tested and maintained at regular intervals.

## 4.2 PIPE AND FITTINGS

The piping will be designed to meet the minimum requirements set forth in (1) the ASA B31.1 Code for Pressure Piping, (2) Nuclear Code Case N-7, (3) ASA Standards B36.10 and B36.19, (4) ASTM Standards, and (5) supplementary plus additional quality control measures.

Minimum wall thicknesses are determined by the ASA Code formula found in the power piping Section 1 of the ASA Code for Pressure Piping. This minimum thickness is increased to account for (1) the manufacturer's permissible tolerance of minus 12-1/2 per cent on the nominal wall, and (2) a 10 per cent allowance for wall thinning on the external radius during any pipe bending operations in the shop fabrication of the subassemblies. Purchased pipe and fittings will have a specified nominal wall thickness that is no less than the sum of that required for pressure containment, mechanical strength, manufacturing tolerance, and an allowance for wall thinning associated with shop bending.

Thermal and/or seismic piping flexibility analyses will be performed as required. The necessity and extent of such analyses will be determined as a result of a thorough review of the final piping layout. Special attention will be directed to the piping configuration at the pumps with the objective of minimizing pipe imposed loads at the suction and discharge nozzles.

Pipe and fitting materials will be procured in conformance with all requirements of the latest ASTM and ASA specifications. All materials will be verified for conformance to specification and documented by certification of compliance to ASTM material requirements. Specifications will impose additional quality control upon the suppliers of pipes and fittings as listed below.

1. Check analyses will be performed on both the purchased pipe and fittings. Supplementary requirement S1 will be performed on pipe purchased to ASTM A312 and ASTM A376; supplementary requirement S1 will be performed on fittings purchased to ASTM A403.

2. Pipe branch lines between the reactor coolant pipes and the isolation stop valves will be purchased to ASTM A376 and the supplementary requirements S2 and S6 covering transverse tension tests and ultrasonic tests, respectively.

3. Fittings will be purchased to the specified requirements of ASTM A403 plus the performance of tension tests as defined by supplementary requirement S2.

Shop fabrication of piping subassemblies is performed by reputable suppliers in accordance with specifications which define and govern material procurement, detailed design, shop fabrication, cleaning, inspection, identification, packaging and shipment.

All welds in run sizes 2-1/2" and larger will be of full penetration design. Reducing tees will be used where the branch size exceeds 1/2 of the header size. Branch connections of sizes that are equal to or less than 1/2 of the header size will be of a design that complies to the ASA rules for reinforcement set forth in the ASA B31.1 Code for Pressure Piping. Bosses for branch connections will be attached to the header by means of full penetration welds.

All welding will be performed by welders and welding procedures qualified in accordance with the ASME Boiler and Pressure Vessel Code Section IX, Welding Qualifications. The Shop Fabricator will be required to submit all welding procedures and evidence of qualifications for review and approval prior to release for fabrication. All welding materials used by the shop fabricator must have prior approval.

Butt welds will be radiographically examined in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section VIII, paragraph UW-51. In addition, butt welds will be liquid penetrant examined in accordance with the procedure of ASME B&PV Code, Section VIII, Appendix VIII and the acceptance standard as defined in the ASA Nuclear Code Case N-9. Finished branch welds will be liquid penetrant examined on both the outside and inside root surfaces.

A post-bending solution anneal heat treatment will be performed on hot-formed stainless steel pipe bends. Completed bends will then be completely cleaned of oxidation from all affected surfaces. The Shop Fabricator will be required to submit the bending, heat treatment and clean-up procedures for review and approval prior to release for fabrication. Cleaning by acid pickling is not permitted.

General cleaning of completed piping subassemblies (inside and outside surfaces) will be governed by basic ground rules set forth in the specifications. For example, these specifications prohibit the use of hydrochloric acid and limit the chloride content of service water and demineralized water.

Packaging of the piping subassemblies for shipment will be done so as to preclude damage during transit and storage. Openings will be closed and sealed with tight-fitting covers to prevent entry of moisture and foreign material. Flange facings and weld end preparations will be protected from damage by means of wooden cover plates securely bolted and/or fastened in position. The packing arrangement that the shop fabricator proposes is subject to approval.

## 4.3 VALVES

### 4.3.1 MOTOR OPERATED VALVES

The stainless steel valves employed in the Safety Injection System are designed and built per detailed Equipment Specifications. The pressure containing parts (body, bonnet and discs) shall follow the design criteria established by the ASA 16.5 or MSS SP66 specifications. The materials of construction for these parts are procured per ASTM A182 F316 or A351 GR CF8M; all materials in contact with the primary fluid, except the packing, are austenitic stainless steel or equivalent corrosion resisting material. The pressure containing components are subject to radiographic inspection as outlined in ASTM E-71 Class I or Class 2. The body, bonnet and discs are subject to a liquid penetrant inspection conducted in accordance with ASME Boiler and Pressure Vessel Code Section VIII, Appendix VIII. The liquid penetrant acceptance standard is as outlined in ASA B31.1 Case N-10.

The body-to-bonnet joint is designed per ASME Boiler and Pressure Vessel Code Section VIII or ASA B16.5 with a fully trapped, controlled compression, spiral wound asbestos gasket with provisions for seal welding if leakage should occur. The body-to-bonnet joint may also be of the pressure seal design with provisions for seal welding. The body-to-bonnet bolting and nut materials are procured per ASTM A193 and A194, respectively.

The entire assembled unit is subject to a hydrotest as outlined in MSS SP-61 with the exception that the test is maintained for a minimum period of 30 minutes. Any leakage is cause for rejection. Special attention is paid to the seating surface design. The units are constructed principally with a venturi design. The venturi design reduces the seating area, hydraulic unbalance, and stroking distance. The seating design is of the Darling parallel disc design or the Crane flexible wedge design or this equal. These designs have the feature of releasing the mechanical holding force during the first increment of travel. Thus, the motor operator has to work only against the frictional component of the hydraulic unbalance on the disc and the packing box friction. The discs are guided throughout the full disc travel to prevent chattering and provide easy gate hauling. The seating surfaces are hard faced (Stellite No. 6 or equivalent) to prevent galling and reduce wear.

The stem material is ASTM A-276 Type 316 condition B or precipitation hardened 17-4 pH stainless procured and heat treated to Westinghouse Specification These materials were selected because of their corrosion resistance, high tensile properties, and their resistance to surface scoring by the packing. The packing material is John Crane 187-I or equal. The valve stuffing box is designed with a lantern ring leak-off connection with a minimum of a full set of packing below the lantern ring and a maximum of one-half of a set of packing above the lantern ring; A full set of packing is defined as a depth of packing equal to 1-1/2 times the stem diameter. The experience with this stuffing box design and the selection of packing and stem materials has been very favorable. in both conventional and nuclear power plants.

The motor operator, usually limitorque, is extremely rugged and it is noted throughout the power industry for its reliability. The unit incorporates a "hammer blow" feature that allows the motor to impact the discs away from the core or backseat upon opening or closing. This "hammer blow" feature not only impacts the disc but allows the motor to attain its operational speed. During safety injection valve opening or closing, all limit switches and torque switches are removed from the control circuit and the operator strokes the valve without any protection against motor overload. The torque and limit switch control is reinserted at approximately 1/2 inch from the opposite position. The philosophy is that the valve will be stroked with no regard for the protection of the motor operator.

The valve is assembled, hydrotested, seat leakage tested (fore and back), operational tested, cleaned and packaged per specifications. All manufacturing procedures employed by the valve supplier such as hard facing, welding, repair welding and testing must be submitted for approval.

### 4.3.2 MANUAL VALVES

The stainless manual globe, gate and check valves are designed and built per the requirement outlined in the motor operated valve description.

The carbon steel valves are built per ASA B16504 MSS SP-66. The materials of construction of the body, bonnet and disc are procured per ASTM A105 Grade II, A181 Grade II or A216 Grade WCB or WCC. If the valves are required to pass radioactive fluids and have an ASA rating above 150 psig, they shall follow the same quality control as outlined for the stainless steel valves. If the valves pass non-radioactive fluids, they will be subjected to hydrostatic tests as outlined in MSS SP-61 except that the test pressure shall be maintained for at least 30 minutes.

The general design philosophy established for the design of the stainless steel valves is followed during the design of the carbon steel equipment. However, since the fluid controlled by the carbon steel valves is not radioactive, the double packing and seal weld provisions are not provided.

## 4.4 MOTORS

### 4.4.1 MOTORS LOCATED OUTSIDE OF THE CONTAINMENT

a) Electrical Insulation Systems

Motor electrical insulation systems will be supplied in accordance with ASA, IEEE and NEMA standards and will be tested as required by such standards. Temperature rise design selection will be such that normal long life will be achieved even under accident loading conditions. Periodic electrical insulation tests made during the lifetime of the plant will detect deteriation, if any, of the insulation system.

b) Loading

The application criteria for motors to be used in the safety injection systems will include performance lifetime equal to or greater than other major motors in the plant which are designed for continuous service throughout the plant lifetime. Pump design and test criteria will insure that motor loading does not exceed the application criteria.

### 4.4.2 MOTORS LOCATED INSIDE OF THE CONTAINMENT

a) Electrical Insulation Systems

Insulation systems which can safely and continuously operate at temperatures well in excess of those calculated to occur under the postulated accident condition have been developed and are routinely used in industry. Internal heat rise limitations are specified such that when the rise is added to the postulated accident ambient conditions, motor insulation hot spot temperatures will be well within the systems withstand capability. Periodic electrical insulation tests during the life of the plant will detect deteriation, if any, of the system.

b) Bearings

Bearings will be anti-friction, ball type, grease lubricated on which high temperature experience has been accumulated. Bearing loading and high temperature tests have been performed and expected life will be equal to or exceed those specified by AFBMA. Motors which have a routine function in addition to a safety injection system function will have bearing vibration detectors to continuously monitor for abnormal bearing conditions. Motor housing design will be such that no air or vapor pressure differential will occur across the bearings during or after the containment pressure rise associated with the postulated loss-of-coolant accident.

c) Motor Housings

Motor housing designs which prevent the moisture in the containment from entering the motors are completely enclosed fan self-cooled or fan heat exchanger cooled. Slight modifications of these designs will be specified such that no interchange other than heat between the motor internal ambient cavity and the containment accident ambient can occur.

d) Standby Service

Motors which operate only during or after the postulated accident will be designed for standby service incorporating space heaters and non-corrosive hardware. Periodic operation of the motors and tests of the insulation will ensure that the motors remain in a reliable operating condition.

Although these motors are normally run only for test, the design loading and temperature rise limits shall be based on accident ambient conditions. Normal design margins will be specified for these motors to make sure that the expected lifetime is well in excess of the required operating time for the accident.

## 4.5 COMPONENT SUPPORTS

For the hypothetical double ended severance of a reactor coolant pipe, the functional integrity of the Safety Injection System connections to the remaining reactor coolant loops will not be impaired. This integrity will be established and maintained by the application of the following design criteria:

(1) The reactor vessel, steam generators and pumps will be supported and restrained to limit their movement under pipe break conditions (including a double ended main pipe rupture) to a maximum amount which will ensure the integrity of the steam and feedwater piping. The safety injection piping in the intact loops will be designed to accommodate the limited movement of the loop components without failure. The coolant loop supports are designed to restrict the motion to about one-tenth of an inch, whereas the attached safety injection piping can sustain a 3-inch displacement without exceeding the working stress range.

(2) The safety injection piping serving each loop will be anchored at the missile barrier in each loop area to restrict potential accident damage to the portion of piping between this point and the connection to the reactor coolant pipe. The anchorage will be designed to withstand without failure, the thrust force on the safety injection branch line severed from the reactor coolant pipe and discharging safety injection flow to atmosphere, and to withstand a bending moment equivalent to that which produces failure of the safety injection piping under the action of free end discharge to atmosphere or motion of the broken reactor coolant pipe to which the safety injection piping is connected. This will prevent possible failure upstream from the support point where the branch line ties in to the safety injection piping header.

All hangers, stops and anchors will be designed in accordance with ASA B31.1 Code for Pressure Piping and ACI 318 Building Code Requirements for Reinforced Concrete which provide minimum requirements on materials, design and fabrication with ample safety margins for both dead and dynamic loads over the life of the equipment. Specifically, these standards require the following:

(1) All materials used must be in accordance with ASTM specifications which establish quality levels for the manufacturing process, minimum strength properties, and for test requirements which ensure compliance with the specifications.

(2) Qualification of welding processes and welders for each class of material welded and for types and positions of welds.

(3) Allowable stress values are established which provide an ample safety margin on both yield strength and ultimate strength.

## 4.6 RESIDUAL AND COMPONENT COOLING HEAT EXCHANGERS

The Residual Heat Exchanger and the Component Cooling Heat Exchangers must meet all the requirements of the ASME Boiler and Pressure Vessel Code, Section III, "Nuclear Vessels, for Class C Equipment". The Code has strict rules regarding the wall thicknesses of all pressure containing parts, material quality assurance provisions, weld joint design, radiographic and liquid penetrant examination of materials and joints, and hydrostatic testing of the unit as well as requiring final inspection of the vessel by a Code inspector.

The designs of the heat exchangers meet all the requirements set forth by TEMA (Tubular Exchanger Manufacturers Association) for Class R heat exchangers. Class R is the most rugged class of TEMA heat exchangers and is intended for units where safety and durability is required under severe service conditions. Things such as: tube spacing, flange design, nozzle location, baffle thickness and spacing, and impingement plate requirements are set forth by TEMA Standards.

In addition to the above, additional design and inspection requirements are imposed to ensure rugged, high quality heat exchangers such as: confined-type gaskets, main flange studs with two nuts on each end instead of one to insure permanent leak tightness, nozzles designed to withstand any load the adjacent piping may impose on them, general construction and mounting brackets suitable for the plant seismic design requirements, tubes and tube sheet(s) capable of withstanding full secondary side pressure and temperature with atmospheric pressure on the primary side, welding of the tubes to the tube sheet with a weld of sufficient size to develop the full tube strength to assure zero leakage at the joint, ultrasonic inspection in accordance with Paragraph N-324.3 of Section III of the ASME Code of all tubes before bending, liquid penetrant inspection in accordance with Paragraph N-626 or N-627 of Section III of the ASME Code of all welds and all hot or cold formed parts, a hydrostatic test duration of not less than thirty minutes, the witnessing of all hydrotests by a qualified inspector, a thorough final inspection of the unit for good workmanship and the absence of any gouge marks or other scars that could act as stress concentration points, a review of the radiographs and of the certified chemical and physical test reports for all materials used in the unit.

The Residual Heat Exchanger is a conventional shell and U-tube type unit having one shell and two tube passes. The channel connections will be welded; the shell side connections flanged to facilitate shell removal for inspection and cleaning. It has a SA-106 Grade A or B seamless carbon steel shell, a SA-234 carbon steel shell end cap, SA-213 TP-304 stainless steel tubes, SA-376 TP 304 stainless steel seamless channel, SA-240 type 304 stainless steel channel cover and a SA-240 type 304 stainless steel tube sheet.

The Component Cooling Heat Exchangers are a fixed tube sheet type heat exchanger with removable flanged channel covers which permit rodding of the tubes. All connections are welded. The heat exchangers have SA-285 Grade B welded carbon steel shields and channels, SA-285 Grade B carbon steel channel covers, SA-240 type 304 stainless steel tube sheets and SA-213 type 304 stainless steel tubes.

## 5.0 SYSTEMS INSTRUMENTATION AND CONTROL

### 5.1 CHANNEL DESIGN

The first step in ensuring reliable safety injection, instrumentation and control is the identification of component function and redundancy requirements, after which normal and extreme system operating and ambient conditions are established. A circuit design is then prepared which incorporates fail safe techniques where applicable. This design is carefully implemented to assure complete independence of circuits in redundant channels. Trip mode switches are provided to allow on-line testing of any channel during plant operation. Placing a channel in the "trip mode" reduces the requirements for trip operation to one out of two of the remaining operative channels.

Selection of the variables which initiate actions is made after system transient analysis during accident conditions. The Safety Injection signal is initiated on coincidence of low pressurizer pressure and low pressurizer level which are the primary indications of a loss of coolant from the reactor coolant system.

After completion of the system design, general equipment specifications and detailed data sheets are prepared to formulate a concise specification of system and component requirements.

### 5.2 REDUNDANCY

Six independent channels provide signals for initiation of safety injection. Two out of three low pressurizer pressure signals in conjunction with two out of three low pressurizer level signals are required to actuate safety injection. Failure of any one component will not cause accidental operation nor will it prohibit proper operation, when required.

## 5.3 PROCUREMENT, SYSTEM CONSTRUCTION AND ASSEMBLY

Hardware and equipment with established standards of operation reliability is selected wherever possible. When suitable standard equipment is not available, deviations from standard design are kept to a minimum and design methods which yield reliable equipment (such as derating of components) are used.

Vendors are carefully selected from those who have proven themselves to be responsible suppliers of reliable equipment. Components and modules are selected with careful attention given to maintenance requirements and past failure rate history. High reliability is achieved through detailed specifications for design, for derating of components, for manufacturing, quality control, inspection, calibration, and tests.

Reliable assembly, wiring and installation techniques are utilized. Isolation of signals is assured through use of shielded twisted pair wiring for all low level and analog signals. In addition, physical separation of signal circuits and power control circuits is maintained to minimize signal interference. Control equipment racks are assembled to assure maximum accessability for maintenance. Precision test resistors are provided in the analog current loops to permit on-line precision calibration checks of the respective channels without interruption of the channel signal.

## 5.4 TESTING

System test procedures are prepared to demonstrate, compliance with channel operational requirements such as system accuracy, time response and the required control actions. These tests are conducted at the vendor's shop and witnessed by Westinghouse personnel.

Additional instrument channel tests are conducted in the field following installation of the control equipment to verify that the system requirements and channel independence are met with the installed system.

Following completion of all of the instrument channel tests, an overall system dynamic test is conducted to verify that all system pressure, flows, capacities and equipment sequencing functions are provided in accordance with the design requirements. These tests include a demonstration that the system redundancy requirements are met by removing individual components from operation.

Consolidated Edison personnel will witness and participate in these tests.

# 6.0 SYSTEM ELECTRICAL SUPPLY

## 6.1 NORMAL POWER SUPPLY

The switching equipment, including switchgear, motor controls, relays and other components which are to supply the plant loads, including the safeguards loads, are specified and applied using a basic criterion that the minimum safeguards power requirements will be met with a failure of a component.

Transformer impedance is set to give adequate voltage conditions under the most adverse motor starting sequence. Short circuit calculations which set switching equipment sizes and capability are based on the most adverse fault conditions.

### 6.1.1 TRANSFORMERS

The four 6900/480 volt station service transformers will be the non-explosive, fire-resistant, air-insulated, dry type, cooled by natural circulation. Solid insulation in the transformer consists of inorganic materials such as porcelain, mica, glass or asbestos in combination with a sufficient quantity of a high temperature binder, to impart the necessary mechanical strength to the insulation structure. This insulation is defined by ASA standards as Group III material.

These transformers will be designed and constructed in accordance with the applicable standards of ASA, IEEE and NEMA. Dry type transformers can be continuously loaded at rated kilovoltamperes and rated delivered voltage. During engineered safeguards loading and operation these transformers will not exceed their kilovoltampere rating. Manufacturer shop tests of the transformers will be conducted in accordance with the latest revision of American Standard Test Code C 57.12.90. This series of tests consists of the following:

1. Resistance measurements of all windings
2. Ratio tests
3. Polarity and phase relation tests
4. No-load losses
5. Exciting current
6. Impedance and load loss
7. Temperature test
8. Applied potential tests
9. Induced potential tests.

During manufacture and testing, qualified personnel not attached to the manufacturer's shop will inspect this equipment and also witness the above tests, to verify that the equipment specifications have been met.

### 6.1.2 480v SWITCHGEAR, MOTOR CONTROL CENTERS, RELAYS

The switchgear and motor control centers are Westinghouse standard 480 volt (600 volt insulation class) metal-enclosed switchgear of draw-out construction furnished with air circuit breakers and magnetic contactors. This equipment is designed and constructed in accordance with applicable standards of ASA and NEMA.

The relays are standard Westinghouse relays used in electric utility industry applications. The breakers and contactors for the system are conservatively rated to interrupt the maximum calculated short circuit current and are selectively set to trip a faulted component off the bus.

Production tests are made to verify the quality and uniformity of workmanship and materials used in the manufacture of this equipment. Standard production tests for assembled equipment are as follows:

1. Sixty-cycle high-potential tests
2. Sequence test to ensure that the devices in the sequence function properly
3. Check of wiring by electrical operation and individual circuit continuity checks.
4. Mechanical tests to insure proper function of shutters and clearance of removable units, etc.

## 6.2 EMERGENCY POWER SUPPLIES

### 6.2.1 BATTERIES

Th heavy duty station batteries are of the type normally furnished for power plants to supply operating and emergency DC power. Two batteries will be furnished, either of which can supply the total demand for DC power associated with full engineered safeguards operation during a loss of outside power.

### 6.2.2 DIESEL GENERATOR SETS

Three diesel-generator sets will be furnished along with the necessary switching equipment to automatically start and run upon loss of voltage to the 480 volt busses to the engineered safeguards equipment in the event the normal outside source of power is lost coincident with requirement for engineered safeguards power. The system will be such that accidental overloading of the units will trip the generator from the bus and not stop the diesel.

The units will be manufactured in accordance with DEMA, ASA, and NEMA standards for emergency quick start service. Units as sized with sufficient overload margin that the loading sequence can be accomplished reliably. Starting equipment and other accessories will be selected to bring the machines to load accepting conditions in approximately 10 seconds.

The units will be periodically started to make sure the machines are in a satisfactory operating condition.

## 6.3 POWER SOURCES FOR VARIOUS COMPONENTS

The vital instruments and control are supplied power from the four-120 volt a-c vital busses. These busses are supplied by inverters, each of which is supplied from one of the station batteries and its chargers. These instrument busses are normally supplied by the battery chargers thru the inverters. On loss of a-c power, the batteries will then pick up the load without an interruption of power to these vital buses.

The power for the safety injection valve motors will be supplied from a split bus motor control center which in turn will be supplied from the 480 volt system. Each section of motor control center bus will be fed through a circuit breaker on the 480 volt system. These circuit breakers will be on different 480 volt buses and the bus that supplies each breaker will be supplied by an emergency diesel generator. There will also be a tie breaker between the two bus sections of the motor control center in order to have a backup source of power for each section in the event of loss of, normal supply to a section.

The engineered safeguards pumps and four motors are connected to the 480 volt buses thru their own circuit breaker. These motors are dispersed on the four 4-480 volt buses and all of this equipment can be supplied from either the outside source of power or from the three emergency diesel generators.

## 7.0 INSPECTION AND INSTALLATION OF EQUIPMENT IN THE FIELD

### 7.1 RECEIPT

Equipment and materials are delivered to the site by either railroad, barge or motor vehicle. As material is received it is checked for cleanliness, damage and checked against the bill of material specification for completeness. If trouble is found, an immediate request is made for rectification. Special inspection procedures and specifications for proper repairs are prepared in the event of damage.

### 7.2 STORAGE

After the receiving check, the materials and equipment are placed in storage if erection cannot proceed immediately. Small items are placed in a warehouse and segregated according to material classification or designated ultimate use. The very large items are stored outdoors, off the ground, and covered. All openings remain sealed until erection except when further inspection or pre-erection work may be required; afterwards they are resealed until installation.

## 7.3 CLEANLINESS

Components and materials destined for use in the nuclear and engineered safeguards systems receive special consideration during storage and installation to assure the assembled systems do not contain foreign material that will create operating problems.

Special attention is given to maintaining the equipment in a clean and uncontaminated condition during erection. Requirements for the highest grade commercial cleanliness are specified. Specifications are prepared which dictate special handling instruction and precautions to be observed when opening and inspecting any internal workings where foreign material could cause damage or impair the proper operation of the equipment.

Dirt and debris which could contaminate the atmosphere and the equipment in the immediate area of the building are continuously removed. All equipment is protected from physical harm, and kept sealed when not open for inspection.

Should it be necessary to open up a piece of equipment in an area where the atmosphere is contaminated as a result of grinding or concrete finishing for example, the cause of the air pollution will be terminated and/or a protective tent will be erected to minimize chances of contamination.

Dessicants are used and periodically monitored in components which are susceptible to damage by moisture. Heaters installed in equipment for moisture control are kept energized. Special precautions are taken to assure that the dessicant has been removed prior to system operation.

As part of the final cleaning procedures, a visual inspection of each system is performed following a solvent wash. All systems will be flushed using demineralized water during which time temporary screens are installed in the pump suction lines as required.

## 7.4 ERECTION

Erection procedures are issued to ensure that the equipment and materials are installed correctly and according to design. These procedures include such items as sequence of installation, when necessary, and specifications for welding. Particular attention is paid to methods which are not standard to the construction industry. Included in the welding specs are non-destructive tests required such as dye penetrant, radiography, and ultrasonic.

Qualified resident supervisory service engineers with training in electrical, civil, mechanical, instrumentation, and welding categories, experienced in installation and checkout of piping and equipment at other nuclear sites, review the specifications and procedures. Special attention is given to systems incorporated in the engineered safeguards. These supervisory engineers continually monitor the installation and checkout of the equipment for conformance to the procedures and specifications. During critical phases of the work, they provide personal guidance and record data for future reference. Specified tests are witnessed and accepted or rejected according to the results. If repairs are required, the work is supervised and the subsequent retesting witnessed.

An example of the above service engineers is the Welding Engineer assigned to the site. This man arrives at the site early in the construction program to instruct and train welders in the art of welding to code specifications. Coupons are fabricated and tested and when all requirements are met, work may proceed. Welders are given the necessary qualifying tests as required in the Boiler, Unfired Pressure Vessel and Piping Codes.

As assemblies of the systems are made, the engineer inspects each fit-up for alignment and symmetry. He supervises the weld fusion pass and monitors the work as it proceeds until the final weld pass.

When welds are completed, the Welding Engineer examines the conditioning of the weld for final non-destructive testing as required by specification. The Welding Engineer approves the interpretation of the radiographs and monitors the welds during hydrostatic testing. He is also responsible for keeping records, inspection reports, and a file of radiographs throughout the job. When work is complete, he prepares a final report.

# 8.0 SYSTEMS INITIAL TESTING AND CHECKOUT

## 8.1 INTRODUCTION

A comprehensive program of plant testing has been formulated for all equipment vital to the functioning of the engineered safeguards including the safety injection systems. This program consists of performance tests of individual pieces of equipment in the manufacturer's shop, initial checkout and testing of the system as a whole, and periodic tests of the actuation circuitry and mechanical components to ensure performance as required throughout the plant lifetime. The overall philosophy of testing of the engineered safeguards systems was discussed in the First Supplement to: Preliminary Safety Analysis Report under Question 2, Criterion 23. The following description of testing pertains to the modified safety inejction systems described in the Fourth Supplement to: Preliminary Safety Analysis Report, Section 3.

## 8.2 SYSTEMS INITIAL CHECKOUT AND TESTING

The initial tests of individual components and the initial functional test of the systems as a whole complement each other to assure performance of the systems and to prove proper operation of the actuation circuitry.

### Shop Tests

Shop testing of pumps will establish the ability of each pump to meet its full range of design requirements. For example, the low-head safety injection pumps will be submitted to a shop test program including the following.

a) Establishment of flow-head characteristics and NPSH requirements over the range of flows possible during injection or recirculation conditions.

b) A thermal shock and high temperature operation test to demonstrate performance under conditions simulating the switchover from injection of refueling water to recirculation of higher temperature water in the containment sump.

c) A test demonstrating the function of the pump and its associated sump suction piping under the suction pressure, water temperature and maximum flow expected during the recirculation phase of operation.

The above tests are in addition to quality control procedures such as the hydrostatic test and dye penetrant examination of the pump casing.

The remote operated valves in the safety injection systems will be motor-operated gate valves. Shop tests for each valve will include a hydrostatic pressure test, leakage tests, a check of opening and closing time, and verification of torque switch and limit switch settings. The ability of the motor operator to move the valve with the design differential pressure across the gate will be demonstrated by opening the valve with an appropriate hydrostatic pressure on one side of the valve.

## 8.3 SYSTEMS INITIAL FUNCTIONAL TEST

An initial functional test of the core cooling portion of the safety injection systems will be conducted during the hot-functional testing of the reactor coolant system before initial plant startup. The purpose of the initial systems test will be to demonstrate the proper functioning of instrumentation and actuation circuits and to evaluate the dynamics of placing the system in operation. This test will be performed following the flushing and hydrostatic testing of the system.

The functional test will be performed with the water level below the safety injection set point in the pressurizer and with the Reactor Coolant System initially cold and at low pressure. The safety injection system valving is set to initially simulate the system alignment for plant power operation.

To initiate the test, the safety injection block switch will be moved to the unblock position to provide control power allowing the automatic actuation of the safety injection relays from the low water level and low-pressure signals from the pressurizer instrumentation. Simultaneously, the breakers supplying outside power to the 480 volt buses will be trapped manually and operation of the emergency diesel system will automatically commence. The high- and low-head safety injection pumps and the residual heat removal pumps will be started automatically following the prescribed diesel loading sequence. The valves will be operated automatically to align the flow path for injection into the reactor coolant system.

The rising water level in the pressurizer will provide indication of systems delivery. Flow into the reactor coolant system will temrinate with filling of the pressurizer, and the operation of the safety injection systems will be terminated manually in the main control room.

This functional test will provide information to confirm valve operating times, pump motor starting times, the proper automatic sequencing of load addition to the emergency diesels, and delivery rates of injection water to the reactor coolant system.

The functional test will be repeated for the various modes of operation needed to demonstrate performance at partial effectiveness, i.e., to demonstrate the proper loading sequence with two of the three emergency diesels, and to demonstrate the correct automatic starting of a second pump should the first pump fail to respond. These latter cases will be performed without delivery of water to the reactor coolant system, but will include starting of all pumping equipment involved in each test.

The systems will be accepted only after demonstration of proper actuation and after demonstration of flow delivery and shutoff head within design requirements.

## 9.0 PERIODIC TESTING

The following series of periodic tests and checks provide continued assurance that the systems can perform their design functions whenever they should be called on during the plant lifetime.

### 9.1 INTEGRATED TEST DURING PLANT OPERATION

The safety injection systems can be actuated on the normal sources of power any time during plant operation when reactor coolant pressure is higher than 1500 psig.

The main actuation relays are tripped manually in this test and all valves and pumps associated with the injection signal are actuated automatically. The starting of the high and low head safety injection pumps can be checked in this manner. Operation of the system verifies the proper functioning of relays and circuit breakers between the main relays and pumps and valves in the system.

Pump operation is verified by observation of pump motor ammeters and discharge header pressure indication. Each pump will approach shutoff head on minimum flow recirculation. No flow will be delivered to the reactor coolant system to disturb normal plant operation since Reactor Coolant System operating pressure exceeds the shutoff head of the injection system pumps. Proper operation of valves is indicated with position indicating lights on the control panel.

## 9.2 TESTS OF INDIVIDUAL COMPONENTS

The high- and low-head safety injection pumps and residual heat removal pumps can also be tested individually during plant operation using minimum flow recirculation lines.

All remote operated valves can be exercised and actuation circuits can be tested periodically during plant operation.

## 9.3 DIESEL GENERATORS

The three diesel generators can be tested at any time during plant operation.

## 9.4 BORIC ACID CONCENTRATION IN THE INJECTION LINES

The injection piping up to the final isolation valve is maintained full of borated water at refueling concentration while the plant is in operation. This concentration will be checked periodically by sampling. The lines will be refilled with borated water as required by using the various system pumps to recirculate refueling water through the injection lines.

# REACTOR PIT CRUCIBLE

## 1.0 SYSTEM DESCRIPTION

Highly reliable, redundant systems have been designed to supply borated water to cool the core in the event of a failure in the reactor coolant system. These systems provide sufficient core cooling to prevent melting fuel from reaching the reactor vessel bottom following such an accident.

An additional feature will be supplied to provide a backup to the emergency core cooling systems in the event that the core might melt and deposit in the reactor vessel cavity. This feature consists of a MgO refractory lined steel crucible located near the bottom of the reactor pit cavity into which the core would fall should emergency core cooling be assumed to fail and melting of the vessel bottom occur. The crucible will be protected against damage by falling objects. The cavity will be filled with borated water following a loss of coolant accident to an elevation of 28 feet above the crucible. Stored energy and residual heat will be removed by radiation, convection, and conduction to the water above the crucible which is in direct contact with the material in the crucible. Additional cooling will be accomplished on the bottom of the crucible by the natural circulation of water from the containment floor through downcomer, along the outer surface of the crucible, and up through the cavity. The resistance to heat transfer from the bottom of the crucible will be controlled by the selection of a refractory thickness to ensure film boiling will not occur. A bond between the refractory and the liner will ensure good heat transfer between these surfaces. Exact experimental heat transfer data under these conditions with these materials are not available; hence this design will be based on an extensive analysis with adequate design margins. However, crucible systems of this principle are well known in the metal casting industry.

## 2.0 EXPECTED PERFORMANCE

Analyses of the transient temperature response of the steel and ceramic crucible, after deposition the core indicate that the system would heat up smoothly to a psuedo-equilibrium condition within one-half hour to one hour. Heat flux from the bottom surface of the steel plate to the water would rise monotonically to the value corresponding to a steady state coresponding to the energy generation rate in the fuel at that time. Thus there is no opportunity for the onset of film boiling, and the plate is well cooled.

The bulk of the fuel, would heat up essentially adiabatically to melting, with significant heat transfer down to the refractory occurring only from a layer two to three inches thick. The heat transfer to the crucible is limited by the thermal resistance of this layer of $UO_2$ itself.

The metallic and metal-oxide remains of the lower vessel head and core internals would tend to be on top of the fuel, being less dense than the fuel. This layer would tend to melt on its under side, depending on its thickness, as the fuel heats up, but it would be cooled on the top by water. Because of the thermal resistance of the fuel, which would remain solid in a thin layer near the top, it is impossible to transfer enough heat to the upper surface to initiate film boiling during the heatup and melting of the fuel. Thus, the crust on the top of the fuel would most likely consist of a loose mixture of solids on top of a thin fused metal and oxide layer, then a molten metal layer, then a solid $UO_2$ + metal oxide layer, all on top of the melting $UO_2$. Such a crust would have essentially no tensile strength. The only way in which a strong crust could be built up would be for molten pieces to float up from the bulk of the molten $UO_2$ to the surface, where they would cool into a solid mass. This type of crust would not be strong eonugh to support a significant pressure buildup within the hot mass. If a solid crust should form, it would tend to be broken up by the expansion of the $UO_2$ before vaporization temperature is reached.

Once the bulk of the $UO_2$ is melted, vapor would start to form. Pressure within the liquid would build up slowly and vapor bubbles presumably rise toward the top, until the crust on top would break and release the vapor. This vapor would excape into the water above, condense, and fall back onto the top of the fuel. The energy generated in about 80% of the fuel would be carried off to the surrounding water by this vapor, after the fuel reached vapor temperature. Of the remaining 20%, about half would be transferred downward through the refractory and steel to the cooling water below and about half would be transferred upward to the water above. Settling of condensed $UO_2$ beneath the crucible is prevented by its geometry and by the strong upward motion of coolant from below.

The exact mechanism for heat removal from the upper part of the $UO_2$ to the water need not be defined in analyzing the integrity of the crucible. For example, one might alternately postulate that $UO_2$ vapor, rising toward the upper crust, would condense under the crust, tending to melt the crust, perhaps thrusting sections up into the water to increase heat transfer to the water. Again, hot liquid might be expelled through the broken or melted crust to the water, thus carrying away heat. The only vital assumption is that the temperature of the bulk $UO_2$ liquid is limited to a maximum temperature, corresponding to the vaporization temperature. This limit on temperature limits the amount of heat which can be transferred downward to the crucible. To maintain this limit, it is essential that heat generated at this temperature be removed upward, and the basic mechanism for this heat removal is migration of vapor toward the top of the melt.

For the purposes of this study, a vapor temperature of 8000°F could be assumed as an extreme. According to extrapolation of Ackerman's data[1], this corresponds to a vapor pressure of approximately 4000 psi. However, as discussed previously, the crust could not support any significant pressure buildup. Thus a more realistic maximum vapor temperature would be about 6000°F corresponding to the reactor containment design pressure, about 60 psia.

## 3.0 TRANSIENT HEAT TRANSFER

In analyzing the transient temperature response of the crucible, the effect of the upper half of the $UO_2$ can be ignored and the molten $UO_2$ region can be treated on a symmetry basis. A four-region lumped parameter model was assumed to facilitate an analog computer solution. The four regions are:

1. The steel bottom plate, in contact with water on the bottom and the refractory liner on the top.
2. The ceramic liner, of constant thickness.
3. A thin film of solid $UO_2$ of varying thickness, with constant internal heat generation. Heat transfer resistance to either boundary of this region is proportional to its thickness.
4. A thick layer of liquid $UO_2$, of varying thickness, with constant internal heat generation. Melting or freezing occurs only at the boundary between the solid and the liquid regions, and determines the location of this boundary. Heat transfer from the liquid region to the solid-liquid boundary is proportional to the difference between the average region temperature and the melting temperature.

A typical transient response calculation is shown in Figure 1. The parameters for this calculation are listed in Table I. Although the lower layer of $UO_2$ is nominally solid, it was possible to start the problem with both $UO_2$ regions initially liquid at the melting temperature. The thickness of the lower layer was held constant until its temperature decreased due to solidification. This represents the worst initial condition that could be seen by the refractory and steel structure. As shown in Figure 1, the refractory and steel temperature rise monotonically to their steady state values. The $MgO-UO_2$ interface temperature, theoretically at a weighed average between the MgO and $UO_2$ temperatures at first, rises during the period taken to freeze the adjacent $UO_2$. When a thin layer of $UO_2$ freezes, the temperature drop through it represents a barrier to heat flow, and the interface cools. The layer of solid $UO_2$ thickens due to heat loss, then thins again as both the bulk molten $UO_2$ and the slower responding MgO heat up.

## TABLE 1

## PARAMETERS FOR TYPICAL TRANSIENT SOLUTION

## (FIGURE 1)

| | |
|---|---|
| **Thicknesses** | |
| Upper $UO_2$ layer | Variable, 15 inches initially |
| Lower $UO_2$ layer | Variable, 0.6 inches initially |
| MgO refractory | 2 inches |
| Stainless steel plate | 1 inch |
| **Initial Temperatures** | |
| Upper $UO_2$ layer | 5000°F, molten |
| Lower $UO_2$ layer | 5000°F, molten |
| MgO refractory | 300°F |
| Stainless steel plate | 300°F |
| Maximum $UO_2$ Temperature | 6000°F |
| Heat Generator Rate in $UO_2$ | 720 Btu/lb-hr (core avg. heat generation at 2200 sec. after shutdown) |
| Heat Transfer Coefficients, $UO_2$ liquid to melting boundary | 50 Btu/hr ft$^2$ F° |

The liquid temperature heatup to the vaporization temperature is almost adiabatic, since its thickness allows generation of much more heat than can be transferred out by conduction. Once this region reaches the vaporization temperature, set at 6000°F for this calculation, all heat in excess of that conducted downward is assumed removed in vapor. After this time the entire system heats up smoothly to an equilibrium consistent with the power generation rate assumed.

Similar calculations were performed withdifferent initial temperatures for the various regions, different thicknesses of the refractory layer, different initial thicknesses of the $UO_2$ layers, different vapor temperatures and different solid to liquid thermal resistance. The basic conclusion of these studies is as follows:

> Heatup of the system for a constant fuel heat generation rate is monotonic, with equilibrium being approached in 1/2 hour to 1 1/2 hours. There would be no significant melting of the refractory, if any, and no surge of heat flux to the water, during the earlier stages of the transient. Thus it is reasonable and prudent to design the system based on the steady state, using a heat generation rate appropriate to a time 1/2 hour to one hour after the assumed fall of the $UO_2$ onto the crucible.

## 4.0 STEADY STATE HEAT TRANSFER

If a thick layer of MgO is provided, that is, more than a two-inch layer, then the resistance between the $MgO-UO_2$ interface and water below would be enough that the surface could be heated to 5000°F, the melting point of both oxides. Upon melting, a mixture might form which has a minimum melting point of 3900°F.[3] Because of this low melting eutectic, it was assumed for this analysis that the maximum MgO temperature is 3900°F, and that MgO above this temperature would melt and float away. Actually, there would be a mixture of $UO_2$ and MgO above that temperature with a consequently reduced volumetric heat generation rate, but this was neglected.

The heat transfer model thus reduces to:

1. A thermal resistance (steel plus MgO) with fixed lower and upper temperatures (300°F and 3900°F).
2. A solid $UO_2$ layer with internal heat generation and resistance and with fixed lower and upper temperatures (3900°F and 5000°F).
3. A liquid $UO_2$ layer with internal heat generation and resistance, and with fixed lower and upper temperatures (5000°F and vapor temperature).

For this analysis, the liquid layer was assumed to conduct heat as a solid. Thus, all heat generated in this temperature band is conducted down through the refractory, and all heat generated in the $UO_2$ at vapor temperature, above the low temperature region, is assumed to be removed by escape of vapor. (The model is illustrated in Figure 2.) To compensate for the possibility of additional downward heat transfer by convection from the vaporizing region, a conductivity in the liquid of 5.2 Btu/hr ft F° was assumed. This is two of four times the presently accepted range of values for conductivity in solid $UO_2$ at the melting point.

The thickness of MgO which would remain solid under these conditions can be calculated directly from the resulting heat transfer resistance of the refractory-steel structure R,

$$R = \frac{T_M - T_W}{\sqrt{2q''' \int_{T_M}^{T_V} K \, dT}}$$

where $T_W$ = steel-water surface temperature, 300°F

$T_M$ = minimum melting temperature of refractory, 3900°F

$T_V$ = vapor temperature

$K$ = $UO_2$ conductivity

$q'''$ = volumetric heat generation of $UO_2$

The heat flux to the water is simply:

$$q'' = (T_M - T_W) / R$$

As would be expected, these equations indicate that conditions are worst, i.e., the lowest MgO thickness and the highest heat flux, if maximum heat generation rate, vapor temperature, and fuel conductivity are assumed. The resulting values for both extreme and best estimate parameters are shown in Table 2. In general, the heat being transferred downward would be that generated in a layer of solid $UO_2$ 1/4 inch to 1/2 inch thick, plus a layer 2 to 3 inches thick of melted $UO_2$ below the vaporization temperature. The MgO could remain solid to a thickness of almost 3 inches, or with the worst assumptions it could be melted down to approximately 2/3 inch thick. Even in this extreme case, the flux to the water would be well below that required for these conditions.

## TABLE 2

## STEADY STATE HEAT TRANSFER SOLUTION

| | MAXIMUM | BEST ESTIMATE |
|---|---|---|
| **Parameters** | | |
| Heat generation rate q''', $Btu/ft^3$-hr | 854,000 | 300,000 |
| Liquid $UO_2$ conductivity, Btu/ft-hr-F° | 5.2 | 2.6 |
| Solid $UO_2$ conductivity, Btu/ft-hr-F° | 2.5 | 1.85 |
| Vapor temperature °F | 8,000 | 6,300 |
| **Results** | | |
| Heat transfer rate of water, $Btu/ft^2$-hr | 177,000 | 52,600 |
| MgO thickness, inches | 0.7 | 2.7 |
| Solid $UO_2$ thickness, inches | 0.2 | 0.3 |
| Liquid $UO_2$ thickness below vapor temperature, inches | 2.3 | 2.1 |
| Maximum steel plate temperature, °F | 1550 | 660 |

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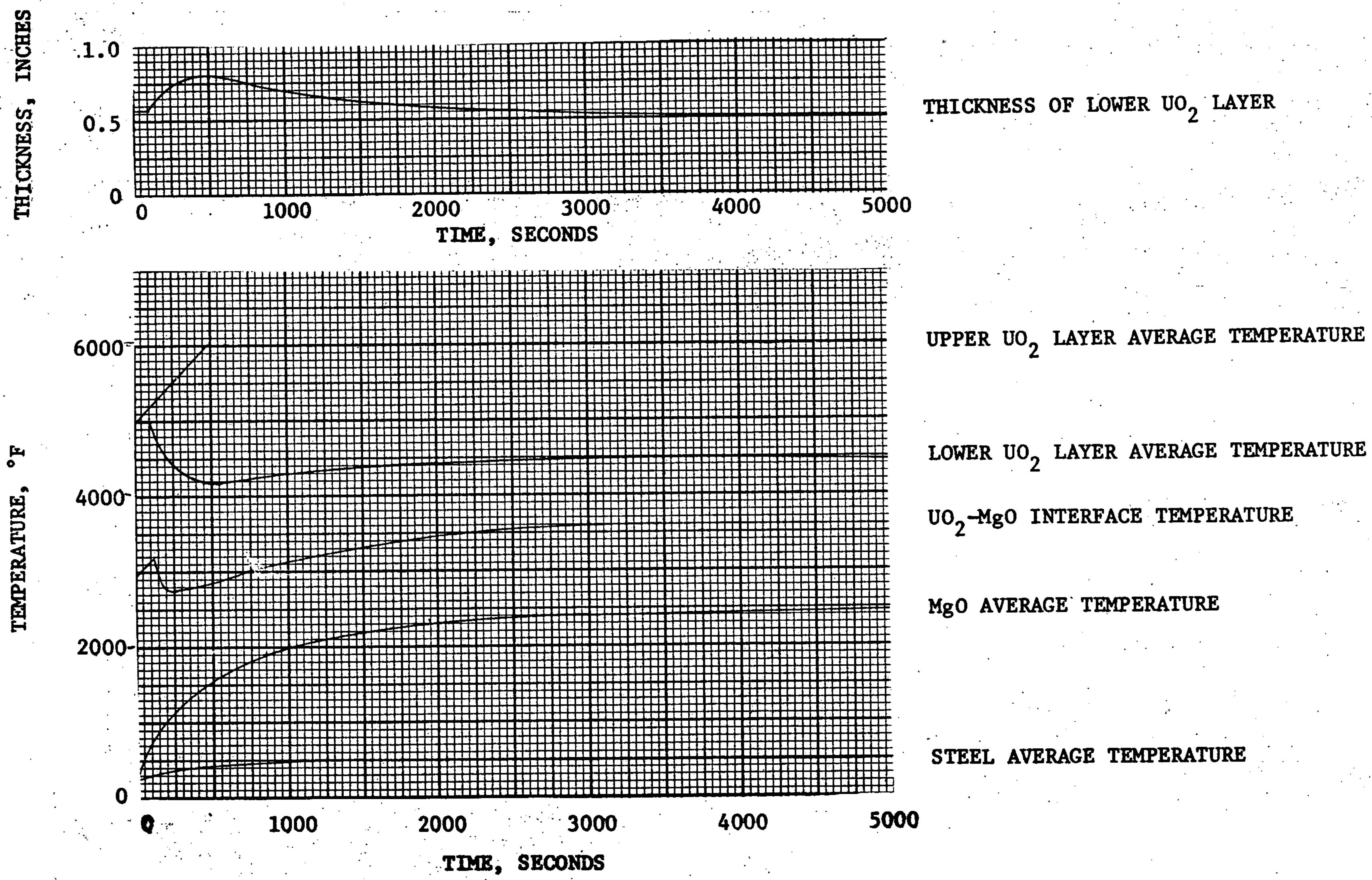


Figure 1
TYPICAL TRANSIENT RESPONSE

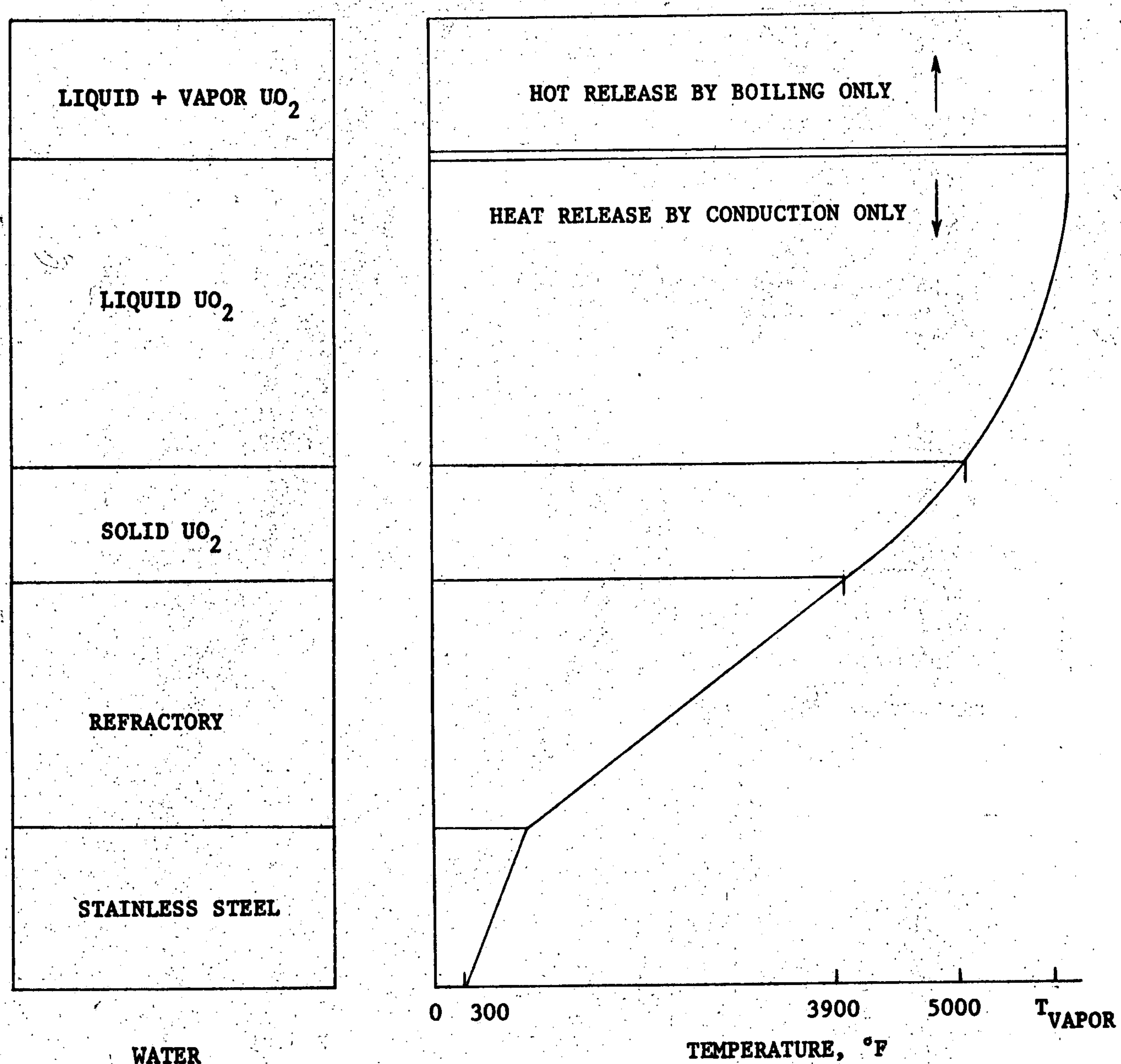


Figure 2
STEADY STATE PURE CONDUCTION MODEL

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