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OAK RIDGE, TENNESSEE

ORNL
CENTRAL FILES NUMBER
60-7-50

External Distribution Authorized
COPY NO. 45

DATE: July 19, 1960

SUBJECT: APPR-1 Startup Analysis

TO: Distribution

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NOTICE

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Introduction

One criterion for an acceptable reactor control system is that the level safety system must be capable of turning the excursion resulting from an uncontrolled rod withdrawal, the so-called "startup accident," without damage to the core.

The APPR-1 control system has been analyzed for its response to such an occurrence.

Method of Calculation

Reactor kinetic and heat transfer equations were written for the reactor core, assuming flat temperature profile in fuel, and uniform temperature in bulk water. Heat transfer across metal-water film was approximated by the formula

$$hA = 104 + 0.043\ T_w - 1.10 \times 10^{-3}\ T_w^{\ 2}\ \frac{BTU}{sec\ ^oF} \quad (1)$$

Total temperature coefficient was taken to be described by equation

$$\frac{\delta K}{\delta T} = 7.70\ (T_w - 57^oF) \times 10^{-7}/^oF \quad (2)$$

This was divided between metal and water according to the volume displaced by expansion of each per ^oF. By this assumption,

$$\frac{\delta K}{\delta T}_{metal} = 2.50\ (T_w - 57^oF) \times 10^{-8}/^oF$$

$$\frac{\delta K}{\delta T}_{water} = 7.45\ (T_w - 57^oF) \times 10^{-7}/^oF$$

Neutron lifetime was taken to be 20 μ sec.[3]

β was assumed to be 0.756%.

Shutdown power = 2/3 mw at -4.1% Δk.[4]

Initial temperature was taken to be 70^{o}F.

The ORNL Reactor Controls Analog Facility was used to find the response of the system described above to a startup accident. The computer flow sheet is available as ORNL Drawing C-RC-203.

Results

In order to conserve time (particularly since the simulation was run at 20:1 expanded time), it was assumed that initial run-up was slow enough to maintain equilibrium with delayed neutrons, so that

Power at -1.0% $\Delta k = \frac{2/3 \times .041}{.01}$ = 2.23 mw, and the rod withdrawal was started from that initial condition at the rate of 0.086%/sec.[4]

The excursion was taken 3 decades at a time, and heating was considered non-existent until the 150 KW level was reached. At this point Δk = 0.7905%, slightly past prompt critical.

The last run was taken starting at 150 KW, Δk = 0.7905%, and with the heat transfer networks connected. Level scram was set to trip at 15 MW, after which there was a 50 millisecond delay, followed by insertion of rods worth 1.72%/inch at an acceleration of 0.4 g.[4]

Under these conditions, and with 0.459 sec. water residence time,[3] the reactor got on a 52 millisecond period, and reached a peak power of 61.8 MW. The integral power in the burst was 5.4 MW sec. = 5120 BTU. Heat capacity of the core is 48.2 $\frac{BTU}{^{o}F}$ [3]; so to raise the core to the melting point, neglecting any heat of fusion and assuming zero heat transfer to the water, requires about (570-70) x 48.2 = 24,000 BTU. On this basis the burst has a safety factor of almost 5.

Under the more realistic conditions simulated, the water went to 76.8^{o}F, the metal to 145^{o}F. This is a rise of 75^{o} in fuel temperature, or about 1/7 the rise allowable before melting.

At 1/10 normal coolant flow (water residence = 4.59 sec.), the reactor went up on a 56 millisecond period, reaching a peak power of 59.9 MW. Integrated power was 1.76 MW sec. = 1670 BTU. Water temperature went to 85.8°F, metal to 113°F. Here the accentuated heating of the water brought the temperature coefficient more strongly into play, and gave a safety factor of perhaps 12.

Conclusion

The conclusion can be reached that so far as startup accidents go, the safety system is entirely adequate, at .086%/sec. rod withdrawal, for operation at at least twice the rated power.

References

1. From formula $h = (0.2528 + 2.300 \times 10^{-3} T_w - 2.675 \times 10^{-6} T_w^{2})$

$$\left(\frac{T_s}{T_w}\right)^{0.164} \frac{V^{0.654}}{E^{0.346}} \frac{BTU}{hr\ ft^2\ ^{o}F} \qquad (4)$$

where T_w = bulk water temperature of fuel, ^{o}F

T_s = surface temperature of fuel, ^{o}F

V = coolant velocity in ft/hr

ϵ = coolant channel in ft.

This formula was fitted by R. D. Cheverton to experimental values of W. R. Gambill (private communication).

Surface area of plates taken to be 571 ft^2.

2. H. W. Giesler, et al; Results and Analysis of the APPR-1 Zero Power Experiments, Part I; APAE Memo No. 61 (November 7, 1956).

3. J. O. Brondel; APPR-1 Reactor Transient Analysis, Basic Kinetic Model and Equations; APAE Memo No. 127, Vol. I (April 25, 1958).

4. J. G. Gallagher and T. M. Silks; Effect of APPR-1 Control Rod Acceleration After Scram on Startup Accident; APAE Memo No. 97 (April 23, 1957).