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KINETIC - A SYSTEM CODE FOR ANALYZING NUCLEAR THERMAL PROPULSION ROCKET ENGINE TRANSIENTS

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NUCLEAR PROPULSION TECHNICAL INTERCHANGE MEETING

LEWIS RESEARCH CENTER

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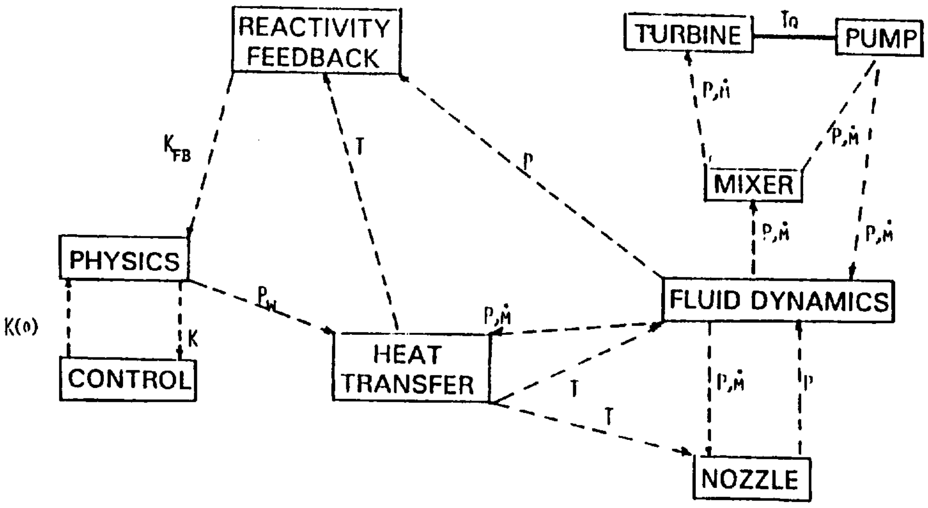
OVERVIEW

- OUTLINE OF KINETIC CODE
- DESCRIPTION OF TEST PROBLEM
- SELECTED RESULTS
- CONCLUSIONS

KINETIC INFORMATION FLOW DIAGRAM



KINETIC NEUTRONIC EQUATIONS

Point kinetic equations

$$\dot{n} = \frac{\kappa(1-\bar{\beta})-1}{\tau} n + \sum_{i=1}^{6} \lambda_i C_i \qquad (1)$$

$$\dot{C}_i = \frac{\beta_i \kappa n}{\tau} - \lambda_i C_i \qquad i = 1......6 \qquad (2)$$

Transformation (n,C) to (ω,Y)

$$\omega = \frac{\dot{n}}{n} \qquad Y_i = \frac{\lambda_i \tau C_i}{n} \qquad (3)$$

Transformed equations

$$\tau\omega = \kappa(1-\bar{\beta})-1 + \sum_{i=1}^{6} Y_i \qquad (4)$$

$$\dot{Y}_i = \kappa\beta_i\lambda_i - (\lambda_i + \omega)Y_i \qquad i = 1......6 \qquad (5)$$

Control equation

$$\tau\dot{\omega} = \dot{\kappa}(1-\bar{\beta}) + \sum_{i=1}^{6} \dot{Y}_i \qquad (6)$$

KINETIC NEUTRONIC EQUATIONS
(PERIOD CONTROL ALGORITHM)

Let ω_t be the desired power trace and ω the actual trace. A simple linear restoration function can be written.

$$\dot{\omega} = \gamma(\omega_T - \omega) \tag{7}$$

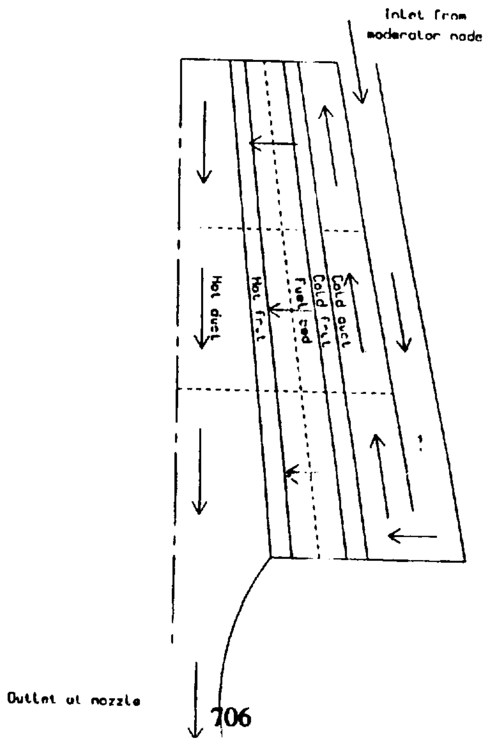
Eliminating κ from equations (6) using equation (4) and letting $\omega = \omega_t$, results in equation (8) (defining G).

$$\sum_{i=1}^{6} \dot{Y}_i = G(\lambda_i, \beta_i, \tau, \omega_T) \tag{8}$$

Equations (6),(7),and (8) result in an equation for κ in the measurable quantity ω and known quantities λ_i, β_i, τ and ω_T.

$$\dot{\kappa}(1-\bar{\beta}) = \tau\gamma(\omega_T - \omega) - G(\lambda_i, \beta_i, \tau, \omega_T) \tag{9}$$

FUEL ELEMENT COOLANT FLOW DIAGRAM



TURBO-PUMP/NOZZLE ALGORITHM

- GIVEN A PUMP ROTATIONAL SPEED DETERMINE PUMP (P,m) FROM PERFORMANCE CURVES.
- GIVEN CHAMBER TEMPERATURE CALCULATE NOZZLE (P,m).
- CALCULATE SYSTEM PRESSURE DROP.
- FROM THESE THREE RELATIONSHIPS (2 PRESSURES AND A FLOW)--OBTAIN TORQUE REQUIRED FOR PUMP FROM PUMP PERFORMANCE CURVES.
- FROM TURBINE PERFORMANCE CURVE AND INERTIAL EQUATION DETERMINE DELTA TORQUE BETWEEN PUMP AND TURBINE AND THUS CHANGE IN TPA SHAFT SPEED.
- REPEAT ABOVE STEPS FOR NEW TIME STEP.

KINETIC HEAT TRANSFER EQUATIONS PER NODE

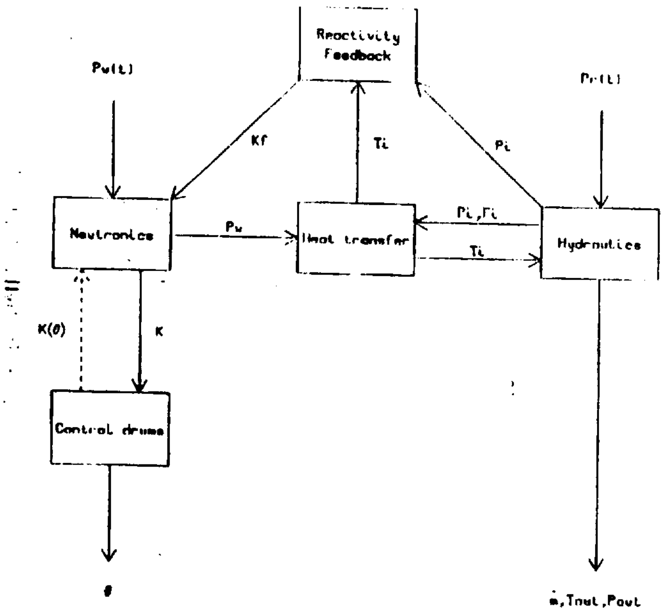
Temperature of solid (S)

$$M_s C_p^s \dot{T}_s = Q - \dot{m} (H_{OUT} - H_{IN}) \qquad (1)$$

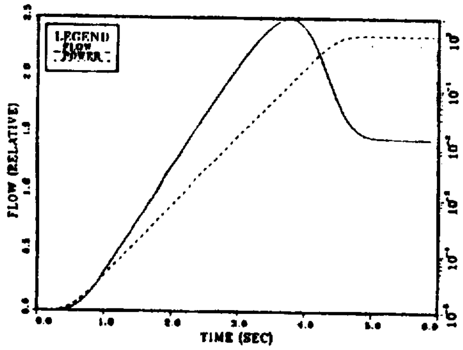
Temperature of coolant as a function of position (C)

$$hP(T_s - T_c)dx = \dot{m}\, C_p^c dT_c \qquad (2)$$

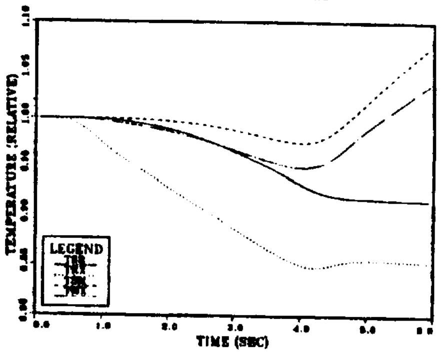
TEST PROBLEM DIAGRAM



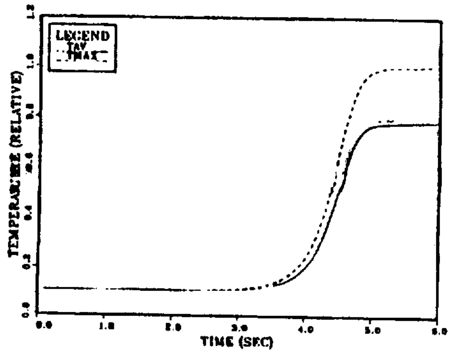
FLOW AND POWER



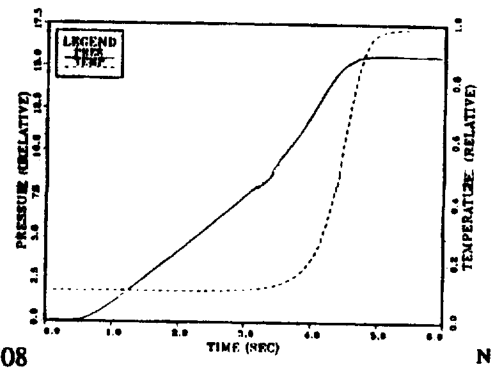
REFLECTOR AND MODERATOR SOLID AND EXIT COOLANT TEMPERATURES

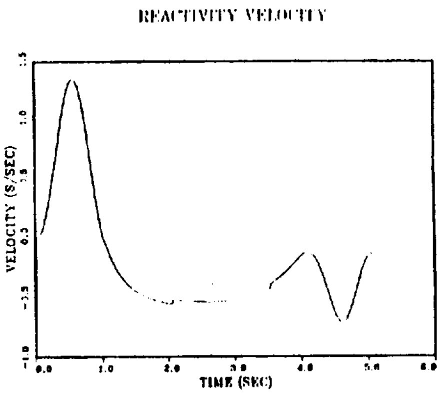


FUEL AVERAGE AND MAX TEMPERATURES

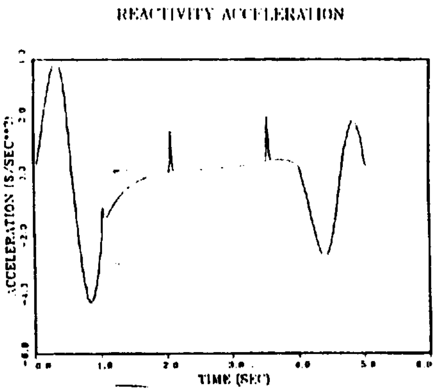


NOZZLE PRESSURE AND TEMPERATURE

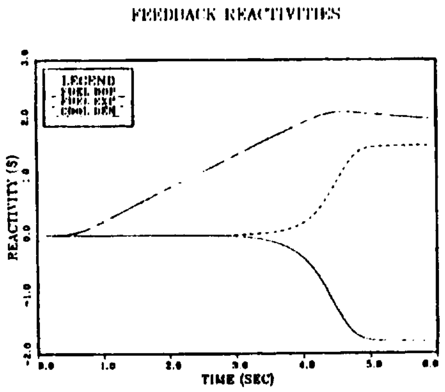




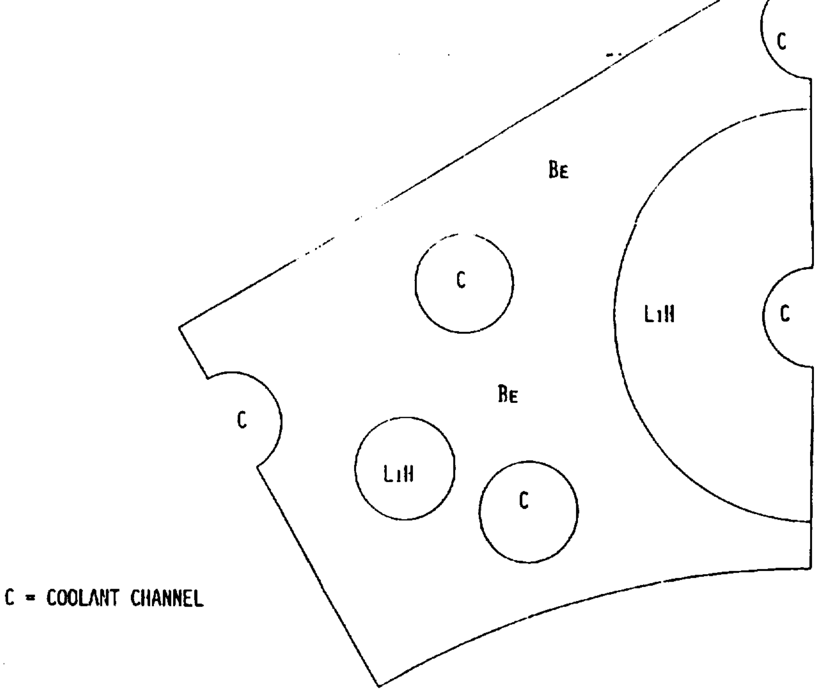
REACTIVITY VELOCITY



REACTIVITY ACCELERATION

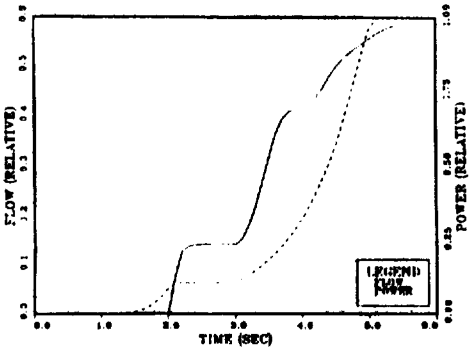


FEEDBACK REACTIVITIES

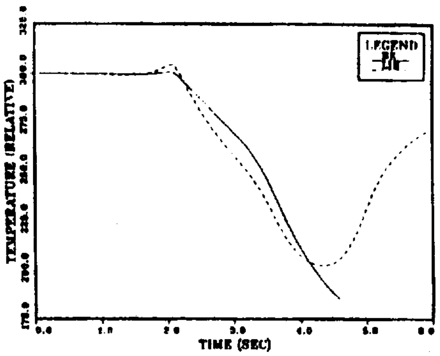


LITHIUM HYDRIDE-BERYLLIUM MODERATOR BLOCK (SYMMETRIC SECTION)

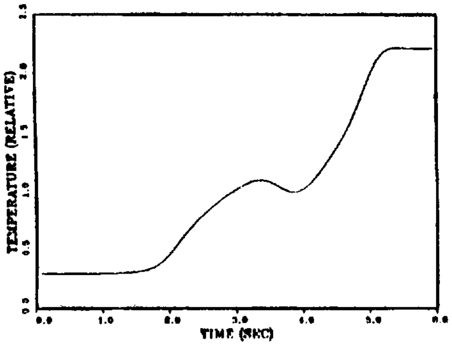
FLOW AND POWER



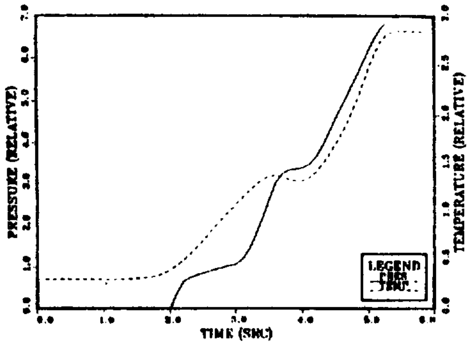
BE AND LH MEAN TEMPERATURES



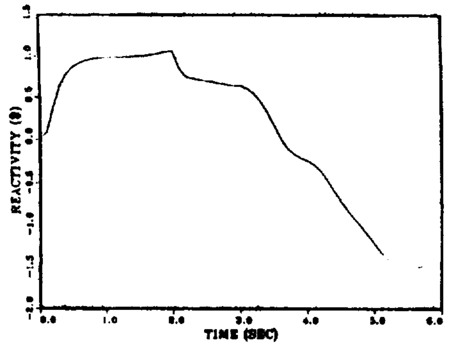
FUEL AVERAGE TEMPERATURE



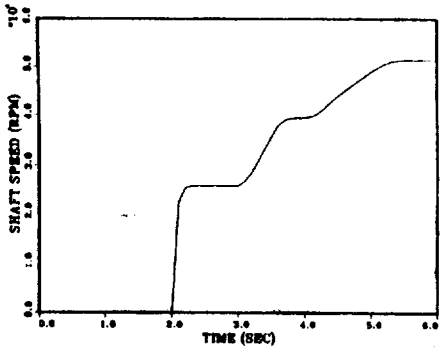
NOZZLE PRESSURE AND TEMPERATURE



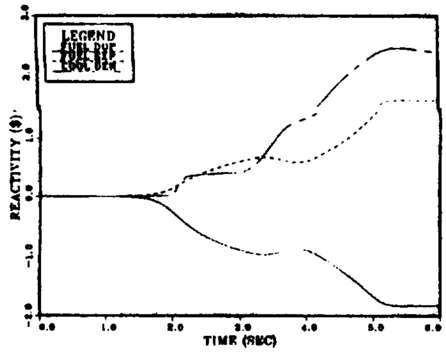
CONTROL REACTIVITY



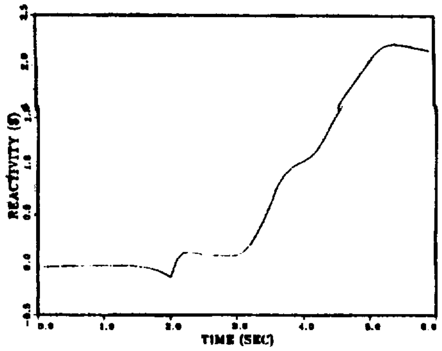
TPA SHAFT SPEED



FEEDBACK REACTIVITIES



FEEDBACK REACTIVITY



CONCLUSIONS

- THE KINETIC CODE SYSTEM IS A VIABLE TRANSIENT ANALYSIS ALGORITHM FOR STUDYING PBR BASED NTP START UP AND SHUTDOWN BEHAVIOR

- THE CODE FLEXIBILITY ALLOWS INVESTIGATION OF
  - TPA START STRATEGIES
  - REACTOR DESIGN VARIATIONS TO MINIMIZE FEEDBACK EFFECTS
  - ENGINE SHUTDOWN STRATEGIES

- TWO-PHASE FLOW AND MULTI-DIMENSIONAL REACTOR KINETICS ARE CURRENTLY NOT MODELED