RRS Modelling in RFSP (*CERBRRS)

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RRS Modelling in RFSP

Objective: Incorporate CANDU 6 RRS algorithms in RFSP

Applications: Model RRS actions in safety analysis e.g., In-Core LOCA, Moderator Drain

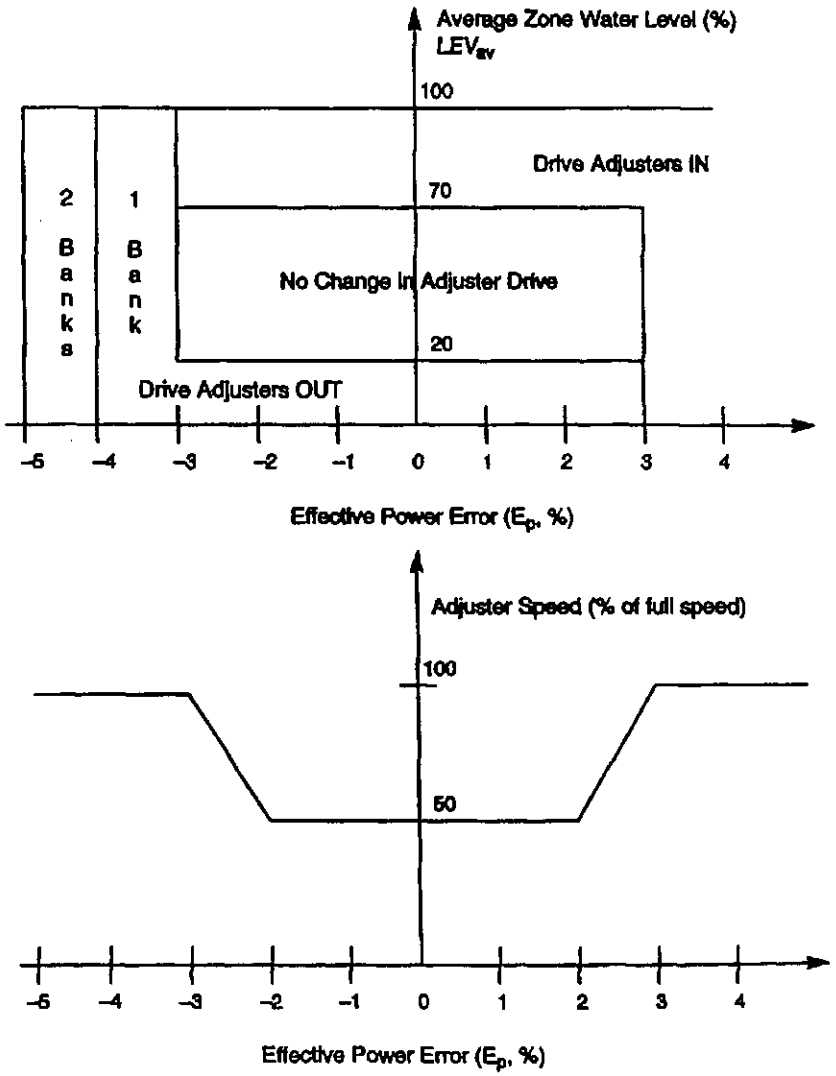
Advantage: Increased accuracy of the well-established neutron kinetics calculations in CERBERUS

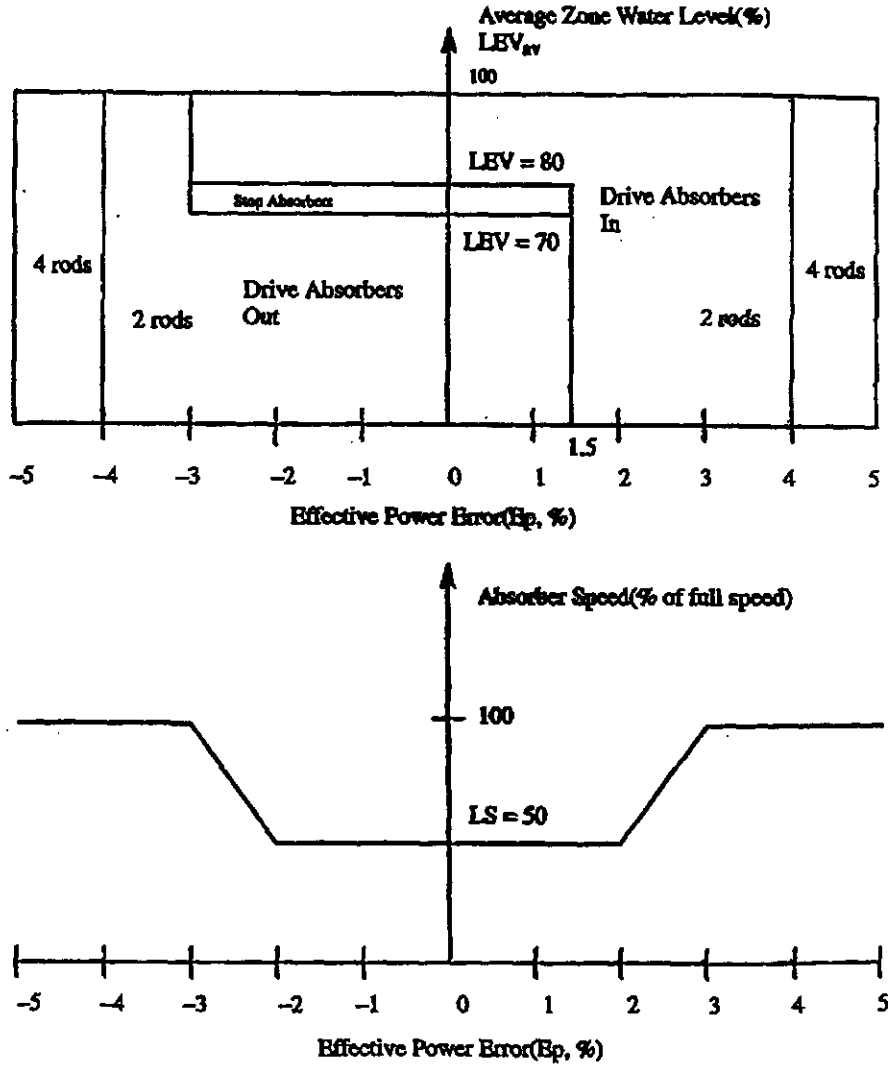
Method: Transplant SMOKIN-G2 RRS Control Routine Package to RFSP, Link up with CERBERUS in a new module *CERBRRS

Status: Functionality Tests and Documentation completed (TTR-565)

Zone Control Rules

- $RLIF_i = BLIF + DLIF_i$
- Bulk Control Valve Lift, BLIF, function of Power Error (multiplied by a Gain Factor), sampled every 0.5 s
- Differential Valve Lift $DLIF_i$ two components, sampled every 2 s
  - Flux Tilt (deviation from reference shape)
  - Level Deviation from average
  - Combined with weighting by gain factors and phase-in factors


Average Zone Water Level (%)
LEV_{av}
100
70
20
Drive Adjusters IN
No Change in Adjuster Drive
Drive Adjusters OUT
2 Banks
1 Bank
-5 -4 -3 -2 -1 0 1 2 3 4
Effective Power Error (E_p, %)
Adjuster Speed (% of full speed)
100
50
-5 -4 -3 -2 -1 0 1 2 3 4
Effective Power Error (E_p, %)


Average Zone Water Level(%)
LEV$_{av}$
100
LEV = 80
Stop Absorber
Drive Absorbers In
LEV = 70
4 rods
Drive Absorbers Out
2 rods
2 rods
4 rods
1.5
-5 -4 -3 -2 -1 0 1 2 3 4 5
Effective Power Error(Ep, %)
Absorber Speed(% of full speed)
100
LS = 50
-5 -4 -3 -2 -1 0 1 2 3 4 5
Effective Power Error(Ep, %)

Stepback Conditions (Neutronic Setpoint)

- **High Zone Power**
  - **Four or more zones with power greater than 1.08 Clears if this condition is not satisfied**
  - **Terminal power set at 0**

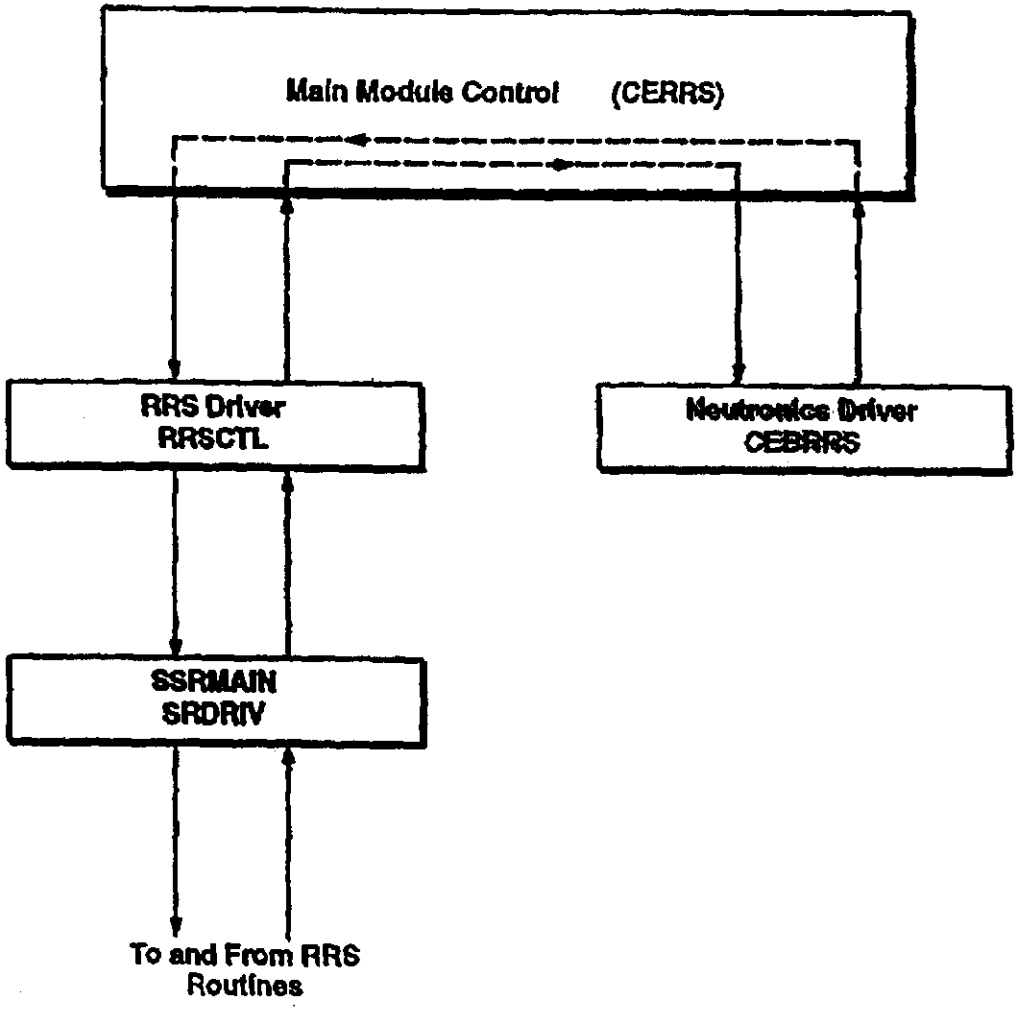
- **High Log Rate**
  - **Medium of the three log rate signal greater than 8%/s**
  - **Clears if is less than 0**
  - **Terminal power set at 0**

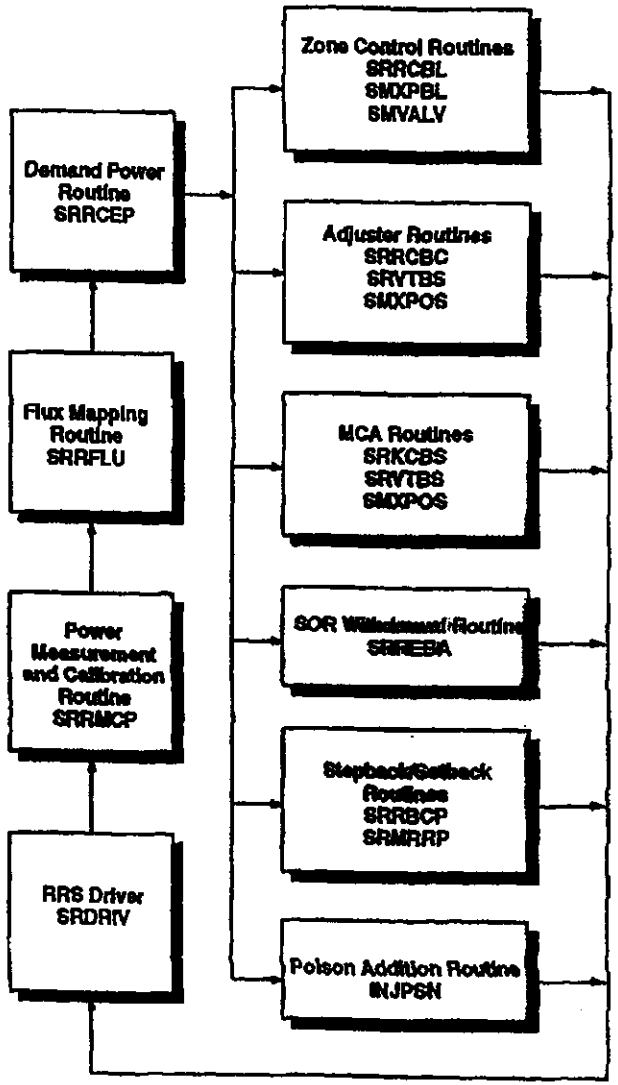
Setback Conditions (Neutronic Setpoint)

- **High Local Neutron Flux**
  - **(Peak/Average) x Reactor Power Initiate** **>1.1**
    <1.05 Clear
  - **Rate** **0.1% / s**
  - **Terminal Power** **60% FP**

Setback Conditions (con't)

- Spatial Control Off Nominal
  - High Zone Power
    Initiate >1.1
    Clear <1.05
  - Max difference between pair of zone powers except the central zones
    Initiate >20%
    Clear <15%
  - Rate 0.1% / s
  - Terminal Power 60% FP


Main Module Control (CERRS)
RRS Driver
RRSCTL
Neutronics Driver
CEBRRS
SSRMAIN
SRDRIV
To and From RRS
Routines


Zone Control Routines
SRRCBL
SMXPBL
SMVALV
Demand Power Routine
SRRCEP
Adjuster Routines
SRRCBC
SRVTBS
SMXPOS
Flux Mapping Routine
SRRFLU
MCA Routines
SRKCBS
SRVTBS
SMXPOS
Power Measurement and Calibration Routine
SRRMCP
SRREBA
Stepback/Setback Routines
SRRBCP
SRMRRP
RRS Driver
SRDRIV
Poison Addition Routine
INJPSN

Running *CERBRRS

- History-Based Fission-Product Driver CERBERUS Framework
  - Case 1: Steady State
  - Case 2: Adjoint Calculation
  - Case 3: .... Transient Calculations
- Current thermalhydraulics conditions (via input) data file Optional internal fuel temperature feedback if no external thermalhydraulic coupling requested
- Xenon evolution tracked
- Continuous change in moderator poison level, isotopic purity, temperature and density
- Restart capability

Running *CERBRRS (con't)

- Data files required
  - RFSP input stream file: "rfsp_input"
  - A direct access store file
  - A thermalhydraulic data file
  - A thermalhydraulic channel grouping specification file
  - Files required by flux-mapping calculations - the coupling matrix coefficients
  - The "rrs_data" file
  - If a restart case, the restart file created in the previous run

Data Required by RRS - "rrs_data" file

- Power manoeuvre rate
- Phi-Noms
- Requested power setpoints
- Spatial control on-off indicator
- Adjuster / MCA (out to fully in) travel time
- Relative weighting of power-change-rate difference in the "effective power error" calculation
- Reactor trip status
- Reactor setback indicator
- Zone bulk control gain factor, zone control level and tilt gain factors
- Zone valve lift bias (in-flow), and time constant
- Adjuster / MCA manual or automatic control indicators
- Adjuster / MCA availability / stuck indicators

Running *CERBRRS (con't)

- Output files from *CERBRRS
  - RFSP output file: "rfsp_output"
  - A "mo_xxxxtoyyyy" file which gives key control parameters such as measured and demand power, power errors at each time step from the starting case xxxx to the ending case yyyy
  - A "dv_xxxxtoyyyy" file which gives the adjuster and MCA rod positions
  - A "zv_xxxxtoyyyy" file which gives the 14 zone fills
  - A restart file "TRANLByyyy.RRS", where TRANLB is the transient label specified by the user
  - A direct access store file

*Examples of RRS Control and *CERBRRS Tests*

- **Manual Trip**
  Trip flag set, MCA's dropped, Zone filled at 0.3 times of nominal rate (about 0.5% / s).
- **Manual Setback**
  Setback flag set, Power ran down at a specified rate (0.5% / s), Zone filled at about 0.16% / s to effect power reduction.
- **Poison Addition**
  Poison introduced at specified rate of 0.5 ppm / m, AA Bank out-drive initiated when AVZL dropped to 20% or when power error more negative than -3%.

*Examples of RRS Control and *CERBRRS Tests (con't)*

- **Power Ramp-Down and Ramp-Up Tests**
  Demonstrated that the Demand Power Routine is functioning properly.

- **Initial Distorted Flux Shapes**
  Setback conditions created, power reduced at 0.1% / s.
  Spatial control responded, setback condition cleared.

- **In-Core LOCA Test**
  Demonstrated the possibility for safety analysis applications.

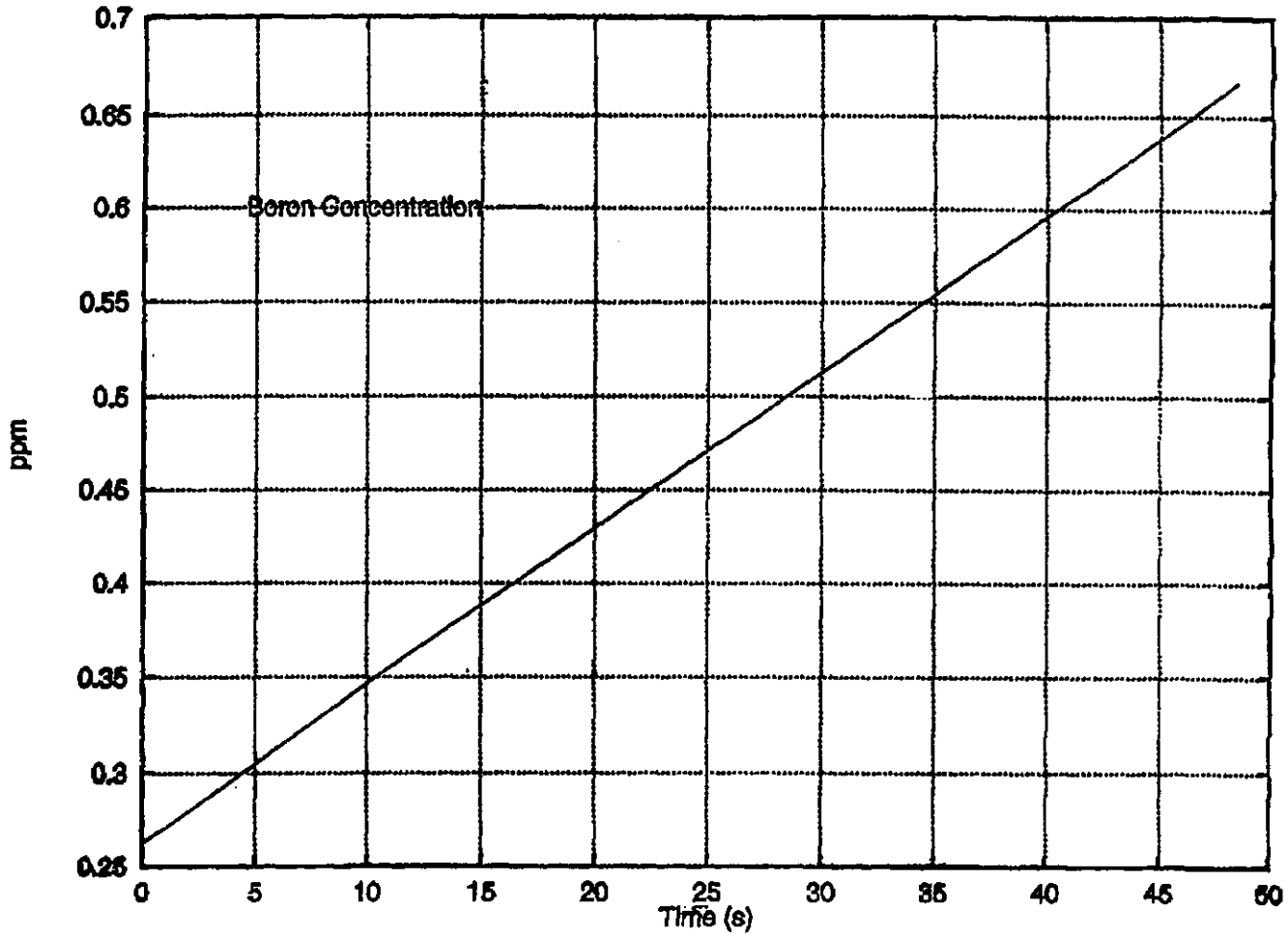
Sample Test Run #1 - Poison Addition Test

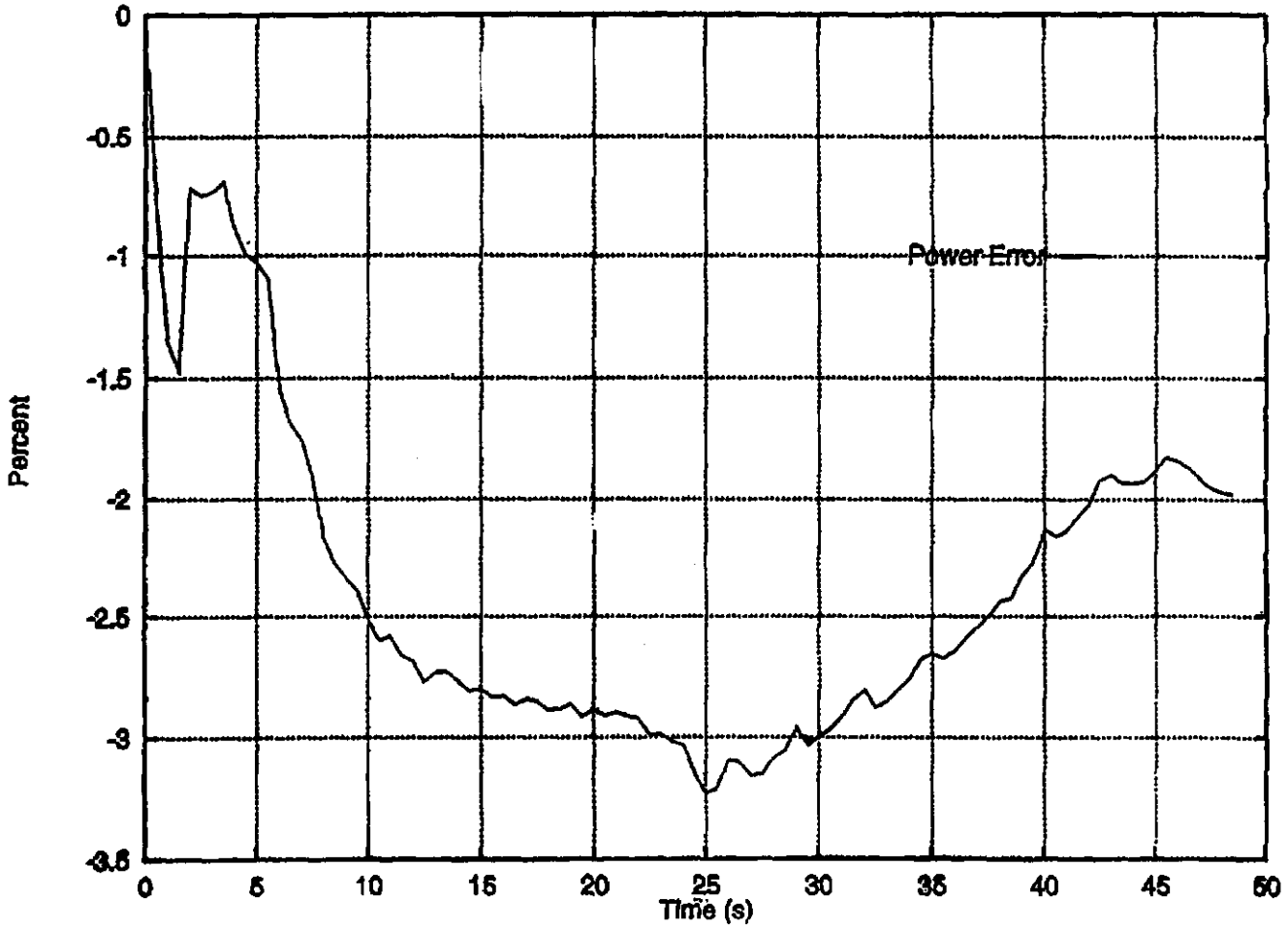
Test Specifications:

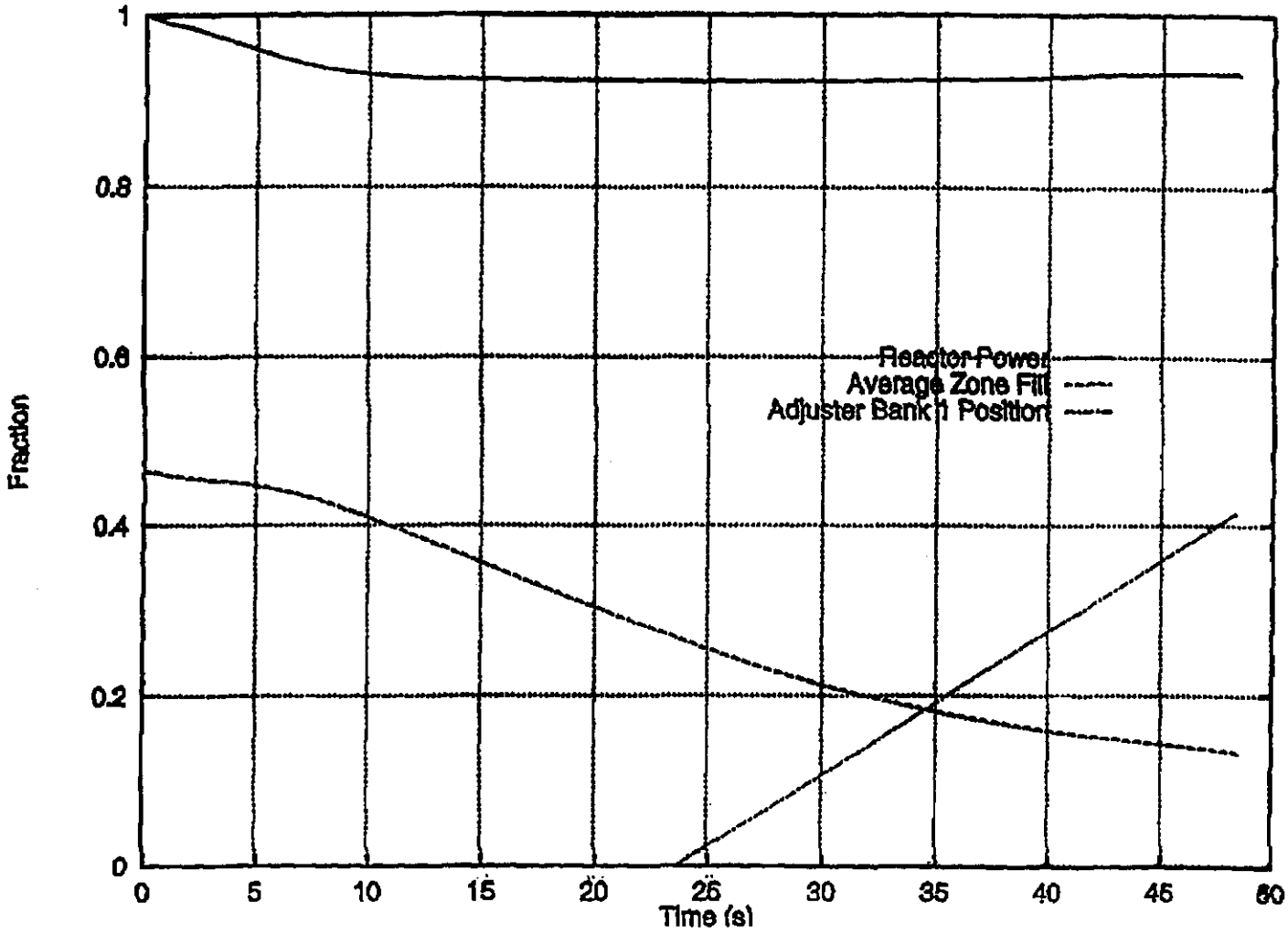
- **Initial steady state at 100% FP**
- **Set requested power at 95% FP and hold setpoint at this level**
- **Boron is added at rate of 0.5 ppm per minute**

Purpose:

To demonstrate the functionality of the demand power routing and the adjuster-control routine.


Boron Concentration
ppm
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0
5
10
15
20
25
30
35
40
45
50
Time (s)


0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
Percent
0
5
10
15
20
25
30
35
40
45
50
Time (s)
Power Error


1
0.8
0.6
0.4
0.2
0
Fraction
0
5
10
15
20
25
30
35
40
45
50
Time (s)
Reactor Power
Average Zone Fil
Adjuster Bank 1 Position

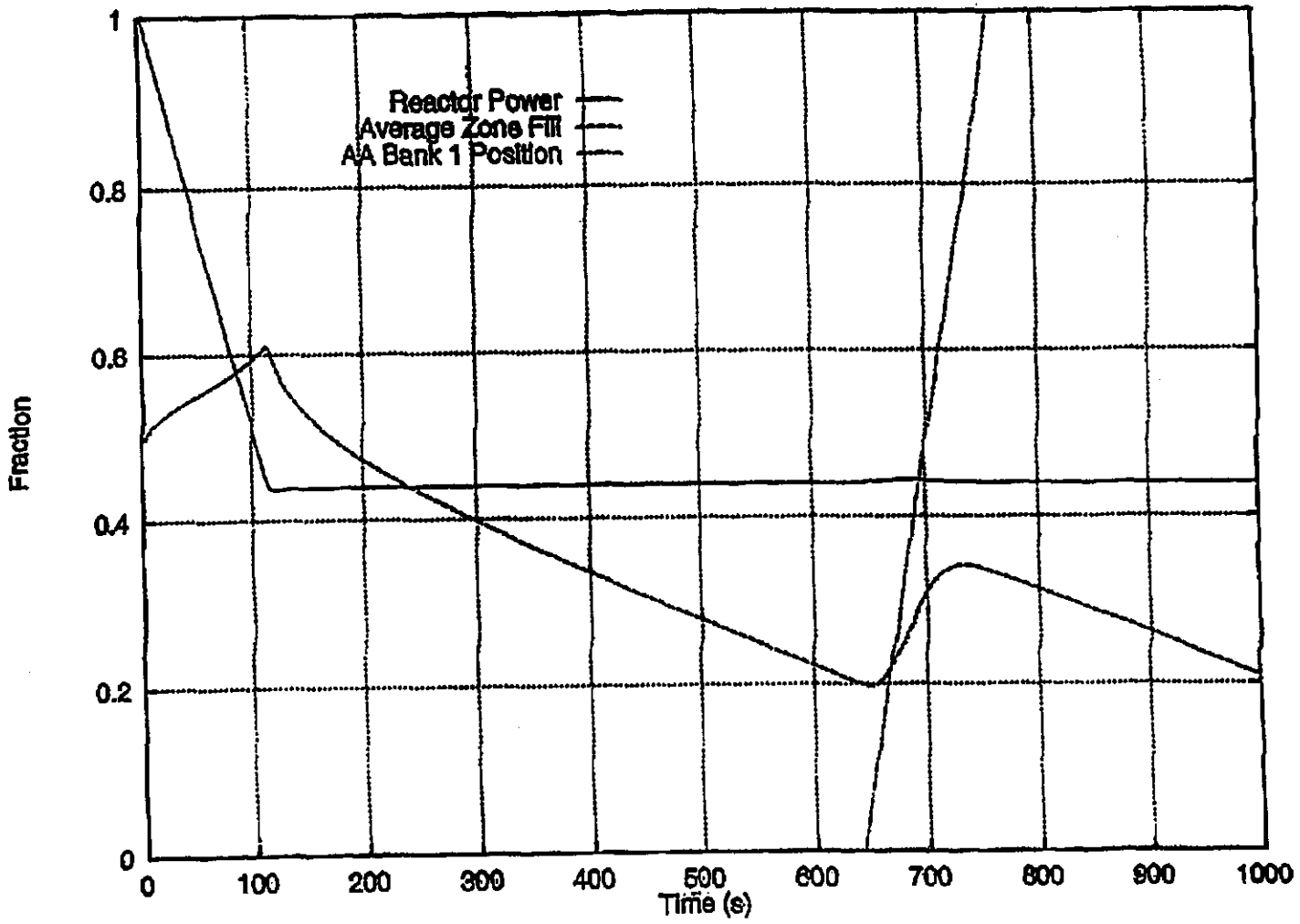
Sample Test Run #2 - Power Reduction from 100% to 44% FP

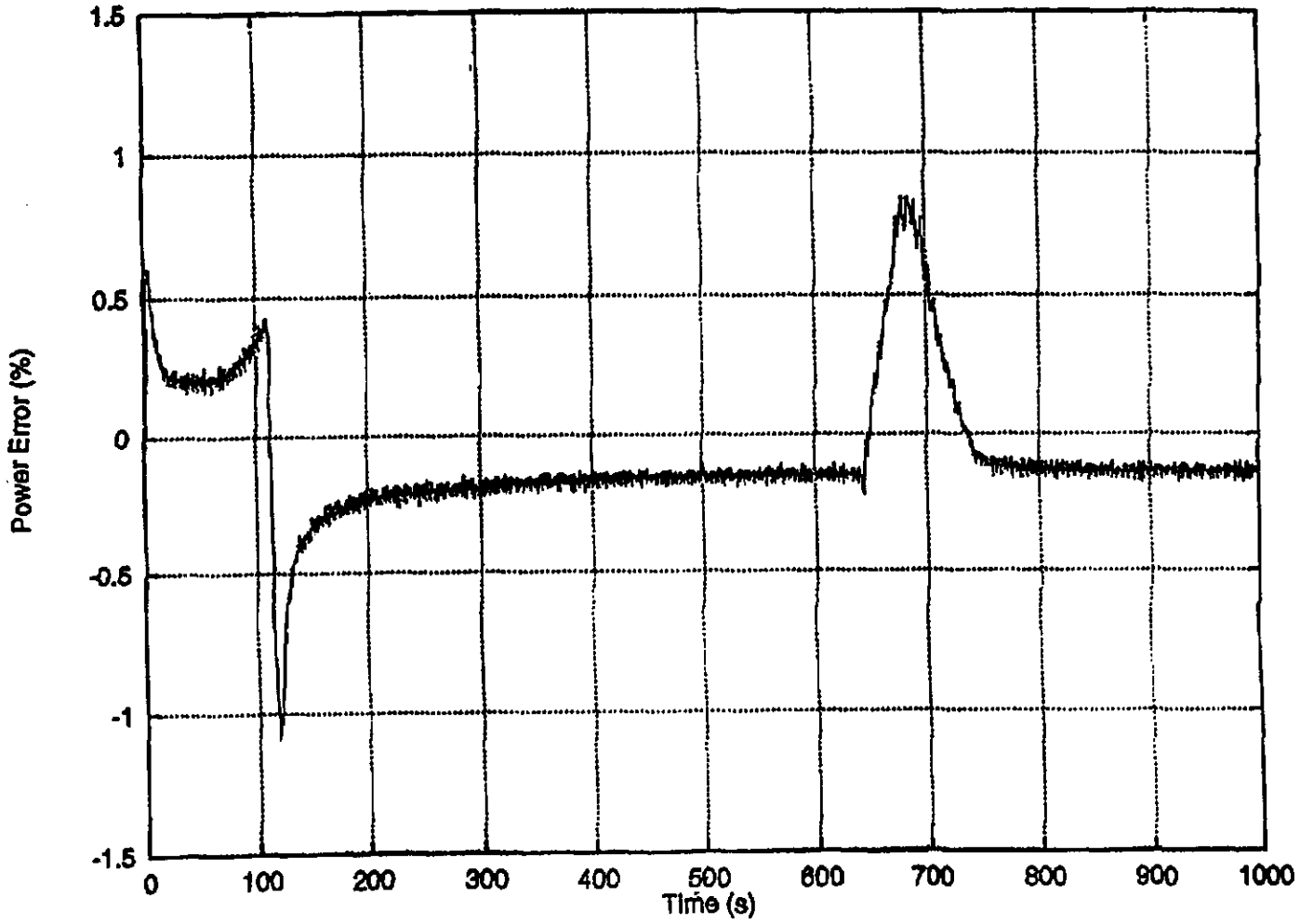
Test Specifications:

- **Steady state at 100% FP**
- **Reduce power to 44% FP at a rate of 0.5% per second**
- **Hold at 44% FP for 1000 seconds**
- **Uniform initial zone fills at 50%**
- **Reactivity effect from fuel, coolant temperature change not included**

Purpose:

To demonstrate the functionality of the zone-control routine and the adjuster-control routine


Reactor Power
Average Zone Fill
AA Bank 1 Position
Fraction
Time (s)
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
900
1000


1.5
1
0.5
0
-0.5
-1
-1.5
Power Error (%)
0
100
200
300
400
500
600
700
800
900
1000
Time (s)