MASTER

MOXY: A DIGITAL COMPUTER CODE
FOR COMPUTING CORE HEAT TRANSFER

by

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I. INTRODUCTION

The loss-of-coolant accident (LOCA), in which a primary water circulation line undergoes a double-ended offset shear fracture, is generally acknowledged to be the maximum credible accident that could occur in a light water-cooled and -moderated, central station, nuclear power reactor.

Three sequential events that can take place during a LOCA are as follows:

- (1) Decompression, during which the water moderator-coolant is expelled through the break, leaving the reactor shut down but with degraded core cooling capability
- (2) Core heatup, during which the core, due to the loss of cooling capability, heats up under the action of fission product decay heat
- (3) Emergency cooling, during which adequate cooling is restored to the core by the action of engineered safety systems.

Idaho Nuclear Corporation, under the auspices of the Division of Reactor Development and Technology of the United States Atomic Energy Commission, is conducting the Loss-of-Fluid Test (LOFT) Project⁽¹⁾ at the National Reactor Testing Station in Idaho. MOXY (MOdel X-Y) is one of several computer codes for the evaluation of power reactors during a LOCA being developed by Idaho Nuclear Corporation in the Loss-of-Coolant Analysis Program⁽²⁾. MOXY solves the equations of the X-Y Model (in which an array of rods is represented in x-y coordinates) for a bundle of rods during an LOCA. The code uses a pseudo-three-dimensional model in which axial conduction and radiation are neglected, but in which the energy balance equation for steam traveling axially upward through the rod bundle is solved. Heat transfer by conduction, convection, and radiation and heat generation by metal-water reaction are considered.

This paper describes the heat transfer models used, discusses the solution techniques for these models, and reports a brief evaluation of the models in which code results are compared with experimental data from the Fuel Heatup Simulation Tests (FHUST)⁽³⁾.

II. MOXY HEAT TRANSFER MODELS

MOXY uses a pseudo-three dimensional model in which radiation and conduction in the axial direction are assumed to be negligible. Because the combined axial conduction and radiation heat flux is less than five percent of the radial heat flux in the rod, these assumptions are reasonable. The three-dimensional aspect is preserved by solving energy and mass balances on the steam traveling axially upward through the bundle.

Models for the heat transfer effects considered in MOXY are discussed in the following paragraphs.

1. RADIATION MODEL

Interchange of thermal radiation among surfaces is computed using the network method described by Sparrow and Cess⁽⁴⁾. The assumptions implicit in this technique are as follows:

- (1) All surfaces are in thermal equilibrium during each time step
- (2) All surfaces are gray, diffuse, and opaque
- (3) All surfaces emit radiation uniformly and are irradiated uniformly
- (4) The medium between surfaces does not absorb, scatter, or emit radiation
- (5) Axial radiation interchange is negligible.

Radiative interchange is described by

$$B_i = \sum_{j=1}^N G_{ij} A_j \left(\frac{\epsilon_j}{1 - \epsilon_j} \right) \sigma T_j^4 \quad (1)$$

where

B_i is the total radiative flux leaving node n (radiosity) $\left(\frac{\text{Btu}}{\text{in.}^2 \cdot \text{sec}} \right)$

G_{ij} are the elements of inverse radiation matrix G^{-1} (in.^2)

G_{ij} are the elements of radiation matrix $A_i \left(\frac{\delta_{ij}}{1 - \epsilon_j} - F_{ij} \right)$ (in.^2)

$\delta_{ij} = 1$ when $i = j$

$= 0$ when $i \neq j$

F_{ij} is the view factor from node i to node j (dimensionless)

A_i is the nodal area (in.^2)

ϵ_i is the total hemispheric emissivity (dimensionless)

σ is the Stefan-Boltzmann constant $\left(\frac{\text{Btu}}{\text{in.}^2 \cdot \text{sec} \cdot \text{R}^4} \right)$

T_i is the nodal surface temperature ($^{\circ}\text{R}$).

The net radiant heat transfer for each surface is expressed by

$$\text{RHT}_n = A_n \left(\frac{\epsilon_n}{1 - \epsilon_n} \right) \left(\sigma T_n^4 - B_n \right). \quad (2)$$

Equations (1) and (2) are developed in detail in Reference 5. The matrix inversion is accomplished using a Gauss-Jordan double-pivotal technique⁽⁶⁾.

2. CONDUCTION MODEL

The one-dimensional heat conduction equation for the fuel rods and vessel is solved numerically in MOXY. The formulation of the difference equations solved in MOXY is discussed in the following paragraphs.

2.1 Conduction in Fuel Rods

Heat conduction in the fuel rods is computed by numerical integration of the one-dimensional Fourier heat conduction equation. The solution is based on the following assumptions:

- (1) Temperature is independent of axial and angular position
- (2) Heat generation in the heated regions is independent of position and temperature. (Any and all regions in the rod can be heated regions.)

Under these assumptions, the unsteady state heat equation reduces to

$$\frac{1}{r} \frac{\partial}{\partial r} \left(kr \frac{\partial T}{\partial r} \right) + q''' = \frac{\partial}{\partial t} (\rho CT) \quad (3)$$

where

r is the radial space coordinate (in.)

k is the thermal conductivity $\left(\frac{\text{Btu}}{\text{in.} \cdot \text{sec} \cdot ^\circ\text{F}} \right)$

T is the temperature ($^\circ\text{F}$)

q''' is the volumetric heat generation $\left(\frac{\text{Btu}}{\text{in.}^3 \cdot \text{sec}} \right)$

t is the time (sec)

ρ is the density $\left(\frac{\text{lb}_m}{\text{in.}^3} \right)$

C is the specific heat $\left(\frac{\text{Btu}}{\text{lb}_m \cdot ^\circ\text{F}} \right)$.

The annular volume element enclosed by $R_n - \frac{\Delta r}{2}$ and $R_n + \frac{\Delta r}{2}$ is defined as ΔV . Integration of Equation (3) over ΔV results in

$$\int_{\Delta V} \frac{1}{r} \frac{\partial}{\partial r} \left(kr \frac{\partial T}{\partial r} \right) dV + \int_{\Delta V} q''' dV = \int_{\Delta V} \frac{\partial}{\partial t} (\rho CT) dV. \quad (4)$$

Expressing the accumulation terms of Equation (4) in finite-difference form and integrating gives

$$\int_{\Delta V} \frac{\partial}{\partial t} (\rho CT) dV \approx \frac{\rho C \Delta V}{\Delta t} \left(T_n^{m+1} - T_n^m \right) \quad (5)$$

where the superscript refers to time step number and the subscript to node number.

Integrating the source term gives

$$\int_{\Delta V} \int \int q''' dV = q''' \Delta V = Q''' \quad (6)$$

where Q''' is the heat generation rate. Expressing the diffusion term in finite-difference form and integrating gives

$$\int_{\Delta V} \int \int \frac{1}{r} \frac{\partial}{\partial r} \left(kr \frac{\partial T}{\partial r} \right) dV = 2\pi \left[\bar{k}_{n,n+1} \left(R_n + \frac{\Delta r}{2} \right) \left(\frac{T_{n+1} - T_n}{\Delta r} \right) - \bar{k}_{n-1,n} \left(R_n - \frac{\Delta r}{2} \right) \left(\frac{T_n - T_{n-1}}{\Delta r} \right) \right] \quad (7)$$

for all nodes except the center-line and surface nodes. For the center-line node, the diffusion term becomes

$$\pi \bar{k}_{1,2} \left(\frac{T_2 - T_1}{2} \right) \quad (8)$$

For the surface node, the diffusion term becomes

$$2\pi \left[R_N k_N \frac{\partial T}{\partial r} \Big|_{r=R_N} - \bar{k}_{N-1,N} \left(R_N - \frac{\Delta r}{2} \right) \left(\frac{T_N - T_{N-1}}{\Delta r} \right) \right], \quad (9)$$

where R_N is the pin radius (in.), and T_N is the surface temperature ($^{\circ}\text{F}$),

The boundary condition for the problem under consideration is

$$-k_N \frac{\partial T}{\partial r} \Big|_{r=R_N} = h (T_N - T_w) + q_r - q_{mwr}, \quad (10)$$

where

h is the convection coefficient $\left(\frac{\text{Btu}}{\text{in.}^2 \cdot \text{sec} \cdot ^{\circ}\text{F}} \right)$

T_w is the temperature of the medium surrounding the rods ($^{\circ}\text{F}$)

q_r is the surface heat flux due to radiation heat transfer $\left(\frac{\text{Btu}}{\text{in.}^2 \cdot \text{sec}} \right)$

q_{mwr} is the surface heat generation due to metal-water reaction $\left(\frac{\text{Btu}}{\text{in.}^2 \cdot \text{sec}} \right)$

Substitution of Equation (10) into Equation (9) results in

$$2\pi \left\{ -R_N \left[h (T_N - T_w) + q_r - q_{mwr} \right] - \bar{k}_{N-1,N} \left(R_N - \frac{\Delta r}{2} \right) \left(\frac{T_N - T_{N-1}}{\Delta r} \right) \right\} \quad (11)$$

The diffusion term is calculated by using a linear combination of the temperature from the old time step and that from the new time step as follows:

$$T_n = \beta T_n^m + (1 - \beta) T_n^{m+1} \quad (12)$$

Setting the constant β equal to one results in forward differencing, and setting β equal to zero results in backward differencing. In this code the Crank-Nicholson scheme⁽⁷⁾ ($\beta = 0.5$) is used. This choice guarantees numerical stability, even for quite large time steps⁽⁷⁾; however, accuracy is sacrificed as time step size is increased. For any problem, the optimum time step size is determined by experience, and satisfactory accuracy can usually be obtained with time steps that would be too large for stability if forward differencing were used.

Combining the accumulation, source, and diffusion terms results in the difference equation

$$\frac{\rho C \Delta V}{\Delta t} (T_1^{m+1} - T_1^m) = Q_1''' + \frac{\pi}{2} \left[\bar{k}_{1,2}^{m+1} (T_2^{m+1} - T_1^{m+1}) + \bar{k}_{1,2}^m (T_2^m - T_1^m) \right] \quad (13)$$

for the center-line node. Similarly, by combining these terms for intermediate diffusion nodes, the following results:

$$\begin{aligned} \frac{\rho C \Delta V}{\Delta t} (T_n^{m+1} - T_n^m) = & Q_n''' + \pi \left[\bar{k}_{n,n+1}^{m+1} \left(R_n + \frac{\Delta r}{2} \right) \left(\frac{T_{n+1}^{m+1} - T_n^{m+1}}{\Delta r} \right) \right. \\ & - \bar{k}_{n-1,n}^{m+1} \left(R_n - \frac{\Delta r}{2} \right) \left(\frac{T_n^{m+1} - T_{n-1}^{m+1}}{\Delta r} \right) \\ & + \bar{k}_{n,n+1}^m \left(R_n + \frac{\Delta r}{2} \right) \left(\frac{T_{n+1}^m - T_n^m}{\Delta r} \right) \\ & \left. - \bar{k}_{n-1,n}^m \left(R_n - \frac{\Delta r}{2} \right) \left(\frac{T_n^m - T_{n-1}^m}{\Delta r} \right) \right] \quad (14) \end{aligned}$$

and for the surface node:

$$\begin{aligned} \frac{\rho C \Delta V}{\Delta t} (T_N^{m+1} - T_N^m) = & Q_N''' + \pi \left[\left(-h T_N^{m+1} - q_r^{m+1} + q_{mwr}^{m+1} \right) R_N \right. \\ & - \bar{k}_{N-1,N}^{m+1} \left(R_N - \frac{\Delta r}{2} \right) \left(\frac{T_N^{m+1} - T_{N-1}^{m+1}}{\Delta r} \right) \\ & \left(-h T_N^m - q_r^m + q_{mwr}^m \right) R_N - \bar{k}_{N-1,N}^m \left(R_N - \frac{\Delta r}{2} \right) \\ & \left. \left(\frac{T_N^m - T_{N-1}^m}{\Delta r} \right) \right] \quad (15) \end{aligned}$$

Equations (13), (14), and (15) form a set of N simultaneous equations in N unknowns that result in a tridiagonal coefficient matrix. The system of equations is easily solved by Gaussian elimination⁽⁸⁾. If constant thermal properties are assumed, the difference equations can be solved in closed form. For temperature-dependent thermophysical properties and for the nonlinear radiation and metal-water

reaction heat boundary conditions used in MOXY the equations must be solved iteratively.

2.2 Conduction in FHUST Vessel

A cross section of the FHUST experimental array is shown in Figure 1. Heat conduction in the vessel is computed by solving the one-dimensional Fourier heat conduction equation as is done for fuel rods. Because the vessel is annular, the diffusion term for the vessel inside surface node is as follows:

$$\int \int \int_{\Delta V} \frac{1}{r} \frac{\partial}{\partial r} (kr \frac{\partial T}{\partial r}) dV = 2\pi \left[\bar{k}_{1,2} \left(R_1 + \frac{\Delta r}{2} \right) \left(\frac{T_2 - T_1}{\Delta r} \right) - k_{1,R_1} \frac{dT}{dr} \Big|_{r=R_1} \right] \quad (16)$$

where the boundary condition for the interior of the vessel is

$$- k_1 \frac{dT}{dr} \Big|_{r=R_1} = h (T_w - T_1) - q_r + q_{mwr} \quad (17)$$

and the boundary condition for the exterior of the vessel is

$$- k_N \frac{dT}{dr} \Big|_{r=R_1} = h' (T_N - T_w') \quad (18)$$

where

h' is the convection coefficient at the outside surface $\left(\frac{\text{Btu}}{\text{in.}^2 \cdot \text{sec} \cdot ^\circ\text{F}} \right)$

T_w' is the jacket coolant temperature ($^\circ\text{F}$).

Substituting Equation (27) into Equation (28) gives

$$\int \int \int_{\Delta V} \frac{1}{r} \frac{\partial}{\partial r} (kr \frac{\partial T}{\partial r}) dV = 2\pi \left\{ - R_1 [h (T_1 - T_w) + q_r - q_{mwr}] + \bar{k}_{1,2} \left(R_1 + \frac{\Delta r}{2} \right) \left(\frac{T_2 - T_1}{\Delta r} \right) \right\} \quad (19)$$

for the vessel inside surface node.

The diffusion term in Equation (19) replaces the diffusion term in Equation (13), and the resulting set of difference equations for the vessel is solved as for the fuel rods.

3. HEAT SOURCES AND SINKS

The solution of conduction equations with associated boundary conditions has been discussed in the previous paragraphs. The means for treating the time-dependent decay heat source, metal-water reaction, convection heat transfer and the time-dependent steam flow rate are discussed in the following sections.

3.1 Heat Generation

The source term in Equations (13), (14), and (15) is calculated by linear interpolation between values in a table.

Fig. 1 Cross Section of FHUST Experimental Array.

3.2 Metal-Water Reaction

The reaction between zirconium and steam is expressed as

When sufficient steam is available, the reaction rate of Zircaloy cladding and steam is assumed to follow the parabolic rate law of Baker and Just⁽⁹⁾. When less steam is available than would be consumed by a reaction following the parabolic rate law, a steam-limited rate law is assumed in which all available steam reacts. Equation (20) is a mathematical statement of the parabolic rate law:

$$-\frac{dr}{dt} = \left(\frac{0.0615}{R_s - r} \right) \exp\left(-\frac{41200}{T}\right) \quad (20)$$

where

r is the radius of the reacting metal-oxide interface (in.)

t is the time (sec)

R_s is the initial rod radius (in.)

T is the temperature at the reacting metal-oxide interface ($^{\circ}\text{R}$).

Integration of Equation (20) over a time step gives

$$-\int_{r_1}^{r_2} (R_s - r) dr = \int_{t_1}^{t_2} 0.0615 \exp\left(-\frac{41200}{T}\right) dt.$$

If the expression $0.0615 \exp\left(-\frac{41200}{T}\right)$ is assumed to be constant during the time step, then

$$-\int_{r_1}^{r_2} (R_s - r) dr = 0.0615 \exp\left(-\frac{41200}{T}\right) \Delta t \quad (21)$$

where $\Delta t = t_2 - t_1$ is the time step size in seconds.

A new variable $r' = R_s - r$ and its differential $dr' = -dr$ are substituted into Equation (17) to obtain:

$$\int_{\text{DRP}}^{\text{DRP1}} r' dr' = 0.0615 \exp\left(-\frac{41200}{T}\right) \Delta t \quad (22)$$

where

DRP1 is the depth the reaction has penetrated the cladding at the end of a time step (in.)

DRP is the depth the reaction has penetrated the cladding at the start of a time step (in.).

Integrating Equation (18) gives

$$\frac{\text{DRP1}^2 - \text{DRP}^2}{2} = (0.0615) \exp\left(-\frac{41200}{T}\right) \Delta t.$$

which reduces to

$$DRP1^2 - DRP^2 = 0.123 \exp\left(-\frac{41200}{T}\right) \Delta t.$$

A new variable is defined as:

$$AP = DRP1^2 - DRP^2 = 0.123 \exp\left(-\frac{41200}{T}\right) \Delta t.$$

Solving for the unknown DRP1 in terms of DRP and AP gives

$$DRP1 = (DRP^2 + AP)^{1/2}. \quad (23)$$

The mass of zirconium reacted during the time step is

$$MZR = \pi \rho_{Zr} \left[(R_s - DRP)^2 - (R_s - DRP1)^2 \right] \quad (24)$$

where

ρ_{Zr} is the density of zirconium in $\frac{lb_m}{in.^3}$.

$$\begin{aligned} MZR &= \pi \rho_{Zr} [R_s^2 - 2 R_s DRP + DRP^2 - R_s^2 + 2 R_s (DRP1) - DRP1^2] \\ &= \pi \rho_{Zr} [2 R_s (DRP1 - DRP) - (DRP1^2 - DRP^2)] \\ &= \pi \rho_{Zr} [2 R_s (DRP1 - DRP) - AP]. \end{aligned} \quad (25)$$

The heat of reaction is 2800 Btu per pound of zirconium reacted. Therefore

$$q_{mwr} = \frac{(2800)(MZR)}{(A_n)(\Delta t)} \quad (26)$$

where

A_n is the surface area of a node ($in.^2$).

The stoichiometric mass of steam required for the parabolic rate law to apply is

$$MSR = 0.395 MZR. \quad (27)$$

If the amount of steam (MSR) is greater than the amount of steam available (MSTA) (steam-limited condition), all available steam is assumed to react. Consequently,

$$MZR = \frac{MSTA}{0.395} \quad (28)$$

and the steam-limited reaction heat is computed through use of Equations (26) and (28). The depth the reaction has penetrated the cladding (DRP1) corresponding to the steam-limited condition is computed by rearranging Equation (24) as follows:

$$(R_s - DRP1)^2 = (R_s - DRP)^2 - \frac{MZR}{\pi \rho_{Zr}}$$

or

$$DRP1 = R_s - \left[(R_s - DRP)^2 - \frac{MZR}{\pi \rho_{Zr}} \right]^{1/2}. \quad (29)$$

The mass of steam available is computed by linear interpolation between values in a table.

3.3 Convection Heat Transfer to Steam

The Dittus-Boelter correlation⁽¹⁰⁾ is used to compute convection heat transfer between the solid surfaces (simulated fuel rods and canisters) and the superheated steam. This relationship has been found to correlate combined radiative and convective heat transfer to steam within 20 percent for Reynolds Number greater than 1000⁽¹¹⁾. Equation (30) expresses this relationship.

$$h = \left(\frac{k}{D_e}\right) Re^{0.8} Pr^{0.4} \quad (30)$$

where

D_e is the hydraulic diameter of the rod bundle (in.)

k is the thermal conductivity of steam ($\frac{\text{Btu}}{\text{sec} \cdot \text{ft} \cdot \text{in.}}$)

Re is the bulk Reynolds Number for steam (dimensionless)

Pr is the bulk Prandtl Number for steam (dimensionless).

4. AUXILIARY CALCULATIONS

Computations peculiar to the code used for the FHUST analysis are discussed below.

4.1 Steam Energy and Mass Balances

As steam rises through the FHUST bundle, it is heated by the rods through convection. Also metal-water reaction replaces steam with hydrogen according to the following reaction:

Consequently, both steam temperature, which affects the convection rate, and steam concentration, which affects the metal-water reaction rate, change as steam rises from one axial level to the next. For a rigorous treatment, the steam energy and mass balances must be solved simultaneously to compute the correct steam temperature and concentration leaving an axial level as shown in Figure 2. When the extent of metal-water reaction is small, the energy and mass balances can be solved separately. Since the FHUST rod temperature operational limit is 2300°F, and since the rate of metal-water reaction is relatively small below this temperature, the energy and mass balances are performed separately.

If the terminology of Figure 3 is used, the energy balance over an axial level n is

$$\dot{m}_{\text{out}} C_{p_{\text{out}}} T_{\text{out}} - \dot{m}_{\text{in}} \dot{C}_{p_{\text{in}}} T_{\text{in}} = \frac{dH}{dt} \approx \frac{\Delta H}{\Delta t}, \quad (31)$$

Fig. 2 Schematic of an Axial Level.

where

- $\dot{m}$ is the mass flow rate of steam $\left(\frac{\text{lb}_m}{\text{sec}}\right)$
- C_p is the heat capacity at constant pressure for steam $\left(\frac{\text{Btu}}{\text{lb}_m \cdot ^\circ\text{F}}\right)$
- T is the steam temperature ($^\circ\text{F}$)
- H is the steam enthalpy (Btu)
- t is the time (sec).

If little metal-water reaction is assumed and if steady state conditions are assumed during a time step,

$$\dot{m}_{\text{in}} = \dot{m}_{\text{out}} = \dot{m}.$$

Solving Equation (31) for the unknown T_{out} gives

$$T_{\text{out}} = \left[\left(\frac{\Delta H}{\Delta t} \right) \left(\frac{1}{\dot{m}} \right) + C_{p_{\text{in}}} T_{\text{in}} \right] \left(\frac{1}{C_{p_{\text{out}}}} \right). \quad (32)$$

Because $C_{p_{\text{out}}}$ is a function of T_{out} and therefore is unknown, Equation (32) is solved iteratively. The change in enthalpy, ΔH , is calculated from individual convection heat losses from the fuel rods and the vessel walls.

The mass balance over an axial level n (Figure 2) is

$$\dot{m}_{\text{out}} - \dot{m}_{\text{in}} = \frac{dm}{dt} \approx \frac{\Delta m}{\Delta t} \quad (33)$$

where m is the mass of steam in the axial level.

The mass of steam consumed (Δm) is calculated from the individual metal-water reaction heat rates.

4.2 Radiation Barrier Temperature

In FHUST, a 16-gauge stainless steel radiation barrier is interposed between the hot rods and the cold vessel to reduce energy losses from the rods. Because of this barrier, two coupled systems of radiative exchange exist, between the rods and the radiation barrier, and between the radiation barrier and the vessel. These systems are coupled by conduction through the radiation barrier. Since the temperature drop across the barrier has been estimated to be a fraction of a degree, and since the thermal capacitance of the barrier is small, both the temperature drop and the capacitance of the barrier are neglected. With these simplifications, the rate of energy radiated to the barrier by the rods is equal to the rate of energy reradiated to the FHUST vessel by the barrier. The rate of energy transfer to and from the barrier is a function of the barrier temperature, and the barrier temperature can be determined by an iteration process.

Equation (34) can be shown to apply to the two-surface system represented by the radiation barrier and the vessel. This equation is based on the same assumptions (gray, diffuse surfaces) as apply to the radiation model discussed earlier.

Thus,

$$q_1 = \left(\frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\epsilon_1} \frac{A_1}{A_2} \left(\frac{1}{\epsilon_2} - 1 \right)} \right) \quad (34)$$

where q_1 is the net radiative heat flux leaving the radiation barrier. Figure 3 shows the iteration process used.

III. CODE EVALUATION

The heat transfer models described in the previous section have been evaluated by comparisons between calculated rod surface temperatures and experimental temperatures from FHUST. Figure 4 shows a comparison of diagonal rod surface temperature profiles for a test in which metal-water reaction occurred.

In this test, the rod power was initially low to maintain the rod temperatures above saturation temperature for the steam in the vessel. Condensing steam maintained the vessel jacket at a constant temperature. When initial conditions were established, power was increased to initiate the transient. A final rod temperature of 2300°F was intended, but a faulty amplifier on a temperature transducer resulted in termination of the test at 2175°F. For this reason, little metal-water reaction occurred. The comparisons between calculated and experimental temperature can be seen to be quite good except at 300 sec, at which time the calculated temperatures are somewhat high. Because radiant heat transfer is the dominant heat transfer mechanism in this test, the good agreement between calculated and experimental temperatures gives considerable credence to the model used to compute radiant heat transfer in MOXY and to the assumptions implicit in that model.

IV. SUMMARY AND CONCLUSIONS

The loss-of-coolant accident (LOCA), in which a primary water circulation line undergoes a double-ended offset shear fracture, is generally acknowledged to be the maximum credible accident that could occur in a light water-cooled and -moderated, central station nuclear power reactor.

MOXY (Model X-Y) is one of several computer codes for the evaluation of power reactors during an LOCA that are being developed by Idaho Nuclear Corporation in the Loss-of-Coolant Analysis Program. MOXY solves the equations of the X-Y Model (in which an array of rods is represented in x-y coordinates) for a bundle of rods during the core heatup transient of an LOCA. The code uses a pseudo-three-dimensional model in which axial conduction and radiation are neglected, but in which the energy balance equation for steam traveling axially upward through the rod bundle is solved. Heat transfer by conduction, convection, and radiation and heat generation by metal-water reaction are considered.

MOXY is economical to run because the rod conduction equation is solved through the use of an implicit numerical technique and because symmetry is applied in the radiation model where possible. The implicit technique reduces computer time by allowing large time steps, because it does not impose stability restrictions on time step size as is the case with explicit techniques. The use of symmetry reduces both computer time and core storage.

The code has been evaluated by comparisons between calculated rod surface temperatures and experimental temperatures from the Fuel Heatup Simulation Test (FHUST) Program. The conclusion reached from these comparisons was that the assumptions in MOXY regarding gray diffuse surfaces and symmetry are realistic.

Fig. 3 Iteration Process for Determining Radiation Barrier Temperature.

Fig. 4 Experimental and Calculated Rod Surface Temperature Profiles For Metal-Water Reaction Test.

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