NMC
Committed to Nuclear Excellence

Kewaunee Nuclear Power Plant
N490, State Highway 42
Kewaunee, WI 54216-9511
920-388-2560

Operated by
Nuclear Management Company, LLC

March 7, 2001

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Ladies/Gentlemen:

Docket 50-305
Operating License DPR-43
Kewaunee Nuclear Power Plant
NUCLEAR MANAGEMENT COMPANY, LLC. REVISED RESPONSE TO NRC 'S REQUEST FOR ADDITIONAL INFORMATION ON WISCONSIN PUBLIC SERVICE CORPORATION RELOAD SAFETY EVALUATION METHODS TOPICAL REPORT, WPSRSEM-NP, REVISION 3

References:
1) Letter from Kenneth H. Weinhauer (NMC) to Document Control Desk (NRC), dated October 12, 2000, Wisconsin Public Service Corporation Reload Safety Evaluation Methods Topical Report, WPSRSEM-NP, Revision 3

2) Letter from John G. Lamb (NRC) to Mark Reddemann (NMC) dated January 23, 2001, Kewaunee Nuclear Power Plant - Request For Additional Information Related To Reload Safety Evaluation Methods Topical Report, WPSRSEM-NP, Revision 3 (TAC NO. MB0306)

3) Letter from John G. Lamb (NRC) to Mark Reddemann (NMC) dated February 1, 2001, Kewaunee Nuclear Power Plant - Request For Additional Information Related To Reload Safety Evaluation Methods Topical Report, WPSRSEM-NP, Revision 3 (TAC NO. MB0306)

4) Letter from Mark Reddemann (NMC) to Document Control Desk (NRC), dated February 7, 2001, Kewaunee Nuclear Power Plant - Nuclear Management Company, LLC. Response to NRC 's Request for Additional Information on Wisconsin Public Service Corporation Reload Safety Evaluation Methods Topical Report, WPSRSEM-NP, Revision 3

In reference 1, Nuclear Management Company, LLC. (NMC) submitted a request for approval of the Kewaunee Nuclear Power Plant (KNPP) Reload Safety Evaluations Methods Topical Report, WPSRSEM-NP, Revision 3. In reference 2 and 3, the NRC staff requested additional information concerning this topical report. Reference 4 provided NMC's original response to the NRC's request for additional information. This letter is NMC's revised response to the NRC's request for additional information.

The response has been revised due to the NMC's discovery that the optional gap linear thermal expansion model had been inadvertently used in RETRAN cases used in an NMC DYNODE to RETRAN benchmark comparison. NMC therefore reran the RETRAN cases used for the benchmark and redid the benchmark comparisons. Although, as discussed in a February 16, 2001 telephone call with the NRC Staff, the main conclusions of the benchmark report remain valid, NMC is revising its Reference 4 response to accurately reflect the details of the revised benchmark comparison. In addition, the main steam line break portion of the NMC response to RAI question D has been expanded to mention how RETRAN is currently used to calculate entrainment and how it is planned to be used in Cycle 25 and beyond to calculate entrainment.

Attachments 1 and 2 to this letter contain NMC's revised response. In attachment 1 some portions of the NRC Staff's request for additional information are excluded. The information excluded was considered background information and therefore unnecessary to be repeated in our response. The information from the NRC's RAI is in bold print to differentiate it from NMC's response. Attachment 3 to this letter contains an explanation of the changes made due to rerunning the benchmark comparison with the optional gap linear thermal expansion model not in use. Attachment 4 contains the revised benchmark report.

In enclosure 1 of reference letter 3 some typographical errors were made which are corrected in this submittal. Comment 2 references DYNODE-Y, this should reference DYNODE-P. In comment 4 a reference is made to RETRAN-2D in the 2D mode, this should be RETRAN-3D in the 2D mode. In enclosure 2 the lettering of the comments should start with an "A" versus an "E". These corrections have been made in our submittal.

If you should have any questions concerning this matter, please contact John Holly (920) 388-8296 or Jerry Riste (920) 388-8424 of my staff.

In accordance with the requirements of 10 CFR 50.30(b), this submittal has been signed and notarized. A complete copy of this submittal has been transmitted to the State of Wisconsin as required by 10 CFR 50.91(b)(1).

Sincerely,

Mark E. Reddemann
Site Vice President

GOR
Attach.
cc - US NRC Senior Resident Inspector
US NRC, Region III
Electric Division, PSCW

Subscribed and Sworn to
Before Me This 7th Day
Of March, 2001

Notary Public, State of Wisconsin

My Commission Expires:

February 27, 2005

ATTACHMENT 1

Letter from M. E. Reddemann (NMC)

To

Document Control Desk (NRC)

Dated

March 7, 2001

KNPP WPSRSEM-NP, Revision 3

Revised NMC Response

To

NRC Request for Additional Information
Dated January 23, 2001

A. As a result of generic review of the RETRAN-3D code, the NRC staff limits the use of the code to certain conditions. Address your compliance with each item of the following conditions identified for use of RETRAN-3D computer code:

NMC NOTE: The staff positions provided in Enclosure 2 of the Request for Additional Information (RAI) are taken into account in assessing the compliance of the Kewaunee Nuclear Power Plant (KNPP) RETRAN-3D models with the conditions identified for use of the RETRAN-3D computer code.

1. Multidimensional neutronic space-time effects cannot be simulated, as the maximum number of dimensions is one. Conservative usage has to be demonstrated.

NMC Response: The KNPP RETRAN-3D (R3D) models do not employ the 3-D nodal kinetics model and therefore are subject to the same condition of use as RETRAN-02 (R02) with respect to neutronic space-time effects, i.e., that conservative usage be demonstrated. The conservative input analysis assumptions in the deterministic methodology used for the Replacement Steam Generator Plant Safety Analysis (RSG PSA) along with the KNPP DYNODE-P RETRAN-3D benchmark ("R3D benchmark", Reference A-1) demonstrate conservative use of R3D. Since the 3-D kinetics model is not used and DYNODE-P, not R3D, is used for the Main Steam Line Break (MSLB) accident, the additional conditions concerning void generation, primary side nodalization and uncertainty evaluation do not apply as conditions over and above the justification of a R02 model. If the 3-D kinetics model is used or R3D is used for MSLB in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

2. There is no source term in the neutronics and the maximum number of energy groups is two. The space-time options assume an initially critical system. Initial conditions with zero fission power cannot be simulated by the kinetics. The neutronic models should not be started from subcritical or with zero fission power without further justification.

NMC Response: The KNPP R3D models are not started from sub-critical or zero fission power conditions. The Rod Withdrawal From A Sub-Critical Condition accident model employs the DYNODE-P code as the Nuclear Steam Supply System (NSSS) simulator. If R3D is used to model accidents starting from sub-critical or zero fission power conditions in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

3. A boron transport model is unavailable. User input models will have to be reviewed on an individual basis.

NMC Response: The Chemical Volume and Control (CVCS) Malfunction accident model is the only KNPP R3D model that explicitly treats boron transport and/or dilution. All KNPP R3D models employ the automatic time-step selection model. This model limits time step size to a small multiple of the Courant limit. A careful review of the CVCS Malfunction accident indicates an acceptable boron transport model. If the boron transport model is used for other applications in the future, such as steam line break, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

4. **Moving control rod banks are assumed to travel together. The boiling-water reactor (BWR) plant qualification work shows that this is an acceptable approximation.**

NMC Response: The KNPP R3D models employ only point-kinetics. If the 1-D kinetics model is used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

5. **The metal-water heat generation model is for slab geometry. The reaction rate is therefore underpredicted for cylindrical cladding. Justification will have to be provided for specific analyses.**

NMC Response: The KNPP R3D models only simulate Non-Loss of Coolant Accidents (Non-LOCA) where core uncovery and heatup are not significant. If R3D is used for LOCA analyses in the future, a separate submittal will be made to the NRC unless R3D is generically approved for LOCA analyses. Therefore, this condition is satisfied.

6. **Equilibrium thermodynamics is assumed for the thermal-hydraulics field equations although there are non-equilibrium models for the pressurizer and the sub-cooled boiling region.**

NMC Response: The KNPP R3D models only simulate Non-LOCA accidents where the conditions of sub-cooled liquid and superheated steam in contact do not arise. If R3D is used for LOCA analyses in the future, a separate submittal will be made to the NRC unless R3D is generically approved for LOCA analyses. Therefore, this condition is satisfied.

7. **While the vector momentum model allows the simulation of some vector momentum flux effects in complex geometry, the thermal-hydraulics are basically one-dimensional.**

NMC Response: The KNPP R3D models do not rely on a detailed accounting of vector momentum flux for validity. The basic 1-dimensional nature of the momentum equation and the limited accounting of 2-dimension momentum effects in R3D are recognized. Therefore, this condition is satisfied.

8. **Further justification is required for the use of the homogeneous slip options with BWRs.**

NMC Response: The KNPP R3D models do not employ a slip model of any kind. If any R3D slip options are used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

9. **The drift flux correlation used was originally calibrated to BWR situations, and the qualification work for both this option and for the dynamic slip option only cover BWRs. The drift flux option can be approved for BWR bundle geometry if the conditions of (16) are met.**

NMC Response: The KNPP R3D models do not employ a slip model of any kind. If any R3D slip options are used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

10. The profile effect on the interphase drag (among all the profile effects) is neglected in the dynamic slip option. Form loss is also neglected for the slip velocity. For the acceptability of these approximations refer to (17).

NMC Response: The KNPP R3D models do not employ a slip model of any kind. If any R3D slip options are used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

11. Only one-dimensional heat conduction is modeled. The use of the optional gap linear thermal expansion model requires further justification.

NMC Response: The KNPP R3D models do not employ a gap expansion model. If the R3D gap linear thermal expansion model is used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

12. Air is assumed to be an ideal gas with a constant specific heat representative of that at containment conditions. It is restricted to separated and single-phase vapor volumes. There are no other noncondensables.

NMC Response: The KNPP R3D models do not employ a non-condensable gas model of any kind. If any R3D non-condensable gas models are used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

13. The use of the water properties polynomials should be restricted to the subcritical region. Further justification is required for other regions.

NMC Response: The KNPP R3D models do not model ATWS events. If R3D is used to model PWR ATWS events in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

14. A number of regime-dependent minimum and maximum heat fluxes are hardwired. The use of the heat transfer correlations should be restricted to situations where the pre-CHF heat transfer or single-phase heat transfer dominates.

NMC Response: The KNPP R3D models employ the forced convection option heat transfer model. Only pre-CHF, single-phase heat transfer regimes are analyzed with the R3D models. If the forced convection option is used again in the future, the applicable conditions pertaining to R3D will again be satisfied. Therefore, this condition is satisfied.

15. The Bennet flow map should only be used for vertical flow within the conditions of the database and the Beattie two-phase multiplier option requires qualification work.

NMC Response: The flow regime maps in R3D are used to select the wall-to-phase and interphase friction models for certain flow structures in the dynamic slip model. The KNPP R3D models do not use a slip model of any kind. If future KNPP R3D models employ the dynamic slip option that utilizes flow regime maps, Bennet flow regime maps will be applied to vertical flows, and Govier flow regime maps will be applied to horizontal flows. Therefore, this condition is satisfied.

16. No separate effects comparison have been presented for the algebraic slip option and it would be prudent to request comparisons with the FRIGG tests before the approval of the algebraic slip option.

NMC Response: The KNPP R3D models do not employ a slip model of any kind. If any R3D slip options are used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

17. While FRIGG tests comparisons have been presented for the dynamic slip option, the issues concerning the Schrock-Grossman round tube data comparisons should be resolved before the dynamic slip option is approved. Plant comparisons using the option should also be required.

NMC Response: This R02 condition of use is not a R3D condition of use.

18. The nonequilibrium pressurizer model has no fluid boundary heat losses, cannot treat thermal stratification in the liquid region, and assumes instantaneous spray effectiveness and a constant rainout velocity. A constant L/A is used and flow detail within the component cannot be simulated. There will be a numerical drift in energy due to the inconsistency between the two-region and the mixture energy equations but it should be small. No comparisons were presented involving a full or empty pressurizer. Specific application of this model should justify the lack of fluid boundary heat transfer on a conservative basis.

NMC Response: The KNPP R3D pressurizer model is justified on the basis that the steady-state initialization process results in reasonable code-calculated pressurizer model parameters, that the pressurizer model exhibits reasonable transient behavior and that the model compares well to the DYNODE-P model (Reference A-1). No numerical discontinuity exists in the KNPP R3D models during a pressurizer filling or draining event and there are no other indications of pressurizer model instability or inadequacy. Therefore, this condition is satisfied.

19. **The nonmechanistic separator model assumes quasistatics (time constant approximately few tenths of seconds) and uses General Electric (GE) BWR6 carryover/carryunder curves for default values. Use of default curves has to be justified for specific applications. As with the pressurizer, a constant L/A is used. The treatment in the off normal flow quadrant is limited and those quadrants should be avoided. Attenuation of pressure waves at low flow/low quality conditions are not simulated well. Specific applications to BWR pressurization transients under those conditions should be justified.**

NMC Response: The KNPP R3D models do not employ the non-mechanistic separator model. If the non-mechanistic separator model is used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

20. **The centrifugal pump head is divided equally between the two junctions of the pump volume. Bingham pump and Westinghouse pump data are used for the default single-phase homologous curves. The SEMISCALE MOD-1 pump and Westinghouse Canada data are for the degradation multiplier approach in the two-phase regime. Use of the default curves has to be justified for specific applications. Pump simulation should be restricted to single-phase conditions.**

NMC Response: The KNPP R3D models employ the same R02 default Westinghouse pump model. Justification for the R02 model is through plant startup test and load rejection data comparisons. The KNPP R3D models employ pump simulations that remain in single-phase conditions. Therefore, this condition is satisfied.

21. **The jet pump model should be restricted to the forward flow quadrant, as the treatment in the other quadrants is conceptually not well founded. Specific modeling of the pump in terms of volumes and junctions is at the user's discretion and should therefore be reviewed with the specific application.**

NMC Response: This R02 condition of use is not a R3D condition of use.

22. **The nonmechanistic turbine model assumes symmetrical reaction staging, maximum stage efficiency at design conditions, a constant L/A and a pressure behavior dictated by a constant loss coefficient. It should only be used for quasistatic conditions and in the normal operating quadrant.**

NMC Response: The KNPP R3D models do not employ a turbine model of any kind. If the non-mechanistic turbine model is used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

23. The subcooled void model is a nonmechanistic profile fit using a modification of Electric Power Research Institute (EPRI) recommendations for the bubble departure point. It is used only for the void reactivity computation and has no direct effect on the thermal-hydraulics. Comparisons have only been presented for BWR situations. The model should be restricted to the conditions of the qualification database. Sensitivity studies should be requested for specific applications. The profile-blending algorithm used will be reviewed when submitted as part of the new manual (MOD003) modifications.

NMC Response: This R02 condition of use is not a R3D condition of use.

24. The bubble rise model assumes a linear void profile, a constant rise velocity (but adjustable through the control system), a constant L/A, thermodynamic equilibrium, and makes no attempt to mitigate layering effects. The bubble mass equation assumes zero junction slip, which is contrary to the dynamic and algebraic slip model. The model has limited application and each application must be separately justified.

NMC Response: The KNPP R3D bubble rise models are justified implicitly in the R3D to DYNODE-P benchmark (Reference A-1). No slip models are used in the KNPP R3D models so there is no inconsistency with other junctions. If any R3D slip options are used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

25. The transport delay model should restricted to situations with a dominant flow direction.

NMC Response: The KNPP R3D models do not employ an enthalpy transport delay model. If the transport delay model is used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

26. The stand-alone auxiliary departure from nucleate boiling ratio (DNBR) model is very approximate and is limited to solving a one-dimensional steady-state simplified homogeneous equilibrium model (HEM) energy equation. It should be restricted to indicating trends.

NMC Response: The KNPP R3D models do not employ the DNBR models in R3D. If the stand-alone DNBR model is used in the future, it will be restricted to only indicating trends. Therefore, this condition is satisfied.

27. Phase separation and heat addition cannot be treated simultaneously in the enthalpy transport model. For heat addition with multidirectional, multifunction volumes the enthalpy transport model should not be used without further justification. Approval of this model will require submittal of the new manual (MOD003) modifications.

NMC Response: This R02 condition of use is not a R3D condition of use.

28. The local conditions heat transfer model assumes saturated fluid conditions, one-dimensional heat conduction and a linear void profile. If the heat transfer is from a local condition volume to another fluid volume, that fluid volume should be restricted to a nonseparated volume. There is no qualification work for this model and its use will therefore require further justification.

NMC Response: The KNPP R3D models do not employ the local conditions heat transfer model. If the local conditions heat transfer model is used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore this condition is satisfied.

29. The initializer does not absolutely eliminate all ill-posed data and could have differences with the algorithm used for transient calculations. A null transient computation is recommended. A heat transfer surface area adjustment is made and biases are added to feedwater inlet enthalpies in order to justify steady-state heat balances. These adjustments should be reviewed on a specific application basis.

NMC Response: All KNPP R3D base models undergo null-transient analysis. In the KNPP R3D models, the steam generator heat transfer area and the feedwater inlet enthalpy are adjusted by the steady-state initialization process. The adjustments are within acceptable ranges based on RETRAN-3D training session guidance and engineering judgement. Therefore this condition is satisfied.

30. Justification of the extrapolation of FRIGG data or other data to secondary-side conditions for pressurized water reactors (PWRs) should be provided. Transient analysis of the secondary side must be substantiated. For any transients in which two-phase flow is encountered in the primary, all the two-phase flow models must be justified.

NMC Response: The KNPP R3D models do not employ a slip model of any kind. If non-HEM two-phase flow models are used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

31. The pressurizer model requires model qualification work for the situations where the pressurizer either goes solid or completely empties.

NMC Response: This R02 condition of use is not a R3D condition of use.

32. Transients which involve three-dimensional space-time effects such as rod ejection, transients would have to be justified on a conservative basis.

NMC Response: This is not a separate condition for R3D (see condition (1)).

33. Transients from sub-critical, such as those associated with reactivity anomalies should not be run.

NMC Response: The KNPP R3D models do not start from sub-critical conditions. If R3D is used to model transients from sub-critical in the future, the applicable conditions pertaining to R3D will be satisfied (see condition (2)). Therefore, this condition is satisfied.

34. Transients where boron injection is important, such as steamline break will require separate justification for the user-specified boron transport model.

NMC Response: This is not a separate condition for R3D (see condition (3)).

35. For transients where mixing and cross flow are important, the use of various cross flow loss coefficients has to be justified on a conservative basis.

NMC Response: The KNPP R3D models do not employ cross flow or mixing models. If cross-flow and mixing models are used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied.

36. Anticipated transients without scram (ATWS) events will require additional submittals.

NMC Response: This is not a separate condition for R3D (see condition (13)).

37. For PWR transients where the pressurizer goes solid or completely drains, the pressurizer behavior will require comparison against real plant or appropriate experimental data.

NMC Response: This is not a separate condition for R3D (see conditions (18) and (31)).

38. PWR transients, such as steam generator tube rupture, should not be analyzed for two-phase conditions beyond the point where significant voiding occurs on the primary side.

NMC Response: This is not a separate condition for R3D (see conditions (16) and (30)).

39. BWR transients where asymmetry leads to reverse jet pump flow, such as the one re-circulation pump trip, should be avoided.

NMC Response: This is not a separate condition for R3D (see condition (21)).

References:

Reference A-1: Voskuil, J.L., Wanner D.J., "Kewaunee Nuclear Power Plant Revised DYNODE-P RETRAN-3D Benchmark," Prepared 02-21-2001, Reviewed 02-22-2001.

B. RETRAN-3D USE IN A RETRAN-02 MODE

In the letter dated October 12, 2000, the NMC staff stated that you intend to adopt use of RETRAN-3D in the 2D mode for system analysis. The NRC staff has determined that it is not possible to use RETRAN-3D in a pure RETRAN-02 mode. The code's numerical solution scheme and various models have been changed so that there is no exact RETRAN-02 substitution that can be performed. However, the code can be used in a near RETRAN-02 mode provided that the user carefully selects models and options that reduce the divergence from those not available to the RETRAN-02 user.

While functionally equivalent to RETRAN-02, RETRAN-3D is more robust. The following models are always active when using RETRAN-3D:

- **Improved transient numerical solution (fully implicit solution of the balance equations, component models and source terms are linearized)**
- **Improvements to the time-step selection logic**
- **Improved water property curve fits**

Other model options have been improved with the improvements being active when the particular option is selected in an input model. For these options, the RETRAN-02 model was replaced by the improved model and there is no backward compatibility option. Consequently, the following improvements, if selected by the user, may be used for RETRAN-02 mode analyses:

- **Fully implicit steady-state solution**
- **Implicit pressurizer solution**
- **Wall friction model revised to use the Colebrook equation, allowing consideration of wall roughness rather than assuming smooth pipe**
- **Control system solution revised to solve a coupled system of equations using a Gauss-Seidel method rather than the single pass marching scheme**
- **Enthalpy transport model revised by eliminating several simplifying assumptions**
- **Improved dynamic slip formulation adding form losses**
- **Improved countercurrent flow junction properties**

- **Implicit solution of the heat conduction equation**

- **Combined heat transfer map updated with an improved set of heat transfer correlations and smoothed transitions**

- **Wall friction and hydrostatic head losses included in critical flow pressure**

The new steady-state option available for initializing models with steam generators makes some problems easier to initialize. The low power steam generator steady-state option can be used with RETRAN-02 mode analyses.

A RETRAN-02 mode model must not use any of the new RETRAN-3D features such as:

- **Generalized laminar friction model**

NMC Response: The KNPP R3D models do not employ the generalized laminar friction model (card 050000 absent).

- **Dynamic gap conductance model**

NMC Response: The KNPP R3D models do not employ the dynamic gap conductance model (card 01000Y, NGAP = 0).

- **Accumulator model**

NMC Response: The KNPP R3D models do not employ the accumulator model (card 01000Y, NACC = 0).

- **Dynamic flow regime model**

NMC Response: The KNPP R3D models do not employ the dynamic flow regime model (card 01000Y, ISFLAG ≠ 6).

- **New control blocks added to improve functionality**

NMC Response: The KNPP R3D models do not employ the new control blocks (card 702XXX, CSYM ≠ ABS, F2D, RAT, STF).

- **Govier horizontal flow regime map and stratified flow friction model**

NMC Response: The KNPP R3D models do not employ the Govier horizontal flow regime map and stratified flow friction model (card 01000Y, ISFLAG = 0; card 08XXXY, IFRJ < 100).

- **Chexal-Lellouche drift flux model**

NMC Response: The KNPP R3D models do not employ the Chexal-Lellouche drift flux model (card 01000Y, ISFLAG = 0).

- **Method of characteristics enthalpy option**

NMC Response: The KNPP R3D models do not employ the method of characteristics enthalpy option (cards 6300XX absent).

- **Noncondensable gas flow model**

NMC Response: The KNPP R3D models do not employ the non-condensable gas flow model (card 01000Y, NCFLOW = 0).

- **3D kinetics**

NMC Response: The KNPP R3D models do not employ the 3D kinetics model (card 01000Y, NODEL = 1).

- **5-equation nonequilibrium model**

NMC Response: The KNPP R3D models do not employ the 5-equation non-equilibrium model (card 01000Y, NEWEQS = 0).

Explain how you comply with the following conditions:

Organizations with NRC-approved RETRAN-02 methodologies can use the RETRAN-3D code in the RETRAN-02 mode without additional NRC approval, provided that none of the new RETRAN-3D models listed in the definition are used. Organizations with NRC-approved RETRAN-02 methodologies must obtain NRC approval prior to applying any of the new RETRAN-3D models listed above for updated final safety analysis report (UFSAR) Chapter 15 licensing basis applications. Organizations without NRC-approved RETRAN-02 methodologies must obtain NRC approval for such methodologies or a specific application before applying the RETRAN-02 code or the RETRAN-3D code for UFSAR Chapter 15 licensing basis applications. Generic Letter 83-11 provides additional guidance in this area. Licensees who specifically reference RETRAN-02 in their Technical Specifications will have to request a Technical Specification change to use RETRAN-3D.

NMC Response: The NMC (formerly WPSC) has NRC-approved RETRAN-02 methodologies for KNPP (Reference B-1) and is not using any of the restricted new R3D models listed in the definition. See the NMC responses above following each of the restricted new R3D models for demonstration of the compliance. The NMC must obtain NRC approval prior to applying any of the restricted new RETRAN-3D models listed in the definition for UFSAR Chapter 14 licensing basis applications.

Also, RETRAN-02 is not specifically referenced in KNPP Technical Specifications. Therefore this condition is satisfied.

The RETRAN-3D five-equation, or nonequilibrium, model uses flow regime maps and flow pattern dependent heat transfer and interfacial area models to simulate the heat and mass transfer processes between phases. A licensee wishing to apply the five-equation model will have to justify its use outside areas of operation where assessment has been documented. This may include either separate effects or integral systems assessment that cover the range of conditions encountered by the application of interest. An assessment of the uncertainties must also be provided. The model is approved subject to these conditions.

NMC Response: The KNPP R3D models do not employ the 5-equation or non-equilibrium models (apart from the pressurizer model, which is previously addressed in question part A). If the 5-equation or non-equilibrium models are used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore this condition is satisfied.

Assessment performed in support of use of RETRAN-3D must also address consistency between the RETRAN-3D calculations and any auxiliary calculations that are a part of the overall methodology, such as, Departure from Nucleate Boiling or Critical Power Ratio. The NRC staff concludes that the lack of a detailed RETRAN-3D specific user guideline document mandates a statement on the user's experience and qualification with the code when analyses are submitted in support of licensing actions. This statement is expected to be consistent with the guidance of Generic Letter 83-11.

NMC Response: The KNPP R3D model transient results are utilized by the VIPRE, TOODEE and CONTEMPT codes for some transients. The basis for the consistency remains the same as it is for the existing consistency between DYNODE-P and RETRAN-02 and these other codes. If other auxiliary calculations are performed in the future, the consistency between R3D and the auxiliary calculation will be assessed.

The NMC has a training program established and implemented to ensure that each qualified user of R3D in a R02 mode has a good working knowledge of the code and methods and is able to set up the input, to understand and interpret the output results, and understands the application and limits of the code. The program ensures that analyses are performed in compliance with the applicable procedures. Training has been provided to the qualified users by the code developer and from other qualified code users.

The KNPP R3D models were developed by qualified NMC (formerly WPSC) staff who have appropriate experience and training consistent with Generic Letter 83-11. R02 has been used extensively for best estimate calculations:

- KNPP simulator verification of selected operational transients
- KNPP Load Rejection Test simulation and comparisons
- Main Feedwater System leak analysis
- Containment Fan Coil Unit downstream piping orifice sizing and licensing analyses:
- Chapter 14 Design Basis Non LOCA transients for topical report (Rev 2)

- Rod Drop in auto control accident
- High Energy Line Break outside containment

Therefore this condition is satisfied.

Application of the RETRAN-02 or RETRAN-3D codes for best estimate analysis of UFSAR Chapter 15 licensing basis events may require additional code and model assessment, and an evaluation of uncertainties to assure accurate prediction of best estimate response. This condition is based on the absence, in the best estimate analysis approach, of the conservative assumptions in traditional UFSAR Chapter 15 licensing basis analyses. For each use of RETRAN-3D in a licensing calculation, it will be necessary for a valid approach to assessment to be submitted, which is expected to include a phenomena identification and ranking table (PIRT) for each use of the code and the appropriate assessment cases and their results. The scope of the PIRT and validation/assessment will be commensurate with the complexity of the application.

NMC Response: The KNPP R3D models utilize only explicitly approved R3D models and are not used in a best estimate UFSAR Chapter 14 analysis methodology. Conservative assumptions are used in the UFSAR Chapter 14 licensing basis analyses. Therefore this condition is satisfied.

References:

Reference B-1: "Wisconsin Public Service Corporation "Reload Safety Evaluation Methods for Application to Kewaunee" (TAC No. 65155), NRC letter from Joseph G. Giitter to D.C. Hintz, dated April 11, 1988. (Docket No. 50-305)

C. Page 2 of Attachment 3 in the letter dated October 12, 2000 specifies two different sets of acceptance criteria for the DYNODE and RETRAN-3D comparison. One is for parameter trend and one is for key parameters comparisons. It is not clear how the two different sets of acceptance criteria are applied to the code comparisons. You are requested to provide a description of the applications of acceptance criteria in the code comparisons and justify its adequacy for the NRC staff approval. Also, key parameters acceptance criteria allow the differences in parameters calculated by DYNODE and RETRAN-3D to be within the following ranges: 30 psi for steam generator or pressurizer pressure, 0.14 for minimum departure from nucleate boiling ratio (MDNBR), 4^{0}F for peak clad temperature. Explain how the ranges of the parameters (especially, 0.14 for MDNBR with consideration of use of the HTP critical heat flux correlation) are determined and how these uncertainties are considered in establishing the limiting peak pressurizer pressure, minimum DNBR and peak clad temperature for the USAR accident analyses. Also, you are requested to identify any results of the DYNODE and RETRAN-3D code comparisons that do not meet the key parameters acceptance criteria and provide reasons in terms of code modeling assumptions for the NRC staff to review.

NMC Response:

Background:

The attachment referred to in the question is the DYNODE to RETRAN-3D benchmark report (Reference C-1). DYNODE has been used extensively by NMC staff (formerly WPSC staff) for analyzing Kewaunee non-LOCA USAR Chapter 14 events since 1979. RETRAN-02 has been used by NMC staff (formerly WPSC staff) for Kewaunee safety analysis since 1988, but has been used less extensively than DYNODE for analyzing Kewaunee non-LOCA USAR Chapter 14 events. Comparisons of both DYNODE and RETRAN-02 to Kewaunee plant and simulator data were included in the October 1988 revision to the Kewaunee reload safety evaluation methods topical report (approved by Reference C-2). These comparisons demonstrated the competency of NMC staff (formerly WPSC staff) to build and use both DYNODE and RETRAN-02 models. These competencies have been maintained by continued use of both models.

The purpose of the benchmark report is to compare RETRAN-3D in RETRAN-02 mode results to existing DYNODE results for Kewaunee non-LOCA USAR Chapter 14 transients. The comparison will verify the ability of NMC staff (formerly WPSC staff) to model the non-LOCA events with RETRAN-3D used in RETRAN-02 mode. The RETRAN-3D in RETRAN-02 mode model created for this comparison was made as similar as possible to the existing DYNODE model in terms of basic inputs (geometry, power level, fluid conditions, et cetera) and sub-system models (charging/letdown, steam generators, et cetera) in order to facilitate a meaningful comparison.

Note that for the remainder of this response, the word "RETRAN" will refer to RETRAN-3D used in RETRAN-02 mode.

As previously stated, the comparison of RETRAN to DYNODE in the benchmark report is intended to verify the ability of the NMC staff (formerly WPSC staff) to build and use a RETRAN model for

Kewaunee safety analysis, particularly the Chapter 14 events that have historically been primarily analyzed in DYNODE. To that end, the benchmark report documents the comparisons and explains any significant, unexpected, or unusual deviations in the calculation of safety related parameters. In order to identify significant, unexpected, or unusual deviations, acceptance criteria were developed. These criteria are only intended to aid in the comparison of results between the two models and are independent of the overall Kewaunee safety analysis methodology. The Kewaunee safety analysis methodology ensures conservative output results by utilizing conservative input values for parameters such as pressure, temperature, power, flow, reactor trip setpoints, safety system setpoints, circuit delays, system configuration, single active failure, et cetera. Use of approved codes such as DYNODE and RETRAN-02 with conservative inputs has ensured conservative output results for use in safety analysis. RETRAN-3D in RETRAN-02 mode will use this same analysis approach.

Acceptance Criteria Used In Benchmark Comparisons:

The acceptance criteria described in the benchmark report are more accurately viewed as review criteria. Based on engineering judgement, differences between DYNODE and RETRAN results that meet the review criteria are considered to be acceptable without further explanation. Differences between DYNODE and RETRAN results that do not meet the review criteria must be explained prior to acceptance. The review criteria are intended to identify areas where parameter differences should be investigated to ensure that the differences are due to the inherent differences between the DYNODE and RETRAN-3D codes, and not due to a modeling error or code misuse.

There are one qualitative review criterion and two sets of quantitative review criteria. The qualitative review criterion states that general trends in parameters plotted in the USAR shall be consistent. All of the plots shown in the USAR for a particular transient were included in the benchmark report, as these are important parameters for the transient. The qualitative trend review criterion, for example, was used to verify that reactor power is rising in both DYNODE and RETRAN at the beginning of the uncontrolled RCCA withdrawal cases. Or that pressurizer water level is rising in both DYNODE and RETRAN soon after the beginning of the automatic control loss of external electric load event. The qualitative review criterion was also used to identify parameter oscillations that warranted further investigation. The few significant trend differences between DYNODE and RETRAN results are explained in the benchmark report discussion of each figure. For example, the last paragraph on Page III.3-1 of the benchmark report explains a trend difference between DYNODE and RETRAN calculated T_{ave} results toward the end of the transient. Another example is on Page III.7-1, which explains the calculated steam generator wide range level oscillations seen on Figure 7-3.

The first set of quantitative review criteria is applied to parameters that are plotted in the USAR, but are not accident acceptance criteria parameters. The list of parameters reviewed under this set of criteria varies from accident to accident. For example, the USAR plots for the Condition II boron dilution (also called CVCS malfunction) at full power transient consist of plots of MDNBR, RCS (pressurizer) pressure, reactor power, T_{ave}, and heat flux as a function of transient time. Of these parameters, MDNBR and RCS pressure are Condition II event acceptance criteria. The remaining parameters (reactor power, T_{ave}, and heat flux) are not event acceptance criteria and are therefore reviewed under the first set of quantitative review criteria. As a result, for this transient, reactor

power would be expected to compare within 5% between DYNODE and RETRAN at all transient times, T_{ave} would be expected to compare within 5°F at all transient times, and heat flux would be expected to compare within 5% at all transient times. Any differences between the DYNODE and RETRAN results at any time that exceed these review criteria would have to be explained prior to acceptance. Since these parameters are not USAR acceptance criteria parameters, the benchmark report does not summarize in detail the instances where pertinent parameters exceed the review criteria. However, significant differences between the DYNODE and RETRAN results for these parameters are explained in the benchmark report discussion of each figure. For example, the first paragraph on Page III.2-1 of the benchmark report explains why the RETRAN case trips later than the DYNODE case for the CVCS malfunction dilution at power. The explanation provides the reason why the Figure 2-1 fraction of reactor power in RETRAN at 88 seconds is still greater than 1.0, while the DYNODE fraction of reactor power has already decreased to less than 0.25.

The second set of quantitative review criteria is applied to parameters that are USAR acceptance criteria. These are the "key parameters" referred to in the question. All parameters that are USAR acceptance criteria parameters are considered under this set of review criteria, regardless of whether or not they are plotted in the USAR. USAR acceptance criteria that are known not to be challenged by a particular event, that are known to be bounded by another event, or that are bounded by other USAR acceptance criteria are not formally summarized for that particular event. For example, as stated earlier, boron dilution (also called CVCS malfunction) at full power is a Condition II event. Condition II events have acceptance criteria related to RCS pressure, MDNBR, fuel centerline temperature, dose consequences, main steam system pressure, and containment pressure/temperature. By meeting the MDNBR acceptance criteria, the fuel centerline temperature and dose acceptance criteria are met. For a Condition II event such as boron dilution there is no challenge to the containment acceptance criteria. Therefore, the USAR acceptance criteria remaining to be considered under the second set of quantitative review criteria are MDNBR, RCS pressure, and main steam system pressure. Any differences between the DYNODE and RETRAN results for these parameters that exceed the second set of quantitative review criteria would have to be explained prior to acceptance. Note that some of the USAR acceptance criteria are not calculated by DYNODE or by RETRAN. For example, MDNBR is not calculated directly by DYNODE or RETRAN. Statepoint output from DYNODE or RETRAN is passed to VIPRE for the MDNBR calculation. Therefore, the DYNODE to RETRAN MDNBR differences are based on the differences in the values of heat flux, RCS pressure, core inlet temperature, and RCS flow passed to VIPRE from DYNODE or RETRAN. The beginning of Section 8 (Page III.8-1) of the benchmark report provides explanations for differences that exceed this set of review criteria for the key parameters for all of the events in the benchmark report.

Note that the second set of quantitative review criteria is slightly more restrictive than the first set of quantitative review criteria. This is not to imply that RETRAN or DYNODE are better able to predict parameters reviewed under the second set of review criteria. It simply means that a smaller difference will require an explanation for the DYNODE to RETRAN differences for these parameters prior to the acceptance of the benchmark results.

Quantitative Review Criteria Values:

Values for both sets of quantitative review criteria were determined using engineering judgement. For the second set of review criteria, the current USAR Section 14.0 steady state errors were used to guide the selection of some of the review criteria. USAR Section 14.0 gives the steady state primary pressure error as ±30 psi. It was therefore decided that DYNODE to RETRAN differences greater than 30 psi for this parameter would have to be explained before acceptance. It is important to note that the 30-psi is just a criteria to initiate a review of the differences in the benchmark analysis. It does not imply that 30 psi must be added to or subtracted from either the DYNODE or RETRAN result to account for uncertainties. As discussed previously, the overall conservatism of a DYNODE or RETRAN transient case when used in safety analysis is based on the use of conservative input throughout, not on applying conservatism to the output value.

The 30-psi RCS pressure review criterion was also used for the secondary side pressure review criterion. Once again, this does not imply that 30 psi must be added to or subtracted from either the DYNODE or RETRAN result to account for uncertainties. The overall conservatism of a DYNODE or RETRAN transient case when used in safety analysis is based on the use of conservative input throughout, not on applying conservatism to the output value.

The peak clad temperature review criterion was established somewhat differently. The only event in the DYNODE to RETRAN benchmark that requires an explicit assessment of the peak-clad temperature is the locked rotor accident. Neither DYNODE nor RETRAN are used to directly calculate peak-clad temperature. Instead, power as a function of time is passed from DYNODE or RETRAN to TOODEE. The values passed to TOODEE are conservative based on the conservative input used to generate them. USAR Section 14.0 gives the steady state core inlet temperature error as ±4°. Although the core inlet temperature is not the same parameter as the peak-clad temperature, it was decided that DYNODE to RETRAN differences greater than 4°F in peak clad temperature would have to be explained before acceptance. Analogous to the case for the RCS pressure parameter, this does not imply that 4°F must be added to or subtracted from TOODEE results based either on DYNODE or RETRAN to account for uncertainties. The overall conservatism in the TOODEE peak clad temperature results based on DYNODE or RETRAN is based on the use of conservative input throughout when performing safety analysis, not on applying conservatism to the output value.

The MDNBR review criterion was also established somewhat differently. As discussed earlier, neither DYNODE nor RETRAN are used to directly calculate MDNBR. Instead, values of heat flux, RCS pressure, core inlet temperature, and RCS flow are passed from DYNODE or RETRAN to VIPRE. The values passed to VIPRE are conservative based on the conservative input used to generate them. The MDNBR review criterion was set at 0.14 guided by the fact that the Kewaunee HTP correlation DNBR limit is 1.14. Once again, this does not imply that 0.14 must be added to or subtracted from a VIPRE MDNBR calculated using either DYNODE or RETRAN results to account for uncertainties when performing safety analysis. The overall conservatism of the VIPRE MDNBR calculation when performing safety analysis is based on the conservative DYNODE or RETRAN transient case output passed to VIPRE. The VIPRE HTP correlation DNBR limit is based on a qualification of VIPRE to experimental data and is independent of whether DYNODE or

RETRAN is being used to provide safety analysis statepoint information to VIPRE. All of the benchmark report events are well within the MDNBR review criterion of 0.14, and would have met an MDNBR review criterion as low as 0.06.

The first set of quantitative review criteria also depended on engineering judgement to establish their values. The values are somewhat less restrictive than the review criteria applied to transient USAR acceptance criteria parameters. Once again these review criteria are not meant to determine a number that must be added to or subtracted from a DYNODE or RETRAN result to account for uncertainties. They are meant to establish criteria to identify areas where parameter differences observed in the benchmark should be investigated to ensure that the differences are due to the inherent differences between the DYNODE and RETRAN-3D codes, instead of to a modeling error or code misuse.

Explanation of Key Parameter Differences Exceeding Acceptance (Review) Criteria:

As was mentioned earlier, the beginning of Section 8 (Page III.8-1) of the benchmark report provides explanations for differences that exceed the second set of quantitative review criteria for the key parameters (USAR event acceptance criteria parameters) for all of the events in the benchmark report.

References:

Reference C-1: "Revised DYNODE-P RETRAN-3D Benchmark," report prepared by J.L. Voskuil, dated February 21,2001(prepared) and February 22, 2001(reviewed).

Reference C-2: Wisconsin Public Service Corporation "Reload Safety Evaluation Methods for Application to Kewaunee (TAC No. 65155), NRC Letter from Joseph G. Giitter to D.C. Hintz, dated April 11, 1988. (Docket No. 50-305)

D. Describe which accidents are intended to be analyzed in the future using DYNODE and RETRAN-3D in the 2D mode. Justify the adequacy of the application of these codes regarding accident conditions analyzed.

NMC Response:

DYNODE and RETRAN-3D are used for the NSSS simulation of various events. Section 3.0 of the submitted topical report contains seventeen sections, sixteen of which describe accidents or transients. The seventeenth section describes power distribution control. The current use of DYNODE and RETRAN-3D and the planned future use of RETRAN-3D for each of these topical report sections are discussed below. Note that current use refers to the analysis of record for the currently operating Kewaunee Cycle 24. Future use refers to the analysis to be used starting with Cycle 25, which is scheduled to start up in Fall 2001.

It should also be noted that in the following discussion, for Cycle 25, "RETRAN" means the use of RETRAN-3D in the 2D mode, with all applicable conditions met. For cycles beyond Cycle 25, "RETRAN" means either of the following:

- The use of RETRAN-3D in 2D mode with all applicable conditions met; or
- The use of RETRAN-3D in other than 2D mode supported by a submittal.

1. Uncontrolled RCCA Withdrawal from a Sub-Critical Condition: This event is currently analyzed using DYNODE for the NSSS simulation. For Cycle 25, it is intended to continue to use DYNODE. At some time after Cycle 25, the NMC may develop a RETRAN model for this event to replace DYNODE. If such a model is developed, the model will meet all applicable RETRAN conditions, notably the conditions related to initially sub-critical RETRAN models.

2. Uncontrolled RCCA Withdrawal At Power: This event is currently analyzed using DYNODE for the NSSS simulation. Starting with Cycle 25, it is intended to use RETRAN for the NSSS simulation.

3. Control Rod Misalignment: No NSSS simulation is performed for this event. Therefore, neither DYNODE nor RETRAN are currently used for this event or planned for future use for this event.

4. Control Rod Drop: No NSSS simulation is performed for this event. Therefore, neither DYNODE nor RETRAN are currently used for this event or planned for future use for this event.

5. Chemical and Volume Control System Malfunction: This event is currently analyzed using DYNODE for the NSSS simulation. Starting with Cycle 25, it is intended to use RETRAN for the NSSS simulation.

6. Startup of an Inactive Coolant Loop: This event is currently analyzed using DYNODE for the NSSS simulation. For Cycle 25, it is intended to continue to use DYNODE. At some time after Cycle 25, the NMC may develop a RETRAN model for this event to replace DYNODE. If such

a model is developed, the model will meet all applicable RETRAN conditions, notably the conditions related to RETRAN models initially at part power.

7. Excessive Heat Removal Due to Feedwater System Malfunction: This event is currently analyzed using DYNODE for the NSSS simulation. Starting with Cycle 25, it is intended to use RETRAN for the NSSS simulation.

8. Excessive Load Increase: This event is currently analyzed using DYNODE for the NSSS simulation. Starting with Cycle 25, it is intended to use RETRAN for the NSSS simulation.

9. Loss of External Load: This event is currently analyzed using DYNODE for the NSSS simulation. Starting with Cycle 25, it is intended to use RETRAN for the NSSS simulation.

10. Loss of Normal Feedwater Flow: This event is currently analyzed using DYNODE for the NSSS simulation. Starting with Cycle 25, it is intended to use RETRAN for the NSSS simulation.

11. Loss of Reactor Coolant Flow – Pump Trip: This event is currently analyzed using DYNODE for the NSSS simulation. Starting with Cycle 25, it is intended to use RETRAN for the NSSS simulation.

12. Loss of Reactor Coolant Flow – Locked Rotor: This event is currently analyzed using DYNODE for the NSSS simulation. Starting with Cycle 25, it is intended to use RETRAN for the NSSS simulation.

13. Fuel Handling Accident: No NSSS simulation is performed for this event. An outside vendor performs a fuel handling accident analysis using its approved methods. The NMC then verifies that the vendor analysis applies to each reload. This is currently the case for Cycle 24 and is expected to continue to be the case in the future.

14. Main Steam Line Break: This event is currently analyzed using DYNODE for the NSSS simulation. For Cycle 25, it is intended to continue to use DYNODE. At some time after Cycle 25, the NMC may develop a RETRAN model for this event to replace DYNODE for the NSSS simulation. If such a model is developed, the model will meet all applicable RETRAN conditions, notably the conditions related to RETRAN models initially at zero power. The entrainment data that is provided to the DYNODE NSSS simulation is currently based on RETRAN-02 calculations. Starting with Cycle 25, it is intended to use RETRAN-3D in RETRAN-02 mode for the entrainment calculations, with all applicable RETRAN conditions met.

15. Control Rod Ejection: This event is currently analyzed using DYNODE for the NSSS simulation. For Cycle 25, it is intended to continue to use DYNODE. At some time after Cycle 25, the NMC may develop a RETRAN model for this event to replace DYNODE. If such a model is developed, the model will meet all applicable RETRAN conditions, notably the conditions related to RETRAN models initially at less than full power.

16. Loss of Coolant Accident: An outside vendor performs the loss of coolant accident analyses using its approved methods. The NMC then verifies that the vendor analysis applies to each reload. This is currently the case for Cycle 24 and is expected to continue to be the case in the future.

17. Power Distribution Control Verification: This verification does not involve an NSSS simulation. Therefore, neither DYNODE nor RETRAN are currently used for this event or planned for future use for this event.

The adequacy of DYNODE and RETRAN-02 for the uses described above was confirmed in the April 11, 1988 safety evaluation (Reference D-1) for Revision 2 to the Kewaunee reload safety evaluation methods topical report. The NRC safety evaluation included the performance of the DYNODE-P and RETRAN-02 codes, stating, "DYNODE-P and TOODEE2 have been approved (Ref. 1) for the reload safety evaluation of the Prairie Island Units 1 and 2, plants similar to Kewaunee. RETRAN-02 is a derivative of RELAP, and both codes have been extensively used to provide best estimate as well as conservative analyses of the transients under consideration. The staff utilized RETRAN-02 to qualify DYNODE-P for the reload safety evaluation of the Prairie Island Units (Ref. 1)."

The transients under consideration in the current submittal are the same as those considered in Revision 2 to the Kewaunee RSE methods topical report. Therefore, both DYNODE and RETRAN-02 continue to be adequate for the uses described above. Meeting the conditions required to use RETRAN-3D in 2D mode ensures that RETRAN-3D used in 2D mode is adequate for the transients under consideration.

<u>References</u>:

Reference D-1: "Wisconsin Public Service Corporation "Reload Safety Evaluation Methods for Application to Kewaunee" (TAC No. 65155), NRC letter from Joseph G. Giitter to D.C. Hintz, dated April 11, 1988. (Docket No. 50-305)

ATTACHMENT 2

Letter from M. E. Reddemann (NMC)

To

Document Control Desk (NRC)

Dated

March 7, 2001

KNPP WPSRSEM-NP, Revision 3

NMC Response

To

NRC Request for Additional Information
Dated February 1, 2001

1. **The response to RAI A.3 states that "This model limits time step size to a small multiple of the Courant limit. A careful review of the CVCS malfunction accident indicates an acceptable boron transport model....". Clarify whether the Courant limit is exceeded or not in selecting the time step size for the CVCS malfunction analysis. Expand the discussion to include acceptance criteria and rationale for drawing the conclusion claiming that the boron transport model is acceptable.**

NMC Response

The text of the response to RAI A.3 is as follows: "NMC Response: NMC Response: The Chemical Volume and Control (CVCS) Malfunction accident model is the only KNPP R3D model that explicitly treats boron transport and/or dilution. All KNPP R3D models employ the automatic time-step selection model. This model limits time step size to a small multiple of the Courant limit. A careful review of the CVCS Malfunction accident indicates an acceptable boron transport model. If the boron transport model is used for other applications in the future, such as steam line break, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied."

In the KNPP R3D CVCS Malfunction accident model the "small multiple" factor used is the recommended (R3D code default) value of 5. The R3D iterative numerics Courant time-step limit (i.e., $C_2 * M_j/|W_j|$, $C_2 = 5$) will never be exceeded for any time step due to R3D code logic. Additionally, based on a review of the KNPP R3D CVCS Malfunction analysis output, the Courant limit proper (i.e., $C_2 * M_j/|W_j|$, $C_2 = 1$) is not exceeded for any time-step of the CVCS Malfunction accident analyses.

Ensuring that the Courant limit is not exceeded for any time ensures that numerical instabilities are not introduced. However, if the time step size is significantly smaller than the Courant limit, significant artificial damping and significant increased downstream propagation can result, yielding inaccurate boron transport model behavior. A comparison of the RETRAN-3D in a RETRAN-02 mode CVCS Malfunction accident results to the DYNODE-P CVCS Malfunction accident results shows that this is not the case.

The acceptability of the boron transport model is demonstrated by a comparison of the transient results of the CVCS Malfunction accident analyzed with RETRAN-3D in a RETRAN-02 mode to the results obtained with DYNODE-P as documented in the DYNODE-P to R3D benchmark report (Ref. C1-1). The benchmark report shows that the important transient parameters, reactor power, reactor coolant system (RCS) average temperature, and core average heat flux that are not USAR acceptance criteria parameters are within the applicable review criteria for the benchmark. In addition, the USAR acceptance criteria parameters all meet the applicable benchmark review criteria.

Furthermore, the core average boron concentration and reactivity insertion due to boron dilution calculated by R3D trend similarly to the values calculated by DYNODE-P. Up to the time of the reactor trip, the R3D to DYNODE-P difference in core boron concentration is less than 3 ppm. The reactivity insertion due to the boron dilution calculated by R3D also trends similarly to DYNODE-P up until the time of the reactor trip, at which point the differences are due to the non-coincident trip times. The R3D to DYNODE-P reactivity insertion differences are consistent with the observed core

average boron concentration differences. Therefore, the R3D and DYNODE-P models both alter the core average boron concentration in a similar manner, with respect to magnitude and rate of change, and the respective core average boron concentration changes result in a similar reactivity change for the two models.

In conclusion, the generally well-behaved character of the R3D numerical results, the physical reasonableness of the R3D transient results and the acceptable comparisons to DYNODE-P results indicate that the KNPP R3D CVCS Malfunction accident model including the boron transport model is acceptable.

References:

Reference C1-1: Voskuil, J.L., Wanner, D.J., "Kewaunee Nuclear Power Plant Revised DYNODE-P RETRAN-3D Benchmark," Prepared 02-21-2001, Reviewed 02-22-2001.

2. **The response to RAI A.24 states that "The KNPP R3D bubble rise models are justified implicitly in the R3D to DYNODE-P benchmark...." You are requested to identify the applicable examples included in Reference A.1 and discuss the R3D and DYNODE-P comparisons to address the acceptability of the bubble rise model used in the KNPP R3D code.**

NMC Response

The text of the response to RAI A.24 is as follows: "NMC Response: The KNPP R3D bubble rise models are justified implicitly in the R3D to DYNODE-P benchmark (Reference A-1). No slip models are used in the KNPP R3D models so there is no inconsistency with other junctions. If any R3D slip options are used in the future, the applicable conditions pertaining to R3D will be satisfied. Therefore, this condition is satisfied."

All of the R3D Benchmark report (Ref. C2-1) events are examples that demonstrate the validity of the R3D bubble rise model since all of the events analyzed in the benchmark report include a bubble rise model in both R3D and DYNODE-P. Phenomena affected by the bubble rise model include the steam generator level and steam dome pressure response, the main steam line flow and pressure response, the steam generator mass and energy throughout the event, and the primary to secondary heat transfer throughout the event. The benchmark report parameters that can be compared to ensure that these phenomena are being modeled acceptably are the steam generator level, the main steam line pressure, the main steam flow, the reactor coolant system temperature and pressure, core delta-T, and the power. As shown in the benchmark report there is acceptable agreement between R3D and DYNODE-P for these parameters.

The R3D and DYNODE-P bubble rise model input parameters can be summarized as follows. The bubble gradient parameter, alpha, (which determines the slope of the vapor density gradient in the liquid region) can range from 0.0 to 1.0. An alpha value of 0.0 implies a homogeneous bubble density; an alpha of 1.0 implies a maximum bubble density gradient from the bottom of the control volume to the mixture level. A typical value is 0.8. The bubble rise velocity parameter, Vbub

(which determines the rate of separation of the vapor phase from the liquid phase at the liquid-vapor interface) can range from 0 ft/s to +infinity ft/s. A Vbub value of 0 ft/s implies no vapor separation, Vbub values greater than 0 ft/s and less than 3 ft/s imply a separation rate due to bubble buoyancy, and Vbub values greater than about 15 ft/s imply more or less complete separation.

A value for alpha is input to both DYNODE-P and R3D. DYNODE-P uses the user specified input value of alpha directly, which for the KNPP DYNODE-P models is 0.8. R3D will use the user specified input value of alpha unless the steady-state initialization requires an adjustment. For the KNPP R3D models, the user specified input alpha value of 0.8 is adjusted by the R3D code during the steady-state initialization to values falling in the range of 0.5 to 1.0. However, as mentioned above, the parameters affected by the bubble rise model continue to show acceptable agreement between DYNODE-P and R3D.

Both R3D and DYNODE-P calculate the Vbub parameter. Vbub values calculated by the KNPP DYNODE-P models range from 0 to 14 ft/s. The Vbub parameters calculated by R3D for the KNPP models range from 3 ft/s to 21 ft/s. Once again, as mentioned above, the parameters affected by the bubble rise model continue to show acceptable agreement between DYNODE-P and R3D.

Since the R3D and DYNODE-P bubble rise parameters used in the KNPP models fall within similar ranges and since the results influenced by the bubble rise model show acceptable agreement between R3D and DYNODE-P for the events in the benchmark report, the R3D bubble rise model is acceptable.

References:

Reference C2-1: Voskuil, J.L., Wanner D.J., "Kewaunee Nuclear Power Plant Revised DYNODE-P RETRAN-3D Benchmark," Prepared 02-21-2001, Reviewed 02-22-2001.

3. The response to RAI A.29 states that "All KNPP R3D base models undergo null-transient analysis..... The adjustments are within acceptable ranges...." Discuss the acceptable ranges and address the acceptability of the acceptable ranges for the null-transient analysis using KNPP R3D.

NMC Response

The text of the response to RAI A.29 is as follows: "NMC Response: All KNPP R3D base models undergo null-transient analysis. In the KNPP R3D models, the steam generator heat transfer area and the feedwater inlet enthalpy are adjusted by the steady-state initialization process. The adjustments are within acceptable ranges based on RETRAN-3D training session guidance and engineering judgement. Therefore this condition is satisfied."

The steady-state initialization process utilized by the KNPP R3D models performs an adjustment to the input steam generator feedwater inlet enthalpy and the input heat transfer areas of the steam generator conductors in order to obtain an overall primary-to-secondary energy balance.

Since the steam dome enthalpy is established by the steam dome pressure, R3D adjusts the user input steam generator feedwater enthalpy as part of the overall primary-to-secondary energy balance. Regardless of the size of the adjustment, the final adjusted steam generator feedwater enthalpy should compare reasonably to plant data. The adjustment to the input steam generator feedwater inlet enthalpies for the full power KNPP R3D models intended for use in KNPP licensing analyses range from +0.5% to +0.9%. The adjustments for the part power R3D models intended for use in KNPP licensing analysis are larger, since the full power input steam generator feedwater enthalpy was retained in the R3D input. However, in all cases, the adjusted steam generator feedwater inlet enthalpies for the KNPP R3D models are within ±2% of plant data, which is judged to be acceptable based on engineering judgement.

The adjustment to the steam generator heat transfer areas for the models intended for use in KNPP licensing analyses range from -0.9% to +5.5%. These adjustments are within the recommended acceptable range of ±10% (Ref. C3-1, Page IX-69), and are therefore judged to be acceptable.

References:

Reference C3-1: "RETRAN-3D – A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems," NP-7450, Research Project 889-10 Computer Code Manuals, December 1997 (Volume 1: Theory and Numerics Manual, Revision 2).

4. **The response to last item in the RAI states that "...for cycles beyond Cycle 25, "RETRAN" means either of the following:**

   - **The use of RETRAN-3D in 2D mode...; or**
   - **The use of RETRAN-3D in other than 2D mode...."**

   The staff notes that in a letter dated October 12, 2000, the licensee originally requested for the staff to review and approve only the use of RETRAN-3D in 2D mode for licensing applications. The staff also finds that all the licensee's submittals are intended to use in support of the original request. Accordingly, the staff will limit its review to evaluate the acceptability of the use of RETRAN-3D in 2D mode as the licensee originally requested. If the licensee is requesting for review of the use of RETRAN-3D in other than 2D mode, the licensee should state its request in a written letter and provide a submittal addressing the restrictions and limitations for the use of RETRAN-3D as specified in all the items of RAI A.

NMC Response

The entire RAI text of the second bullet item shown in the comment reads:

- The use of RETRAN-3D in other than 2D mode supported by a submittal.

The words "supported by a submittal" refer to a future submittal other than that of the October 12, 2000 letter. The licensee agrees that, with respect to RETRAN, the letter dated October 12, 2000,

requested the staff to review and approve only the use of RETRAN-3D in 2D mode (RETRAN-02 mode) for licensing applications. The licensee is not requesting review for the use of RETRAN-3D in other than 2D mode in the letter dated October 12, 2000.

Any use of RETRAN-3D in other than 2D mode for licensing applications for any Kewaunee cycle, including those beyond Cycle 25, will be supported by separate future licensee interaction with the NRC. This interaction could be a separate licensee submittal, a separate licensee notification based on a future approved RETRAN-3D in other than 2D mode submittal in accordance with Supplement 1 to Generic Letter 83-11, or other means acceptable to the NRC at the time.

ATTACHMENT 3

Letter from M. E. Reddemann (NMC)

To

Document Control Desk (NRC)

Dated

March 7, 2001

Explanation of Changes caused by Benchmark Rerun.

Reference 4 provided the original NMC responses to NRC Request for Additional Information (RAI) questions A, B, C, and D and 1, 2, 3, and 4. Questions A through D were from a January 23, 2001 RAI (reference 2) and Questions 1 through 4 were from a February 1, 2001 RAI reference 3). A discussion of the effect of the revised benchmark on the Reference 4 responses follows.

RAI question A is concerned with NRC staff condition limitations placed on the use of RETRAN-3D. Although the NMC response to RAI question A mentions the original benchmark report in several places, it is referred to only with respect to the general form and main conclusions of the report. Since the general form and the main conclusions of the original benchmark report are unchanged in the revised benchmark report, the statements made in the response to RAI question A regarding the DYNODE to RETRAN benchmark report remain valid as originally stated. Therefore, the revised benchmark report does not require any changes to be made to the RAI question A portion of Reference 4 beyond recognizing that the benchmark report referred to is now the revised benchmark report instead of the original benchmark report .

RAI question B is concerned with the use of RETRAN-3D in the RETRAN-02 mode. The NMC response to question B does not mention the DYNODE to RETRAN benchmark. It does refer to part 18 of the RAI question A response, which did mention the DYNODE to RETRAN benchmark in a general sense. However, as discussed above, the revised benchmark report does not require any changes to be made to the RAI question A portion of Reference 4 beyond recognizing that the benchmark report referred to is now the revised benchmark report instead of the original benchmark report. Therefore, the revised benchmark report does not require any changes to be made to the RAI question B portion of Reference 4.

RAI question C is concerned with the review criteria established by NMC for the DYNODE to RETRAN benchmark report. The original DYNODE to RETRAN benchmark report is mentioned throughout the RAI question C response. The benchmark report is often mentioned in a general sense. In these cases, since the general form and the main conclusions of the original benchmark report are unchanged in the revised benchmark report, the statements made concerning the DYNODE to RETRAN benchmark report remain valid as originally stated with the understanding that the benchmark report referred to is now the revised benchmark.

However, there are several instances where details of the original benchmark report that have been affected by the revised benchmark were included in the NMC RAI question C response. These are discussed in detail as follows:

> In the <u>Acceptance Criteria Used In Benchmark Comparisons</u> section, the last two sentences of the third paragraph (Attachment 1, page 16 of Reference 4) read: "For example, the first paragraph on Page III.2-1 of the benchmark report explains why the RETRAN case trips earlier than the DYNODE case for the CVCS malfunction dilution at power. The explanation provides the reason why the Figure 2-1 fraction of reactor power in DYNODE at 80 seconds is still greater than 1.0, while the RETRAN fraction of reactor power has already decreased to less than 0.25." The reason for the large discrepancy in reactor power for a certain period of time late in the event is still valid. However, not

using the optional gap linear thermal expansion model in the revised benchmark case causes the RETRAN T_{ave} to rise slightly more slowly than the DYNODE T_{ave} instead of slightly faster as had been the case in the original benchmark report. Therefore, the RETRAN trip occurs slightly later than in the original benchmark report RETRAN case, and occurs closer to, but slightly later than, the DYNODE case instead of somewhat before it. Therefore, the last two sentences of the third paragraph of the Acceptance Criteria Used In Benchmark Comparisons section should be revised to read: "For example, the first paragraph on Page III.2-1 of the benchmark report explains why the RETRAN case trips later than the DYNODE case for the CVCS malfunction dilution at power. The explanation provides the reason why the Figure 2-1 fraction of reactor power in RETRAN at 88 seconds is still greater than 1.0, while the DYNODE fraction of reactor power has already decreased to less than 0.25."

In the Quantitative Review Criteria Values section, the last three sentences of the fourth (second-to-last) paragraph (Attachment 1, page 17 of Reference 4) read: "The Uncontrolled Rod Withdrawal, Fast Rate, Intermediate Power is the only benchmark report event for which the MDNBR review criterion is exceeded. An explanation for the review criterion being exceeded is provided in Section 8 (Page III.8-1) of the benchmark report. All other benchmark report events are well within the NDNBR review criterion of 0.14, and would have met an MDNBR review criterion as low as 0.06." In the revised benchmark report the Uncontrolled Rod Withdrawal, Fast Rate, Intermediate Power meets the MDNBR review criterion. This is because the revised RETRAN benchmark case trip time is now closer to the DYNODE case trip time than it was in the original benchmark report. All of the events considered in the benchmark meet the MDNBR review criterion of 0.14 in the revised benchmark report, and would have met an MDNBR review criterion as low as 0.06. Therefore, the first two of the last three sentences of the fourth (second-to-last) paragraph should be removed and the last sentence should be changed to read: "All of the benchmark report events are well within the MDNBR review criterion of 0.14, and would have met an MDNBR review criterion as low as 0.06."

With the above changes taken into consideration and considering that the general form and the main conclusions of the original benchmark report are unchanged in the revised benchmark report, the statements made in the RAI question C response concerning the DYNODE to RETRAN benchmark report remain valid as originally stated. This is with the understanding that the benchmark report referred to is now the revised benchmark report instead of the original benchmark report .

RAI question D is concerned with identifying accidents that are to be analyzed with DYNODE and with RETRAN in the future. The NMC response to RAI question D does not mention the original DYNODE to RETRAN benchmark report. Therefore, the presence of the revised benchmark report does not require any changes to be made to the RAI question D portion of Reference 4.

However, there is one clarification that the NMC wishes to make regarding the Reference 4 response to RAI question D (Attachment 1 page 20, question 14). Since DYNODE and RETRAN are mainly used as NSSS simulation codes, and since DYNODE can not be used to calculate entrainment, the NMC response to RAI question D was answered with respect to the use of DYNODE and RETRAN as NSSS simulation codes. However, there is one other use of RETRAN for the Chapter 14 events discussed in WPSRSEM-NP, Revision 3. RETRAN is used to calculate entrainment for the main steam line break accident. Since DYNODE can not be used for calculating entrainment, entrainment was not considered in the DYNODE to RETRAN benchmark. In addition, the RETRAN model used to calculate entrainment does not include a core model, so the optional gap linear thermal expansion model is not used in the RETRAN entrainment calculations, which also meet all other applicable restrictions for the use of RETRAN-3D in RETRAN-02 mode.

RAI question 1 is concerned with the RETRAN-3D boron transport model. The original DYNODE to RETRAN benchmark report is mentioned throughout the NMC response to support the conclusion that the KNPP RETRAN-3D boron transport model in CVCS malfunction event is acceptable. A review of the revised benchmark CVCS malfunction results show that, with one exception, the statements made with respect to the original benchmark report remain valid based on the revised benchmark report. In particular, the pre-trip 3-ppm agreement in core boron concentration between DYNODE and RETRAN observed in the original benchmark report is also observed in the revised benchmark results. The one exception is related to the main steam system pressure (Attachment 2, page 1). The last two sentences of the fourth paragraph of the Reference 4 NMC response read: "In addition, the USAR acceptance criteria parameters all meet the applicable benchmark review criteria, with the exception of the main steam system pressure. The main steam system pressure result is explained in section 8 of the benchmark report." In the revised benchmark report, the main steam system pressure criterion is met due to the fact that the revised benchmark RETRAN trip time is closer to the DYNODE trip time than had been the case in the original benchmark. Therefore, the two sentences quoted above should be changed to read:. "In addition, the USAR acceptance criteria parameters all meet the applicable benchmark review criteria." As was the case with other Reference 4 responses, it must be recognized that the benchmark report referred to in the RAI question 1 response is now the revised benchmark report instead of the original benchmark report.

RAI question 2 is concerned with the RETRAN-3D bubble rise model. The DYNODE to RETRAN benchmark report is mentioned throughout the NMC response to support the conclusion that the KNPP RETRAN-3D bubble rise model is acceptable. A review of the revised benchmark results show that the statements made with respect to the original benchmark report remain valid based on the revised benchmark report. In particular, the ranges of values for parameters alpha and Vbub observed in the original RETRAN benchmark cases remain the same in revised benchmark report. Therefore, the presence of the revised benchmark report does not require any changes to be made to the RAI question 2 portion of Reference 4 beyond recognizing that the benchmark report referred to is now the revised benchmark report instead of the original benchmark report (Reference 4).

RAI question 3 is concerned with RETRAN-3D steady state initialization adjustments. The NMC response to RAI question 3 does not mention the original DYNODE to RETRAN benchmark report. A review of the revised benchmark results shows that the steady state initialization adjustments continue to fall within the ranges discussed in the original response to RAI question 3. Therefore, the presence of the revised benchmark report does not require any changes to be made to the RAI question 3 portion of Reference 4.

RAI question 4 is concerned with use of RETRAN-3D in other than RETRAN-02 mode. The NMC response to RAI question 4 does not mention the DYNODE to RETRAN benchmark report. Therefore, the presence of the revised benchmark report does not require any changes to be made to the RAI question 4 portion of Reference 4.

ATTACHMENT 4

Letter from M. E. Reddemann (NMC)

To

Document Control Desk (NRC)

Dated

March 7, 2001

Revised DYNODE to RETRAN Benchmark Report

Kewaunee Nuclear Power Plant

Revised
DYNODE-P RETRAN-3D Benchmark

Prepared by J. L. Voskuil Date 2-21-2001

Reviewed by D. J. Wanner Date 2-21-2001

I. Introduction

Note: The revised benchmark report supercedes the original benchmark report dated 06-12-2000 (prepared) and 06-14-2000 (reviewed). All of the original RETRAN-3D computer code results are superceded by the revised results which include the constant gap conductance model and upon which the revised benchmark report is based.

DYNODE-P has been the primary Nuclear Steam Supply System (NSSS) analysis computer code in the Kewaunee Nuclear Power Plant (KNPP) safety analysis methodology since the decision was made in 1978 to independently perform Kewaunee plant transient and accident analyses. At that time the DYNODE-P code was benchmarked to the design basis transient analysis results in Chapter 14 of the KNPP Final Safety Analysis Report to demonstrate the safety analysis capability and knowledge base of Wisconsin Public Service Corporation (WPSC) (Ref. 1). The DYNODE-P code has been used since 1979 to address plant operating, licensing, and design change issues and to support the reload core design and safety evaluation.

In the mid-1980's RETRAN was fast becoming the industry standard for transient and accident analysis, leading WPSC to adopt it as a second system analysis code. RETRAN was included in Revision 2 to the reload safety evaluation methods topical report (Ref. 2) to complement the DYNODE-P analyses and to provide independent verification of the DYNODE-P calculations. As RETRAN has continued to develop and improve, it is now beneficial to shift some or all of the system analyses from DYNODE-P to RETRAN. Having both codes operational through the years has provided analysis diversity and enabled the DYNODE-P to RETRAN-3D change to be made at the most appropriate time.

The need for safety analyses to support the steam generator replacement (SGR) project provides an excellent opportunity to make the change in computer codes. The KNPP steam generators are to be replaced in the fall of 2001 with most safety analyses being completed in 2000. All of the design basis transients need to be reanalyzed for the SGR project. WPSC (NMC) also has access to detailed design and thermal hydraulic information for the steam generator replacement components, which facilitated the RETRAN-3D steam generator modeling. In addition, RETRAN-3D has a utility submittal for generic review by the Nuclear Regulatory Commission and offers the potential for improved analytical sophistication, e.g. the 3D core model.

WPSC (NMC) has built up considerable knowledge and experience with RETRAN-3D both with conservative safety analysis calculations and with best-estimate plant response calculations. RETRAN-3D design inputs for the Updated Safety Analysis Report (USAR) (Ref. 3) Chapter 14 non-LOCA design basis transient events have also been developed.

This report documents the comparisons between the DYNODE-P and RETRAN-3D computer codes for the KNPP non-LOCA design basis accidents with the existing steam generators. It supports the change process for analysis methods that are being used for the SGR project. It also supports the WPSC (NMC) topical report on reload safety evaluation methods (Ref. 4) which has been revised to document, among other things, the RETRAN-3D methods and representative results.

DYNODE-P, currently the code used for the analysis of record, is considered the standard and RETRAN-3D is benchmarked to it. The approach of this benchmark is to create RETRAN-3D models that resemble as closely as possible the DYNODE-P models with respect to both basic input (geometry, power level, fluid conditions, etc.) and sub-system models (charging/letdown, SG, etc.). As a result, primarily code calculational differences are compared rather than code modeling capabilities. For example, even though RETRAN-3D can provide a more general model of charging/letdown operation, the RETRAN-3D model used is a less general one that more closely emulates the DYNODE-P model. This approach best assesses the calculational differences between the two codes and minimizes the differences due to DYNODE-P limitations.

Each non-LOCA USAR Chapter 14 design basis accident has the DYNODE-P and RETRAN-3D calculated parameters of interest compared. The review criteria (see below) for the comparison are established a priori and provide a threshold beyond which a more detailed review and explanation of the results is required. The benchmark enables WPSC (NMC) to draw conclusions on the acceptability of the RETRAN-3D code for application to KNPP design basis transient analyses.

This report is arranged by USAR Chapter 14 section. No RETRAN-3D NSSS model exists for the following accidents:

- Uncontrolled Rod Withdrawal from a Subcritical Condition
- Startup of an Inactive Loop
- Anticipated Transient Without SCRAM.
- Main Steam Line Break
- RCCA Ejection

These accidents, at the present time are still run with DYNODE-P as the NSSS simulator. A conversion to RETRAN-3D will be accomplished at a later date.

II. Methodology and Acceptance Criteria

DYNODE-P inputs to the design basis accidents of Chapter 14 of the USAR are well understood and well documented. The plant safety analyses (PSA) of the non-LOCA transients were performed with DYNODE-P in 1998 to support the implementation of the Siemens Power Corp. heavy fuel design and the increased steam generator tube plugging to a 30 % level. These 1998 safety analyses are the basis for the current analyses of record for the non-LOCA transients and are documented in the KNPP USAR. Detailed inputs for these analyses are documented in the PSA DYNODE-P case setup guides (Ref. 5) and are controlled on the WPSC (NMC) computer system. Results of the DYNODE-P analyses to which the RETRAN-3D results are benchmarked are documented in the USAR and the PSA 1998 notebook (Ref 6). All case outputs are on microfiche.

For the purpose of benchmarking the DYNODE-P and RETRAN-3D computer codes, the inputs to the two codes are set as close to the same as possible. RETRAN-3D base case and transient case input are developed using the DYNODE-P base case and transient case inputs as documented in the case setup guides. The benchmark strategy is to compare the codes with the same inputs so that only the software computational differences are present.

The following review criteria are used for the comparison.

1. General trends in parameters plotted in the USAR shall be consistent.
2. 5% of nominal for normalized power, flow or heat flux, 5% of full span for levels, 5% of total volume for volumes, 50 Psi for pressures, and 5 °F for temperatures for parameters plotted in the USAR that are not USAR acceptance criteria.
3. 30 Psi for steam generator or pressurizer pressure, 0.14 for MDNBR, 4 °F for peak clad temperature for parameters that are USAR acceptance criteria.

Any difference of greater than these review criteria shall be explainable in terms of code modeling assumptions.

Sections III.1 through III.7 address review criteria 1 and 2. Review criteria 3 is addressed in Section III.8.

III. Results

1. Uncontrolled Rod Withdrawal at Power

Four cases are run, the fast rate at 100% power, the slow rate at 100% power, the fast rate at 60% power, and the slow rate at 60% power.

Fast Rate 100% Power

Figure 1-1 shows the reactor power versus time. The reactor trip on overpower is 0.13 seconds earlier in DYNODE.

Figure 1-2 shows the pressurizer pressure versus time. The pressures agree to within 50 Psi between the two codes for about the first 15 seconds of the transient. For the remaining 5 seconds, the pressures agree to within 75 Psi and the trends remain qualitatively similar. The result is due to the extra cooldown in DYNODE from the increased feedwater flow relative to RETRAN. Unlike DYNODE, RETRAN does not vary the feedwater flow according to steam generator pressure (see the summary of code differences on page III.8-2).

Figure 1-3 shows T_{ave} versus time. T_{ave} agrees to within 4° F between the two codes.

Figure 1-4 shows the minimum departure from nucleate boiling ratio (MDNBR) versus time. Due to the later reactor trip, the MDNBR reaches a slightly lower value in RETRAN than in DYNODE.

Slow Rate 100% Power

Figure 1-5 shows the reactor power versus time. Power values are quite close.

Figure 1-6 shows the pressurizer pressure versus time. The pressures agree to within 50 Psi until about the last 1-2 seconds of the transient. For the remaining 1-2 seconds the pressures agree to within about 55 Psi and the trends remain qualitatively similar. The result is due to the extra cooldown in DYNODE from the increased feedwater flow relative to RETRAN. Unlike DYNODE, RETRAN does not vary the feedwater flow according to steam generator pressure (see the summary of code differences on page III.8-2).

Figure 1-7 shows T_{ave} versus time. The difference in T_{ave} for the last 1-2 seconds of the transient is explained by the same argument given above for pressurizer pressure.

Figure 1-8 shows the MDNBR versus time. Due to the earlier reactor trip and slightly lower heat flux, the MDNBR does not go as low in RETRAN as in DYNODE.

Fast Rate 60% Power

Figure 1-9 shows the reactor power versus time. The reactor trip on overpower is 0.54 seconds earlier in DYNODE. The difference in reactor trip time explains the power differences in the sense that if the trends were normalized to the same trip time the powers would agree to within the review

criterion of 5%. A similar effect was observed in the Fast Rate 100% Power case but to a lesser degree.

Figure 1-10 shows the pressurizer pressure versus time. A slightly delayed reactor trip in RETRAN allows pressure to peak slightly later.

Figure 1-11 shows T_{ave} versus time. A slightly delayed reactor trip in RETRAN allows T_{ave} to rise to a slightly higher value before turning around due to the reactor trip.

Figure 1-12 shows the minimum departure from nucleate boiling ratio (MDNBR) versus time. Due to the later reactor trip and higher heat flux at the time of trip, the MDNBR reaches a lower value in RETRAN than in DYNODE.

Slow Rate 60% Power

Figure 1-13 shows the reactor power versus time. Power values are quite close before the trip, but DYNODE trips on overtemperature ΔT 46 seconds earlier than RETRAN, due to a faster T_{ave} increase.

Figure 1-14 shows the pressurizer pressure versus time. The pressure increase is faster in DYNODE than in RETRAN due to the faster T_{ave} increase.

Figure 1-15 shows T_{ave} versus time. T_{ave} increases faster in DYNODE than RETRAN because DYNODE models the reduced feedwater flow due to effect of higher steam generator pressures on the pump curve. This phenomenon is not modeled in RETRAN.

Figure 1-16 shows the MDNBR versus time. Due to the lower T_{ave}, the MDNBR does not go as low in RETRAN as in DYNODE.

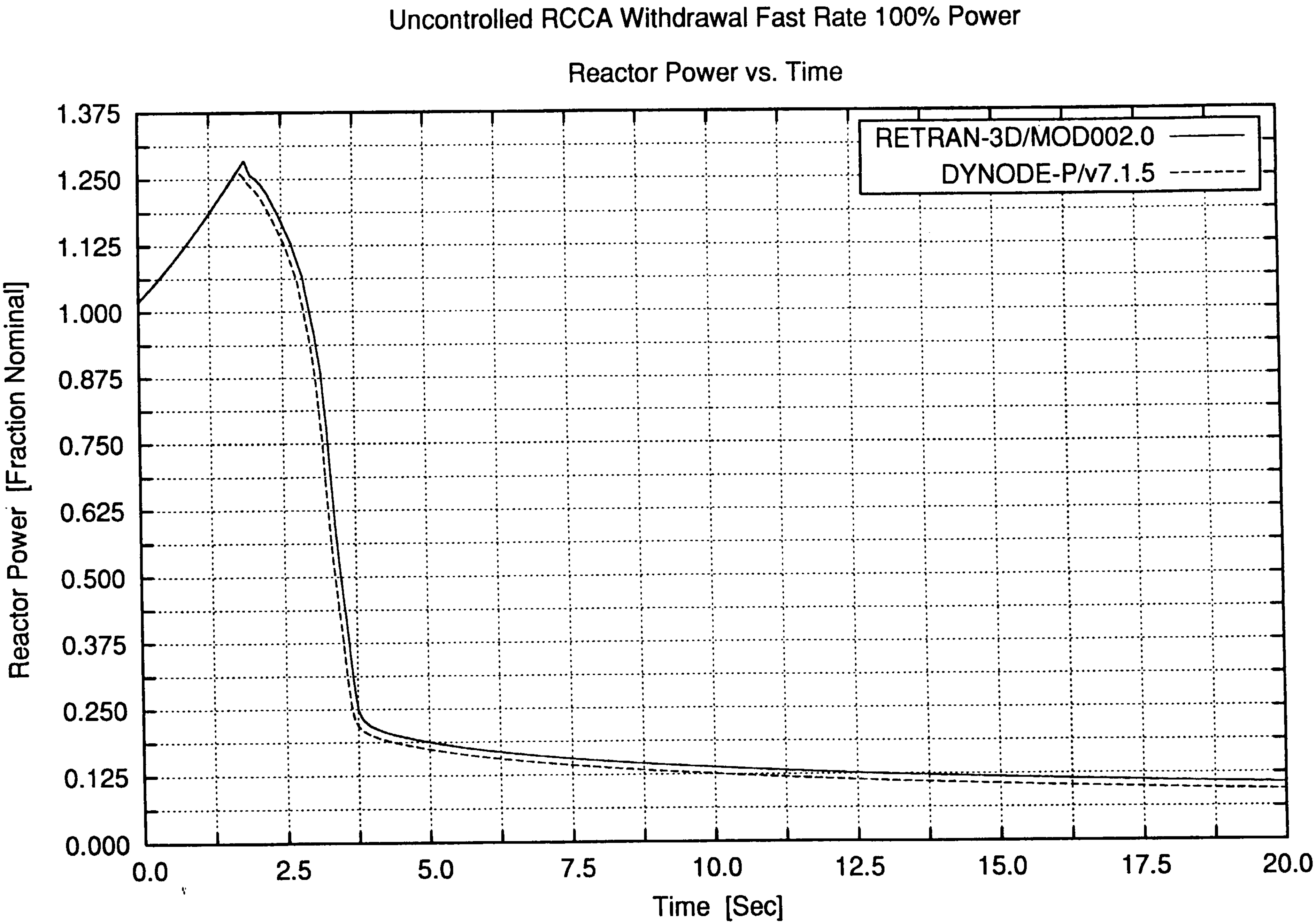

Uncontrolled RCCA Withdrawal Fast Rate 100% Power
Reactor Power vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Reactor Power [Fraction Nominal]
1.375
1.250
1.125
1.000
0.875
0.750
0.625
0.500
0.375
0.250
0.125
0.000
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
Time [Sec]

Figure 1-1

Uncontrolled RCCA Withdrawal Fast Rate 100% Power

Pressurizer Pressure vs. Time

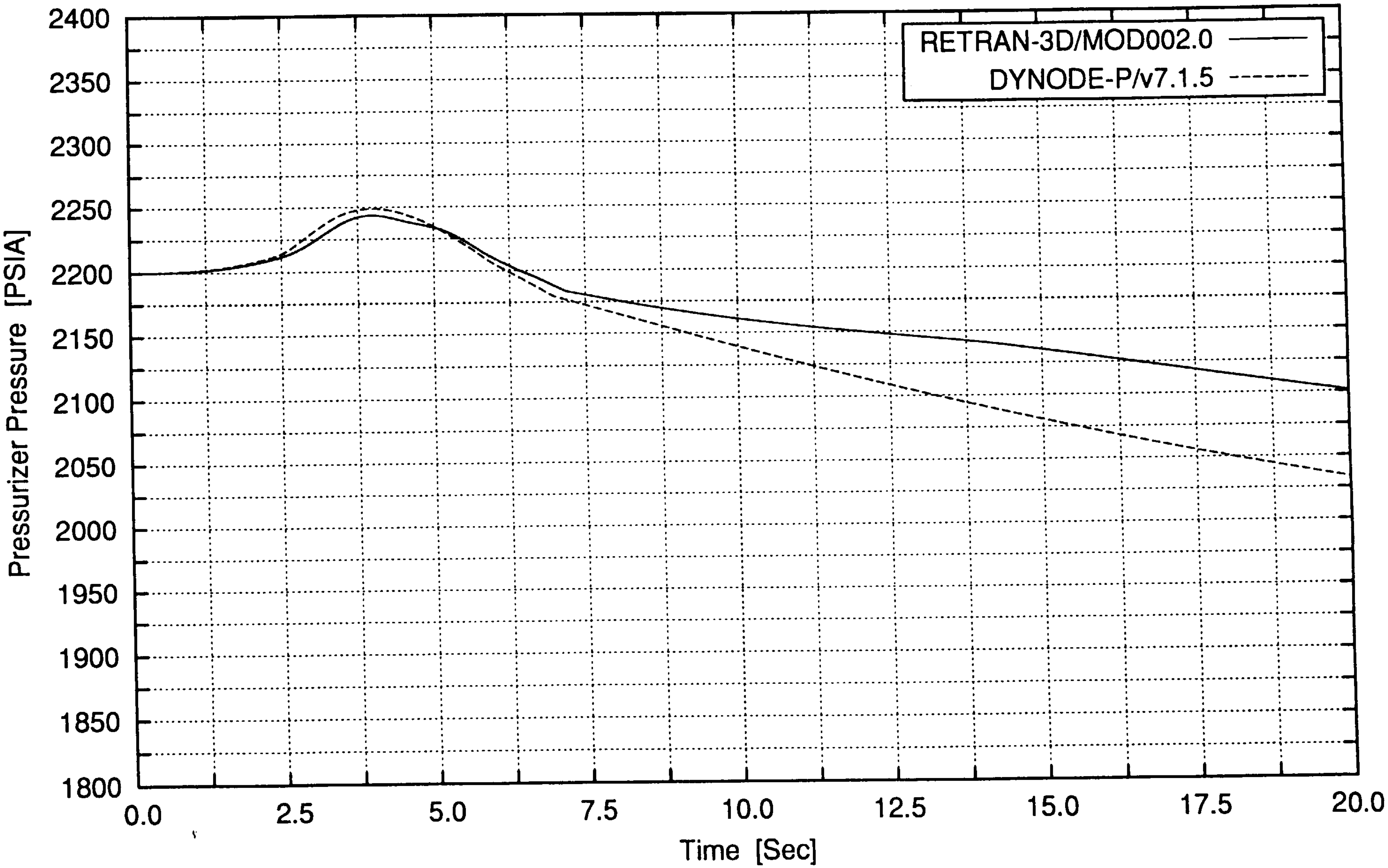


Figure 1-2

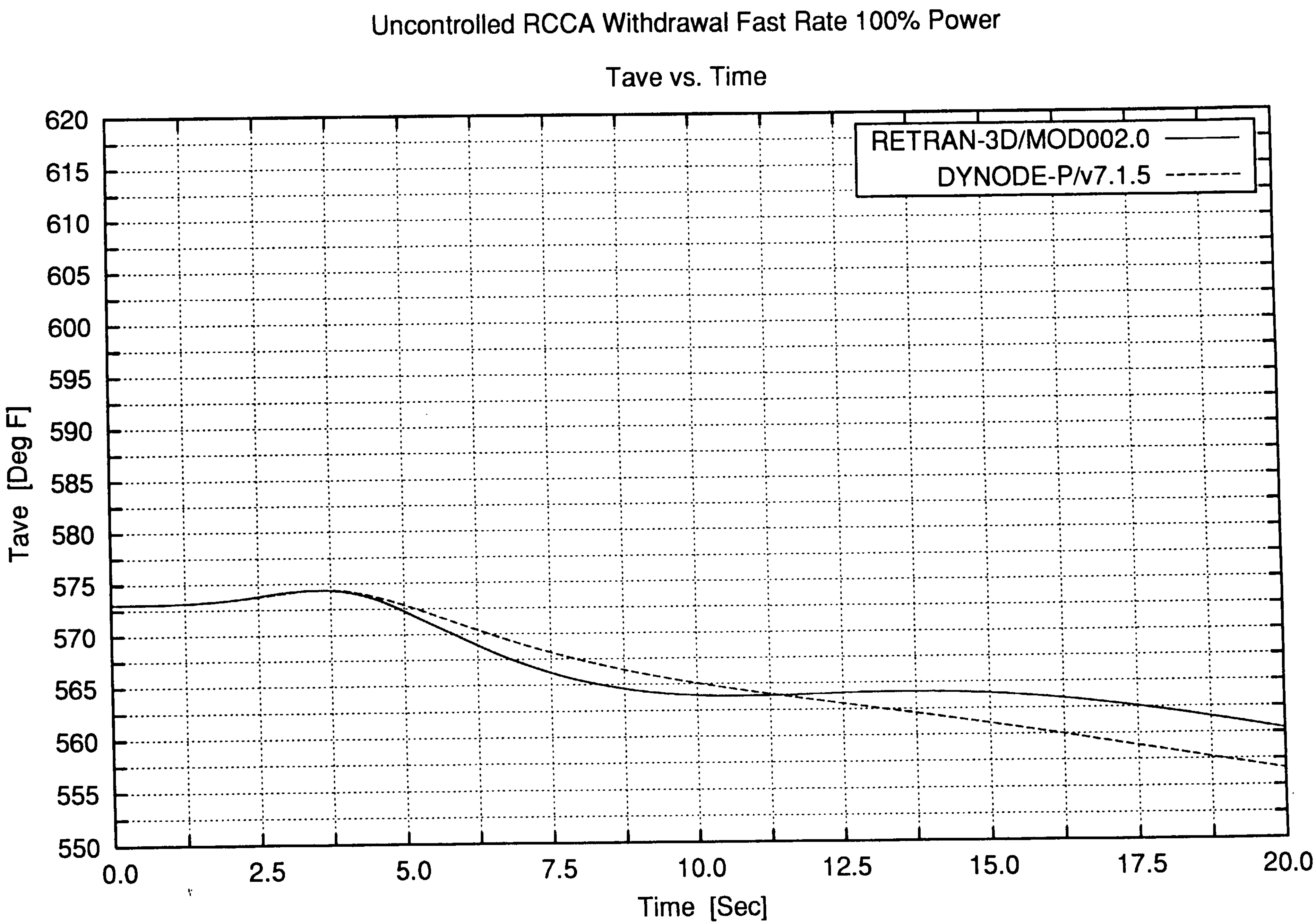

Uncontrolled RCCA Withdrawal Fast Rate 100% Power
Tave vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Tave [Deg F]
620
615
610
605
600
595
590
585
580
575
570
565
560
555
550
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
Time [Sec]

Figure 1-3

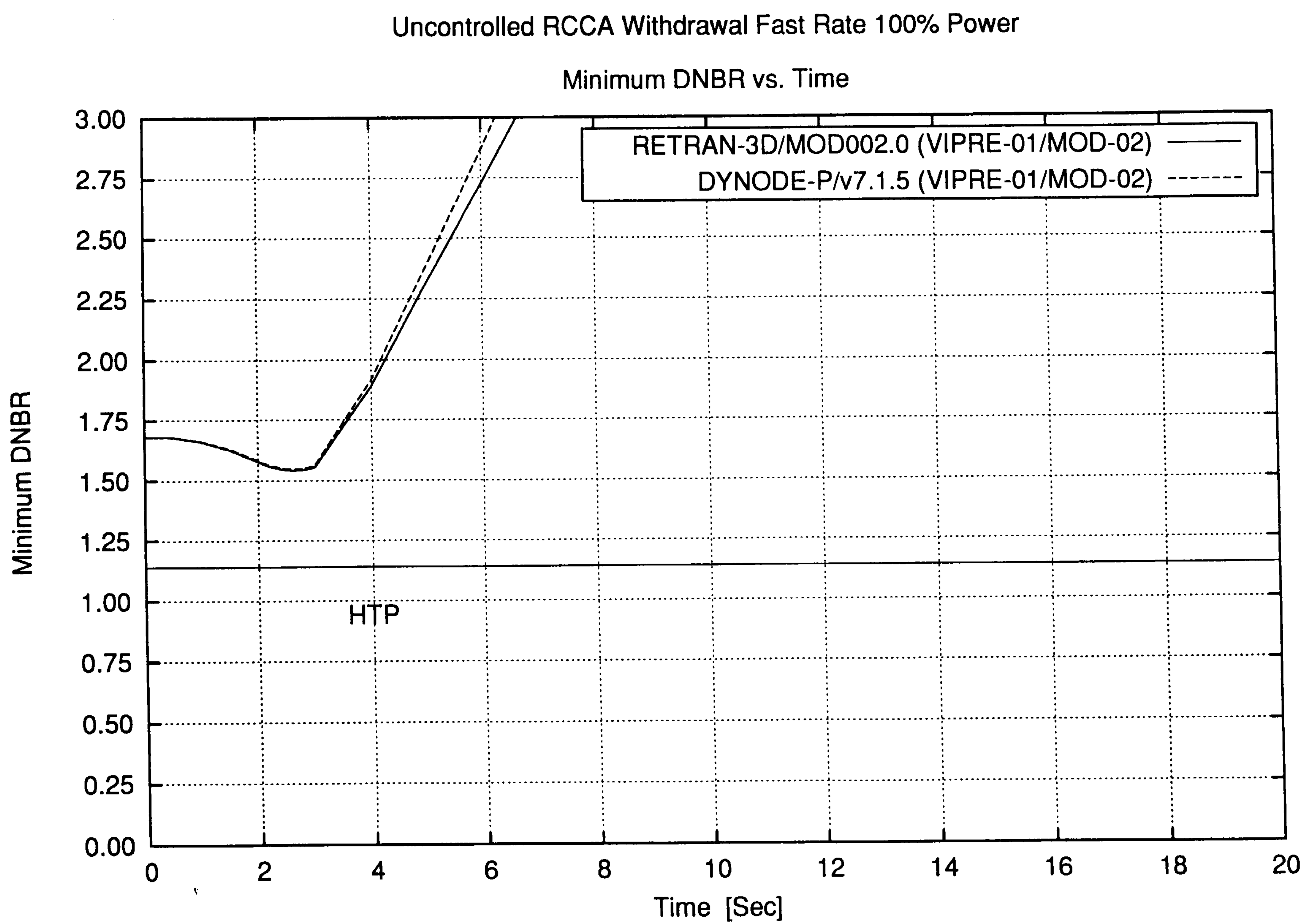
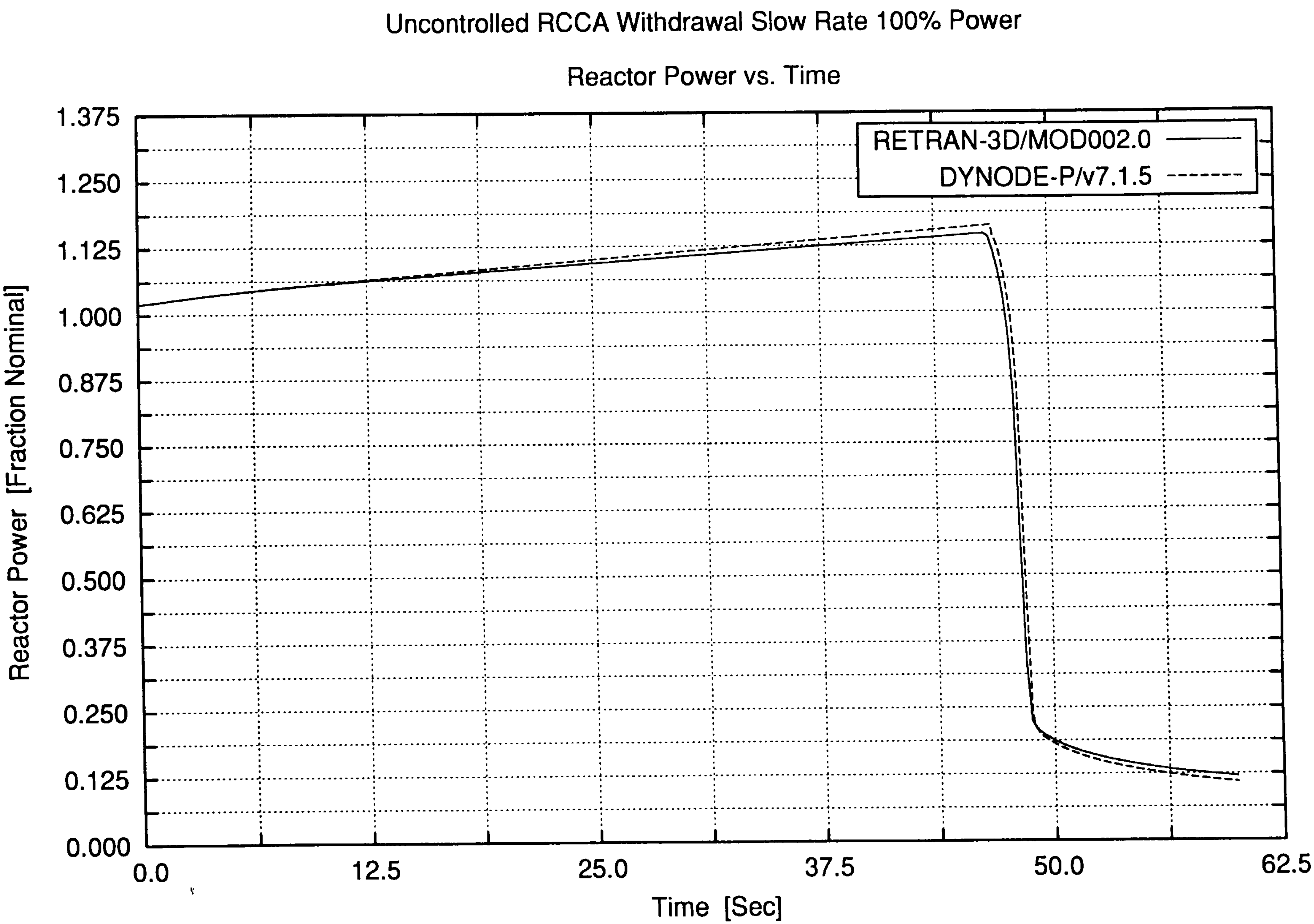
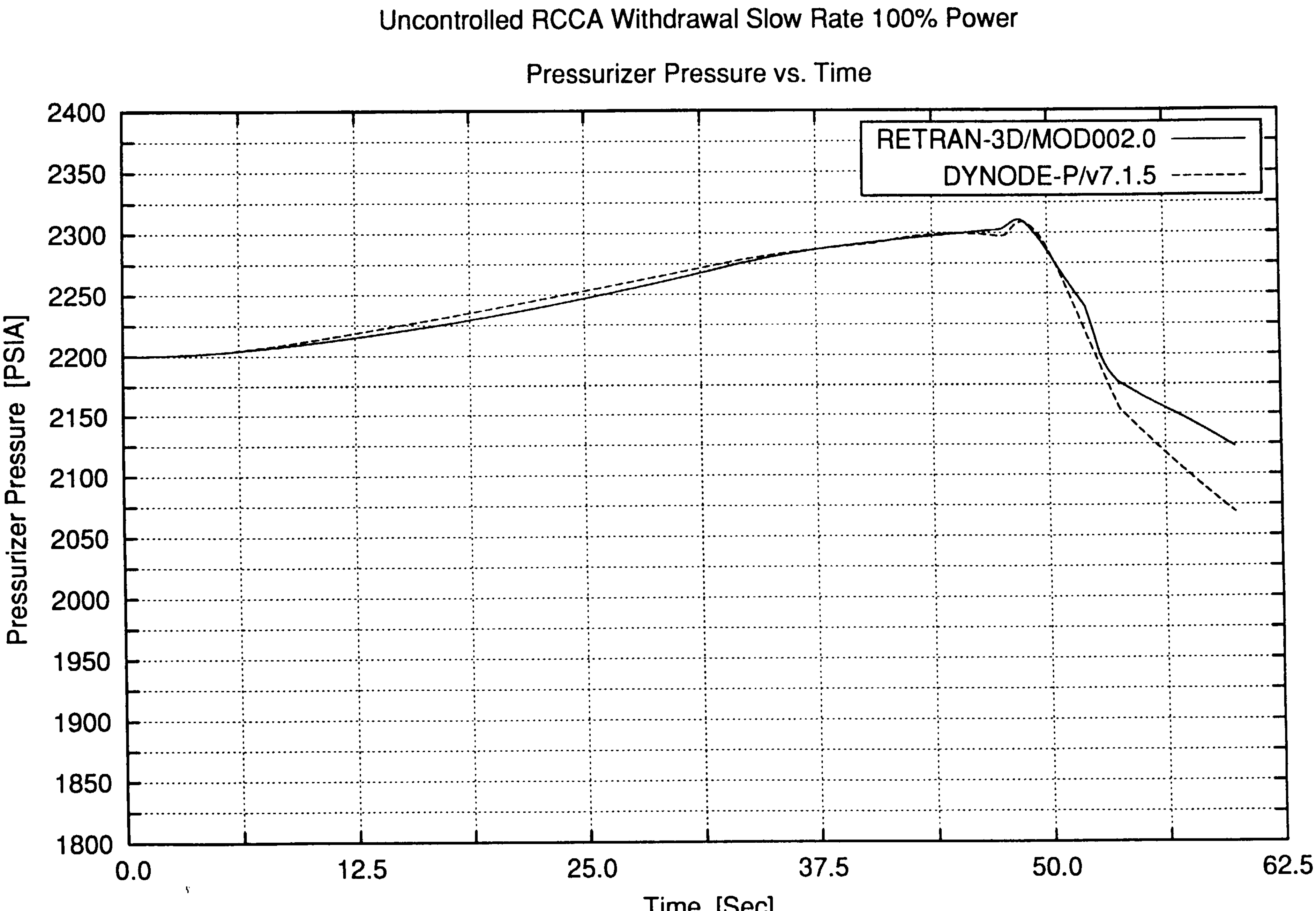

Uncontrolled RCCA Withdrawal Fast Rate 100% Power
Minimum DNBR vs. Time
RETRAN-3D/MOD002.0 (VIPRE-01/MOD-02)
DYNODE-P/v7.1.5 (VIPRE-01/MOD-02)
Minimum DNBR
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
HTP
0
2
4
6
8
10
12
14
16
18
20
Time [Sec]

Figure 1-4



Uncontrolled RCCA Withdrawal Slow Rate 100% Power
Reactor Power vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Reactor Power [Fraction Nominal]
1.375
1.250
1.125
1.000
0.875
0.750
0.625
0.500
0.375
0.250
0.125
0.000
0.0
12.5
25.0
37.5
50.0
62.5
Time [Sec]

Figure 1-5



Uncontrolled RCCA Withdrawal Slow Rate 100% Power
Pressurizer Pressure vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Pressurizer Pressure [PSIA]
2400
2350
2300
2250
2200
2150
2100
2050
2000
1950
1900
1850
1800
0.0
12.5
25.0
37.5
50.0
62.5
Time [Sec]

Figure 1-6

Uncontrolled RCCA Withdrawal Slow Rate 100% Power

Tave vs. Time

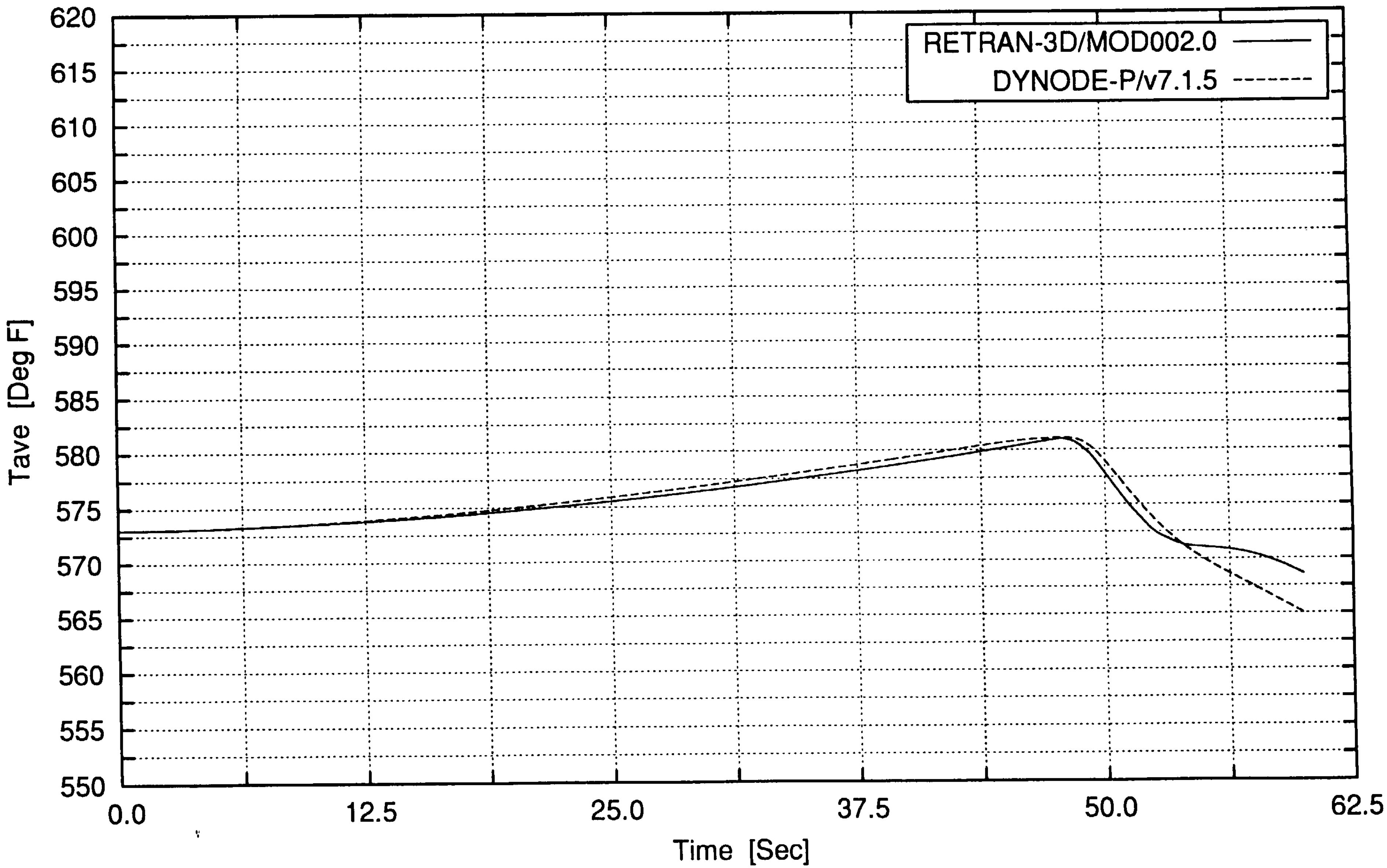


Figure 1-7

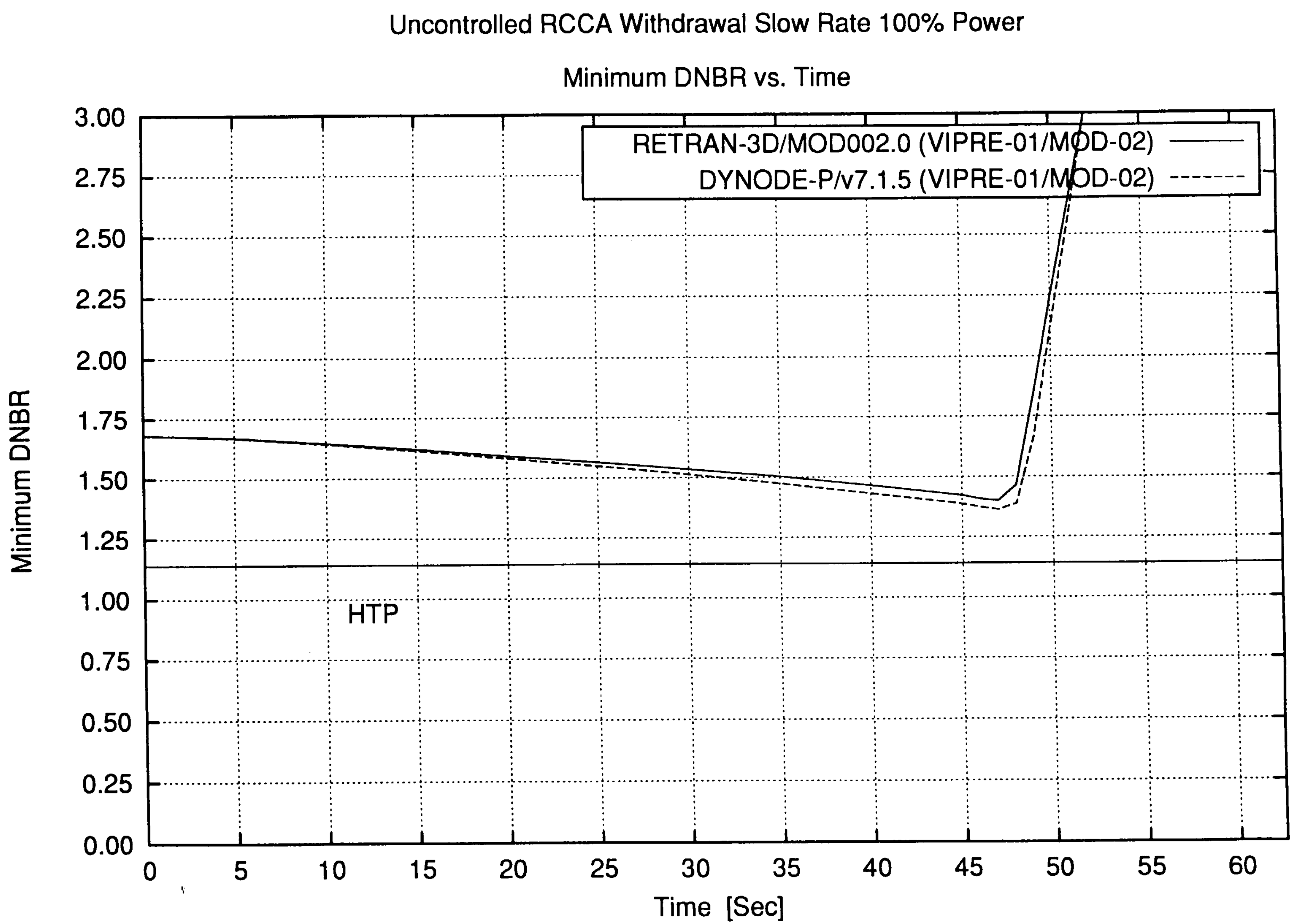

Uncontrolled RCCA Withdrawal Slow Rate 100% Power
Minimum DNBR vs. Time
RETRAN-3D/MOD002.0 (VIPRE-01/MOD-02)
DYNODE-P/v7.1.5 (VIPRE-01/MOD-02)
HTP
Minimum DNBR
Time [Sec]
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
5
10
15
20
25
30
35
40
45
50
55
60

Figure 1-8

Uncontrolled RCCA Withdrawal Fast Rate 60% Power

Reactor Power vs. Time

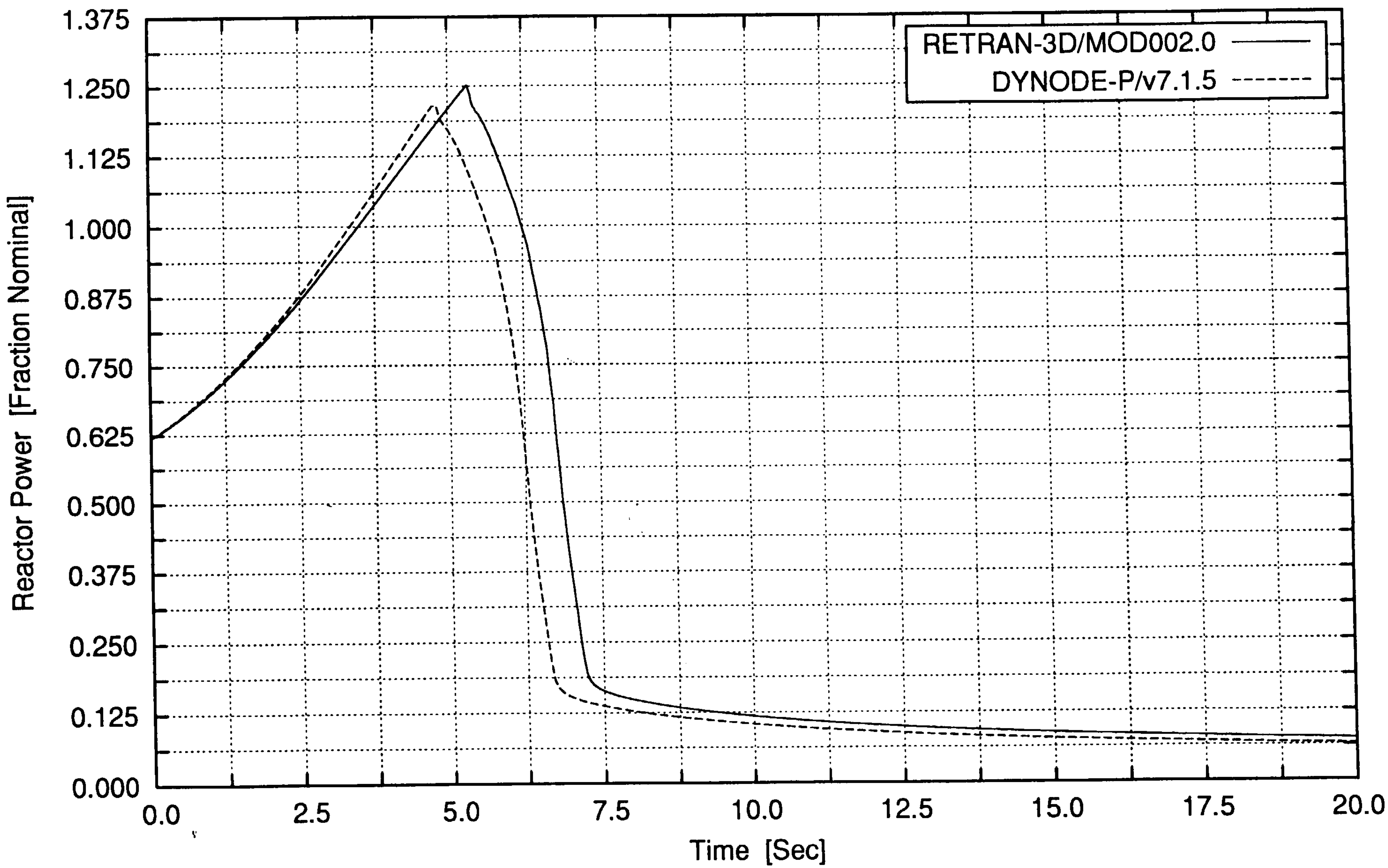


Figure 1-9

Uncontrolled RCCA Withdrawal Fast Rate 60% Power

Pressurizer Pressure vs. Time

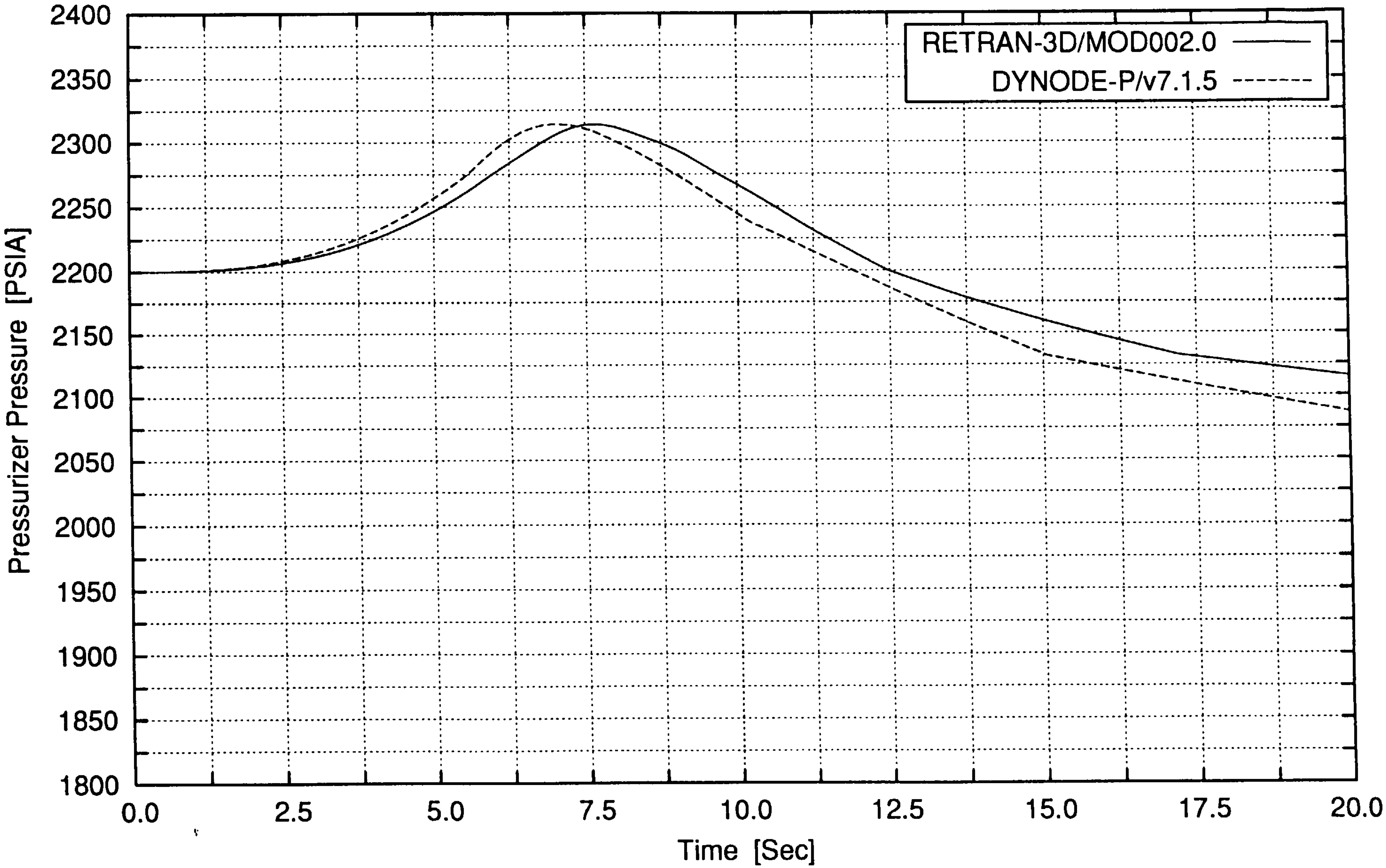


Figure 1-10

Uncontrolled RCCA Withdrawal Fast Rate 60% Power

Tave vs. Time

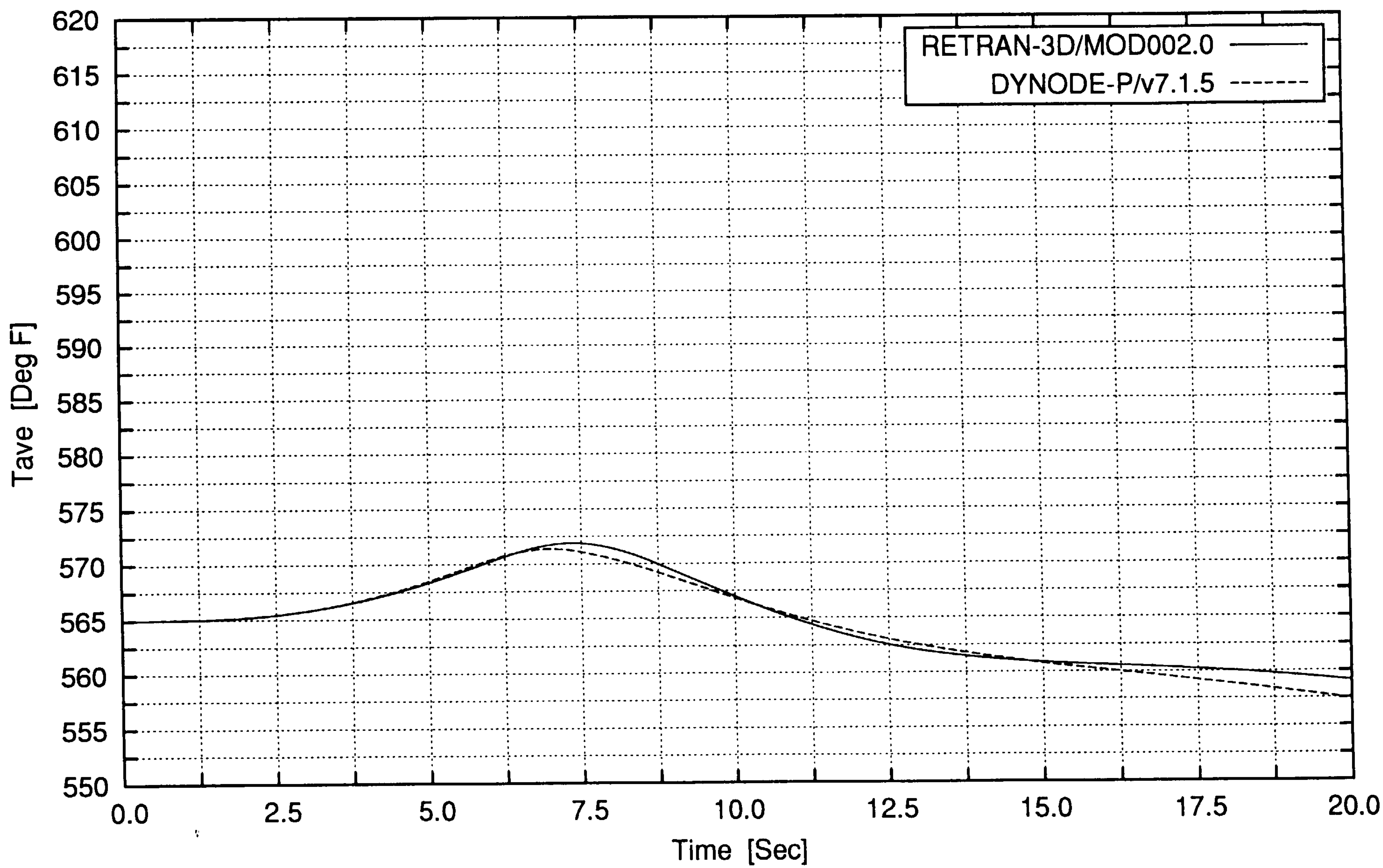


Figure 1-11

Uncontrolled RCCA Withdrawal Fast Rate 60% Power

Minimum DNBR vs. Time

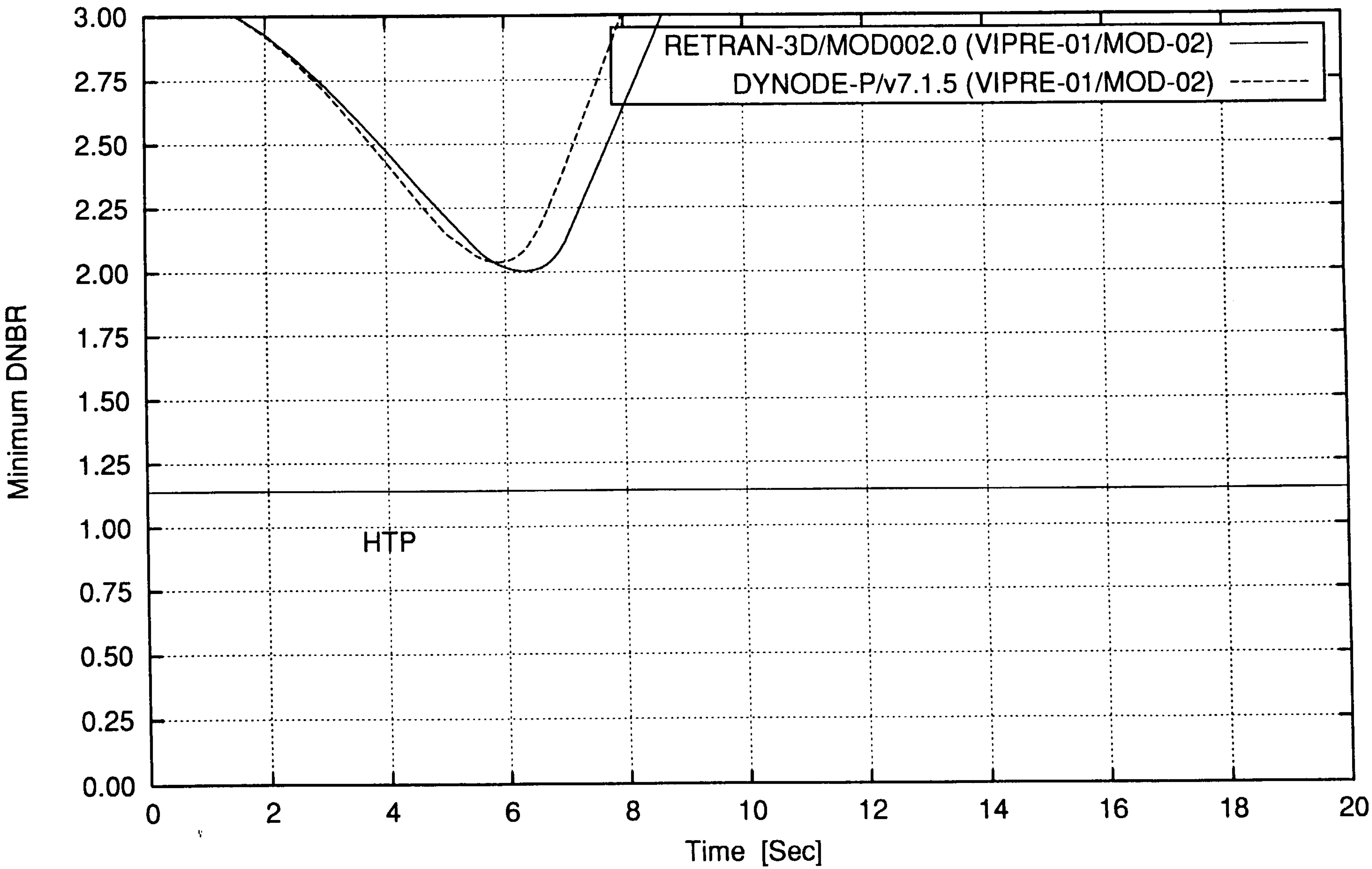


Figure 1-12

Uncontrolled RCCA Withdrawal Slow Rate 60% Power

Reactor Power vs. Time

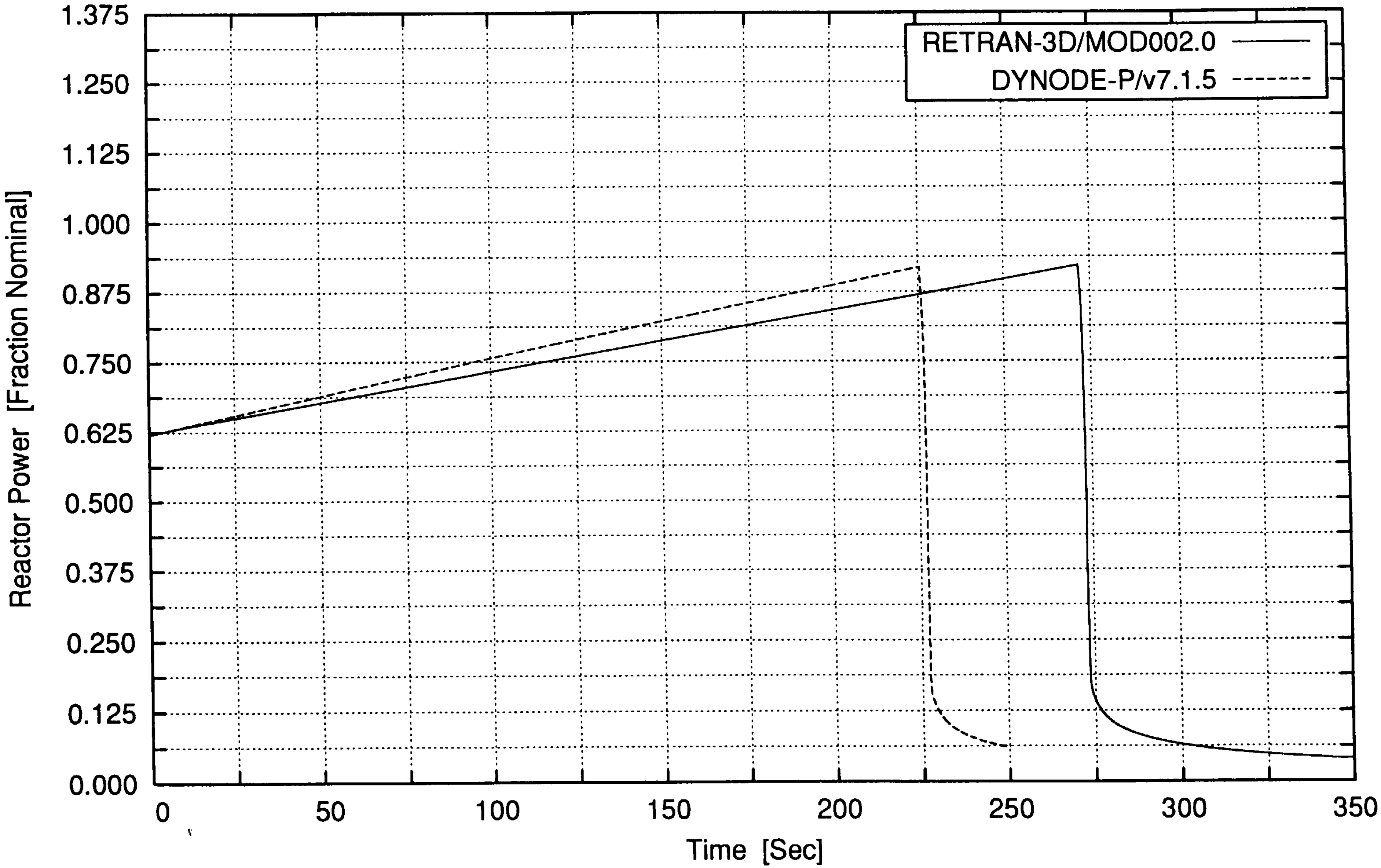


Figure 1-13

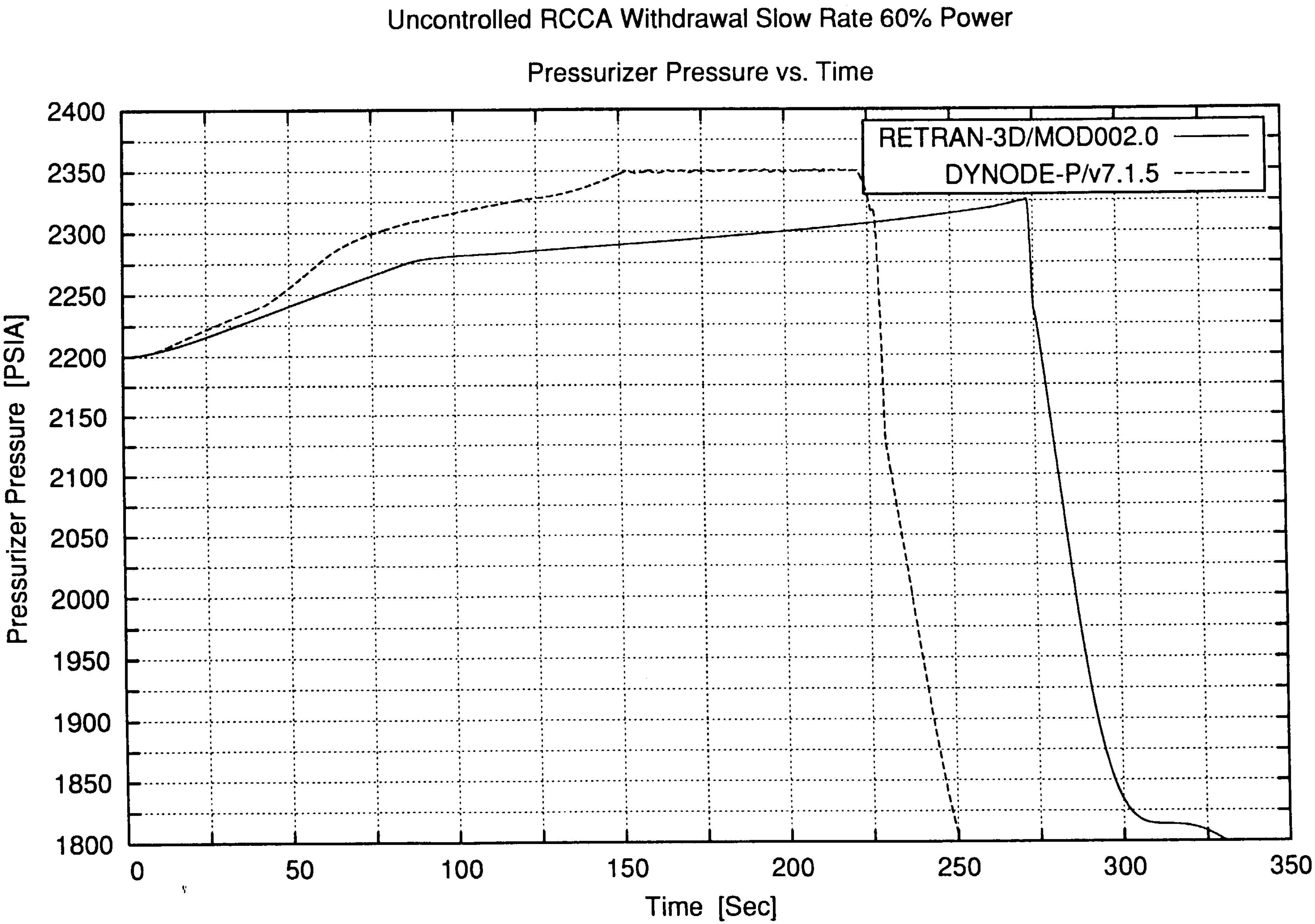

Uncontrolled RCCA Withdrawal Slow Rate 60% Power
Pressurizer Pressure vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Pressurizer Pressure [PSIA]
2400
2350
2300
2250
2200
2150
2100
2050
2000
1950
1900
1850
1800
0
50
100
150
200
250
300
350
Time [Sec]

Figure 1-14

Uncontrolled RCCA Withdrawal Slow Rate 60% Power

Tave vs. Time

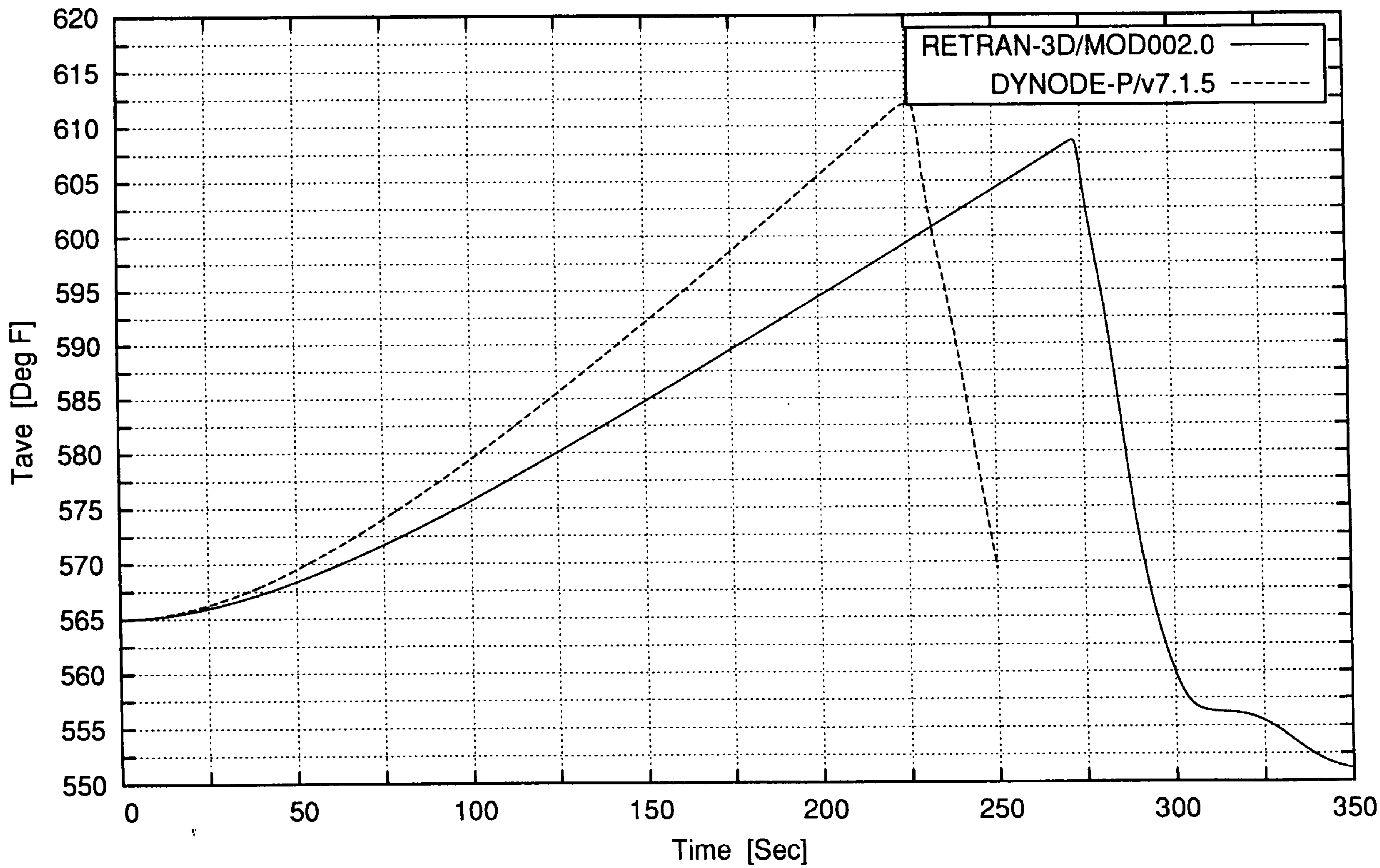


Figure 1-15

Uncontrolled RCCA Withdrawal Slow Rate 60% Power

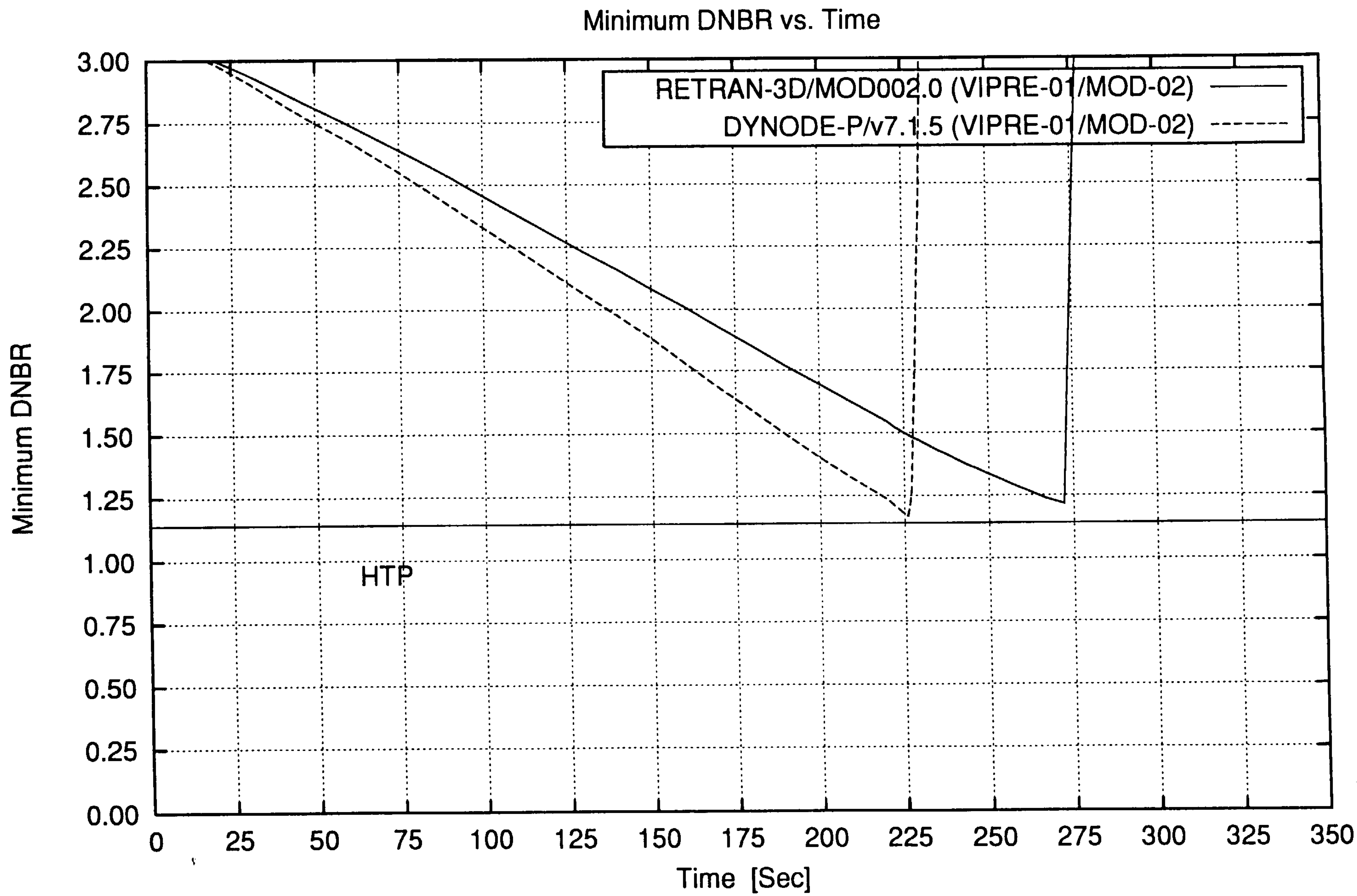


Figure 1-16

2. CVCS Malfunction Dilution at Power

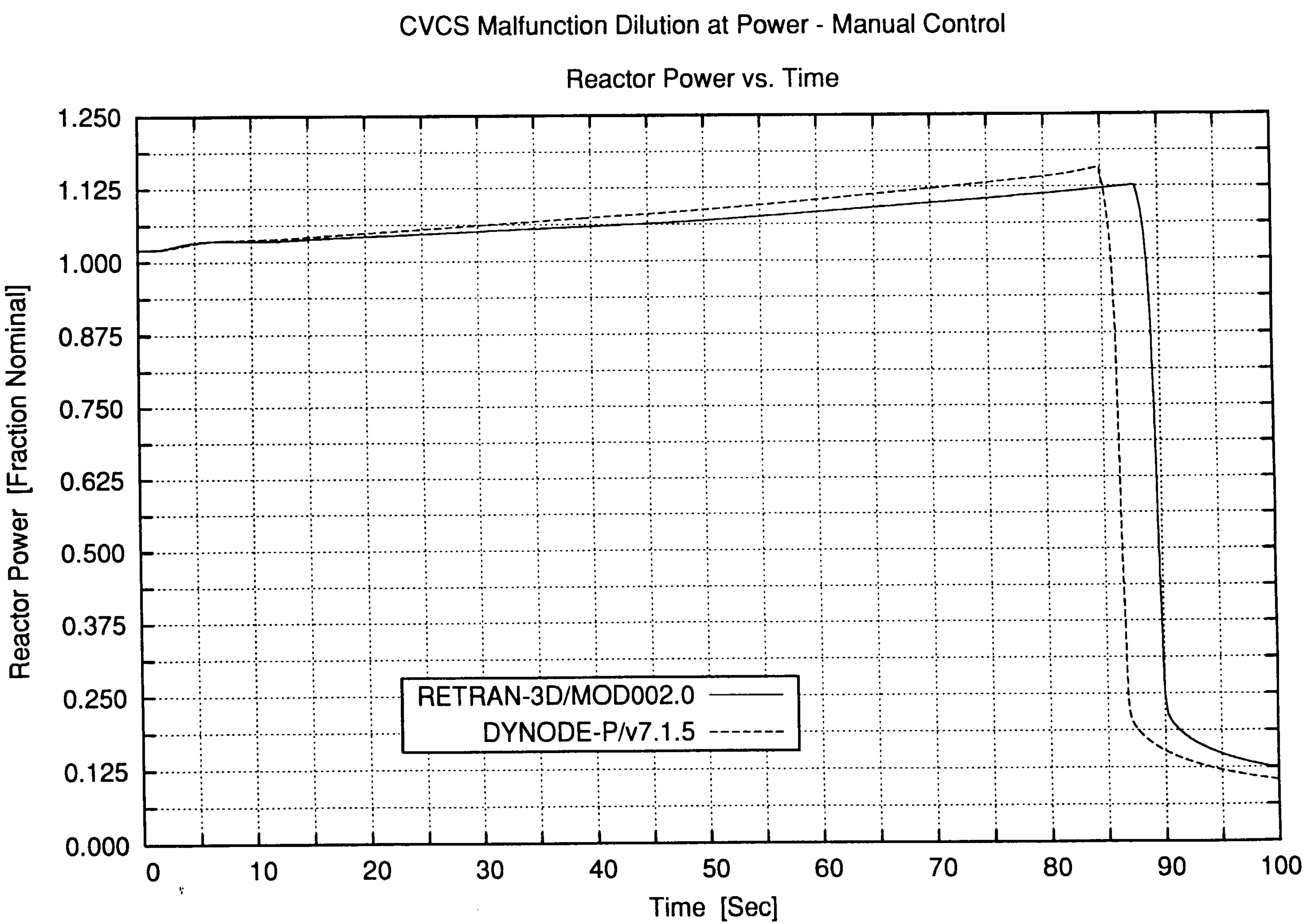
Figure 2-1 shows the reactor power versus time. RETRAN trips on overtemperature ΔT about 3.5 seconds later than DYNODE due to the slower T_{ave} increase.

Figure 2-2 shows the pressurizer pressure versus time. The pressures are quite close before the trip. The difference after the trip is due to the difference in trip time.

Figure 2-3 shows T_{ave} versus time. Tave increases slightly slower in RETRAN than DYNODE because of differences in the feedwater flow model discussed in Section III.1. T_{ave} is still within 2°F before the trip.

Figure 2-4 shows heat flux versus time which, as expected in a slow transient, looks very much like power versus time.

Figure 2-5 shows MDNBR versus time. The lower heat flux in RETRAN results in a higher MDNBR.



CVCS Malfunction Dilution at Power - Manual Control
Reactor Power vs. Time
Reactor Power [Fraction Nominal]
1.250
1.125
1.000
0.875
0.750
0.625
0.500
0.375
0.250
0.125
0.000
0
10
20
30
40
50
60
70
80
90
100
Time [Sec]
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5

Figure 2-1

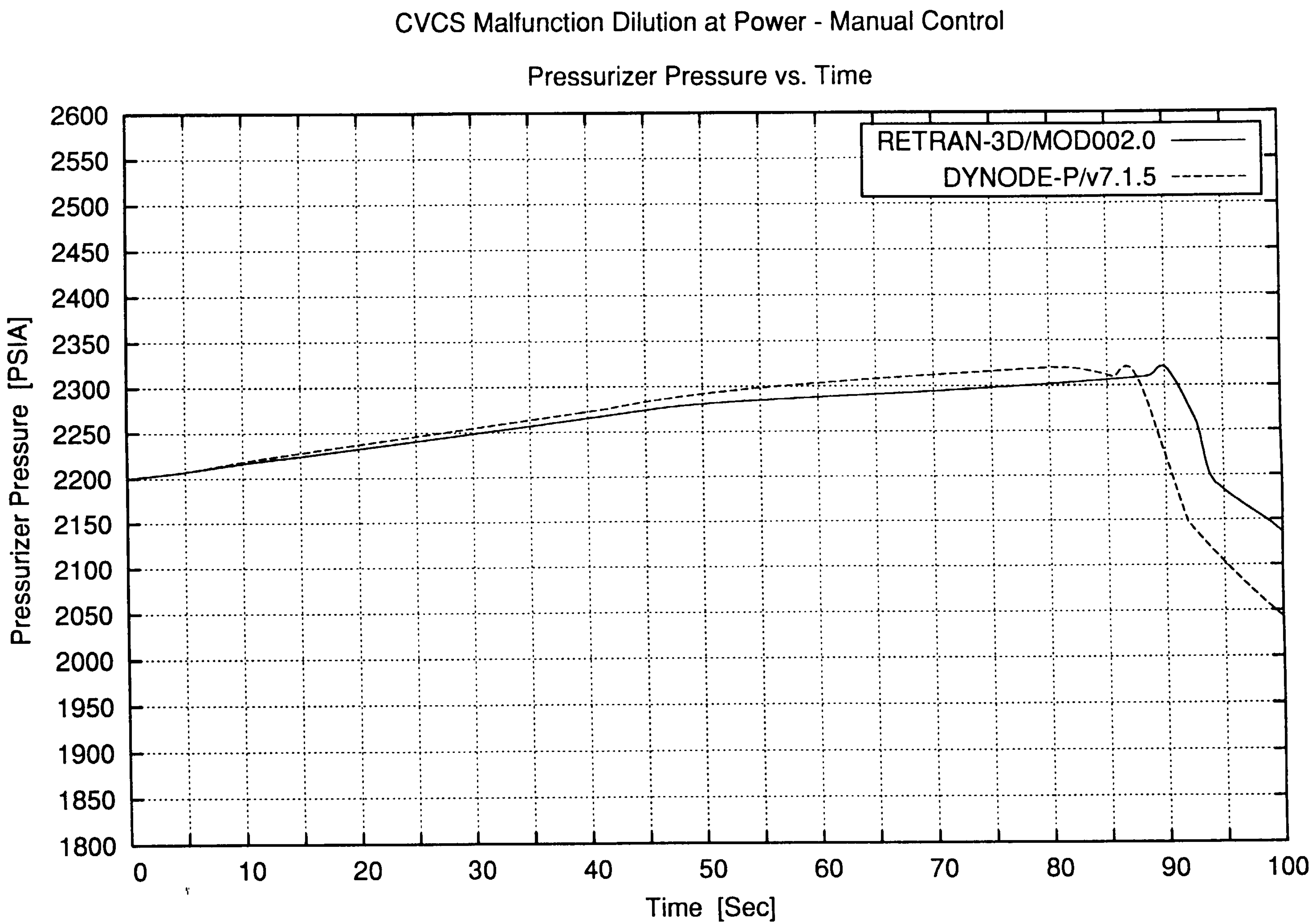

CVCS Malfunction Dilution at Power - Manual Control
Pressurizer Pressure vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Pressurizer Pressure [PSIA]
2600
2550
2500
2450
2400
2350
2300
2250
2200
2150
2100
2050
2000
1950
1900
1850
1800
0
10
20
30
40
50
60
70
80
90
100
Time [Sec]

Figure 2-2

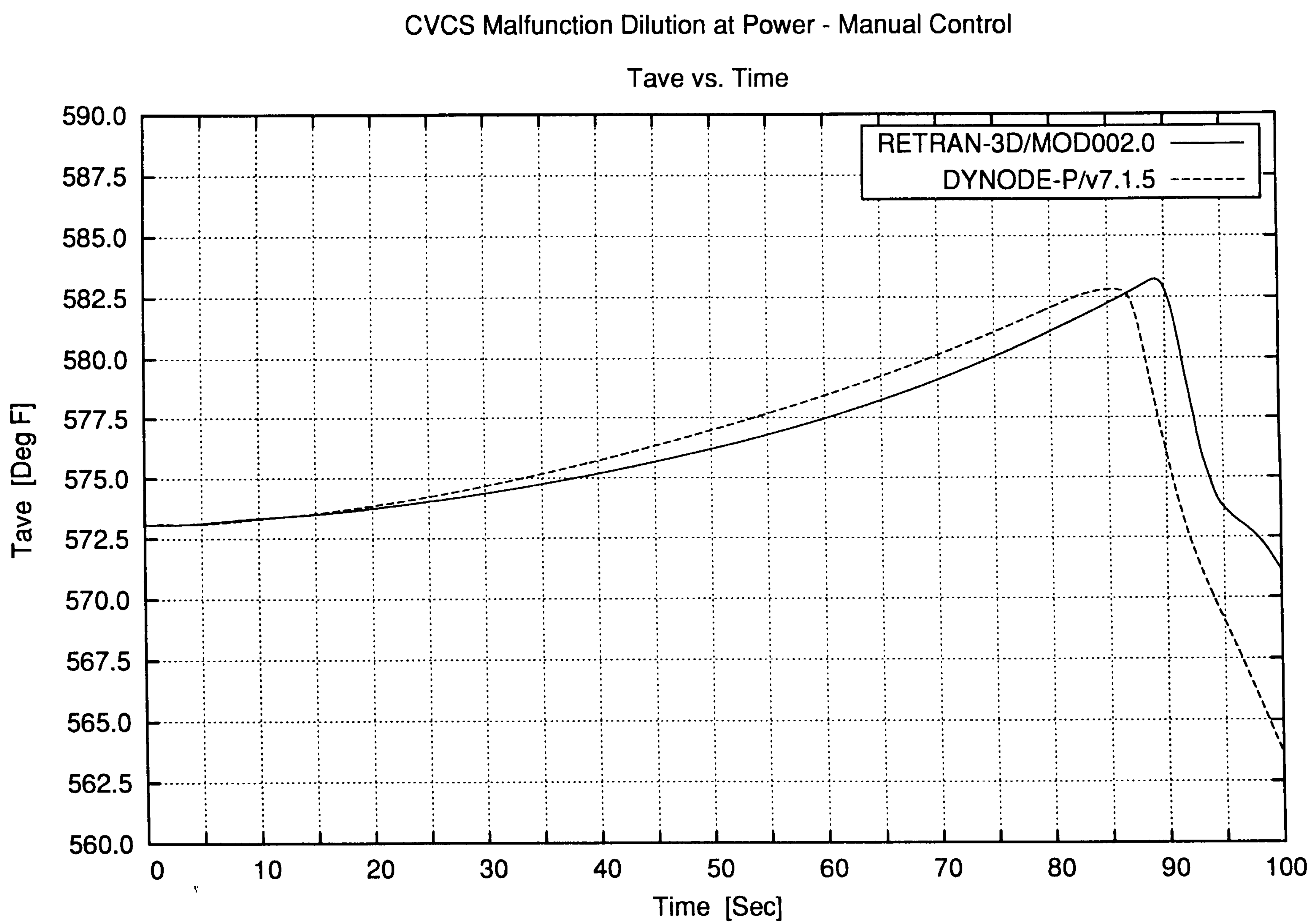

CVCS Malfunction Dilution at Power - Manual Control
Tave vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Tave [Deg F]
590.0
587.5
585.0
582.5
580.0
577.5
575.0
572.5
570.0
567.5
565.0
562.5
560.0
0
10
20
30
40
50
60
70
80
90
100
Time [Sec]

Figure 2-3

CVCS Malfunction Dilution at Power - Manual Control

Heat Flux vs. Time

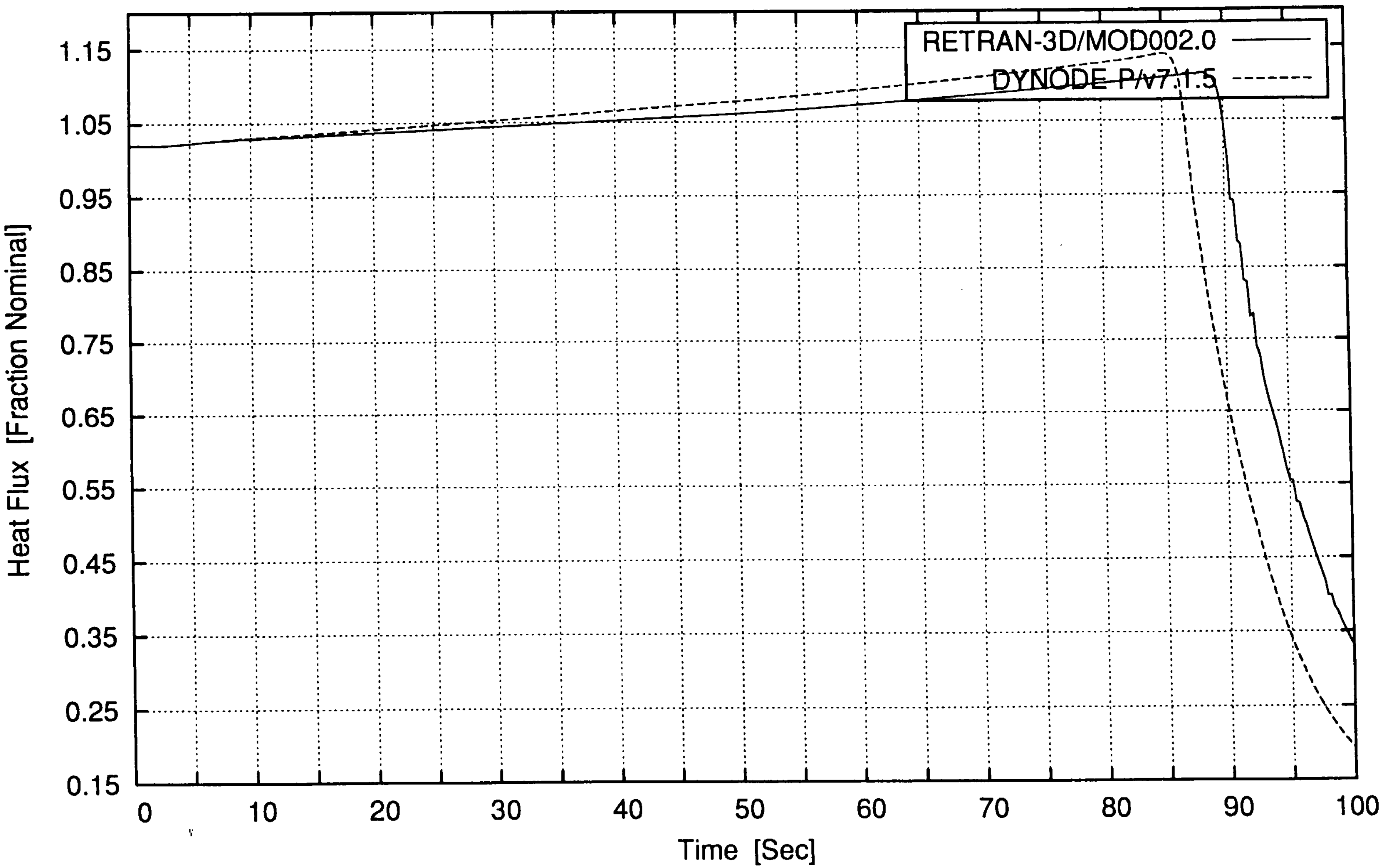


Figure 2-4

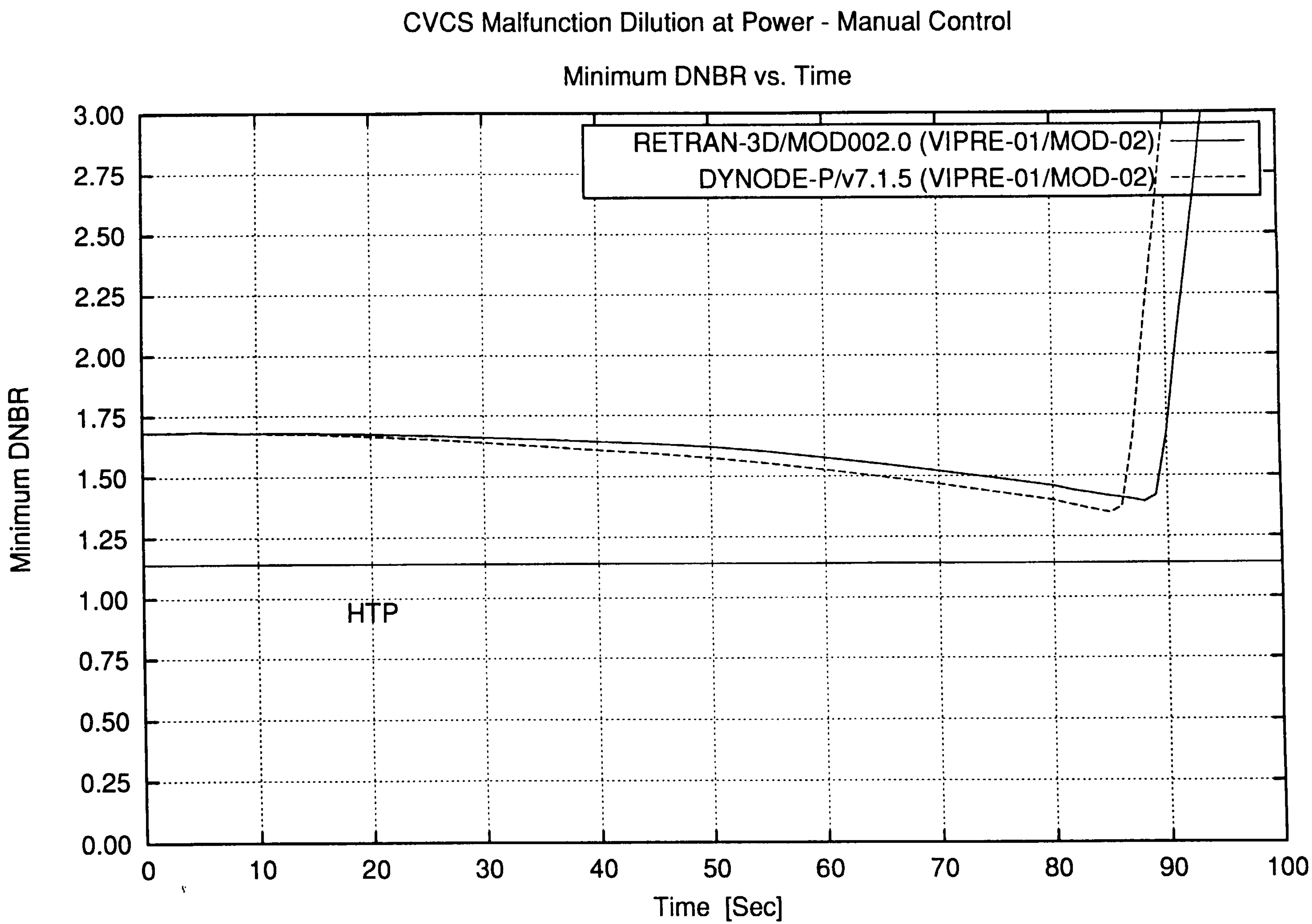

CVCS Malfunction Dilution at Power - Manual Control
Minimum DNBR vs. Time
RETRAN-3D/MOD002.0 (VIPRE-01/MOD-02)
DYNODE-P/v7.1.5 (VIPRE-01/MOD-02)
HTP
Minimum DNBR
Time [Sec]
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
10
20
30
40
50
60
70
80
90
100

Figure 2-5

3. Excessive Heat Removal – Feedwater System Malfunction

BOC Manual Control

Figure 3-1 shows the reactor power versus time. The power is almost identical between RETRAN and DYNODE.

Figure 3-2 shows the pressurizer pressure versus time. With both codes, the pressurizer pressure changes very little, by no more than 40 Psi. The results agree to within 50 Psi.

Figure 3-3 shows T_{ave} versus time. T_{ave} agrees to within 0.5°F between the two codes.

Figure 3-4 shows core ΔT versus time. The results are almost identical, within 0.2 degrees.

Figure 3.5 shows MDNBR versus time. The result is almost identical between the two codes.

EOC Automatic Control

Figure 3-6 shows the reactor power versus time. The power is almost identical between RETRAN and DYNODE except DYNODE has a slight perturbation at 80-90 seconds due to a flow regime discontinuity.

Figure 3-7 shows the pressurizer pressure versus time. With both codes, the pressurizer pressure changes very little, by no more than 12 Psi.

Figures 3-8, 3-9, and 3-10 show T_{ave}, core ΔT, and MDNBR versus time. The results are almost identical between the two codes.

Opening of Regulating Valve

Even though this case is not plotted in the USAR, it is presented here for completeness.

Figure 3-11 shows the reactor power versus time. The power is almost identical before the reactor trip on high steam generator level. The trip occurs 6.4 seconds later in RETRAN because the level rises slower. The reason the level rises slower is because in RETRAN the average area of the steam dome (127.37 ft^2) is used for the entire steam dome, whereas DYNODE uses a more accurate representation based on steam generator volume versus height curves from the Westinghouse PWEE document, resulting in an area of about 106 ft^2 at elevation of the initial level. For the replacement steam generators, more accurate information will be entered into RETRAN.

Figure 3-12 shows the pressurizer pressure versus time. The difference in pressurizer pressure response is due to the difference in T_{ave}.

Figure 3-13 shows T_{ave} versus time. The difference immediately after the trip is due primarily to the difference in the trip time. T_{ave} begins to increase in DYNODE toward the end of the transient because of a difference in the steam generator models. DYNODE models the entire riser as one

volume. When the cold leg temperature decreases to the steam generator riser temperature, the steam generators no longer remove heat and the reactor coolant system temperature begins to rise. In RETRAN, on the other hand, the riser volumes are colder than the steam dome volume. This thermal stratification allows the steam generators to cool the reactor coolant system further, even though the cold leg is colder than the steam dome.

Figure 3-14 shows the core ΔT versus time. The difference is due to the difference in the trip time.

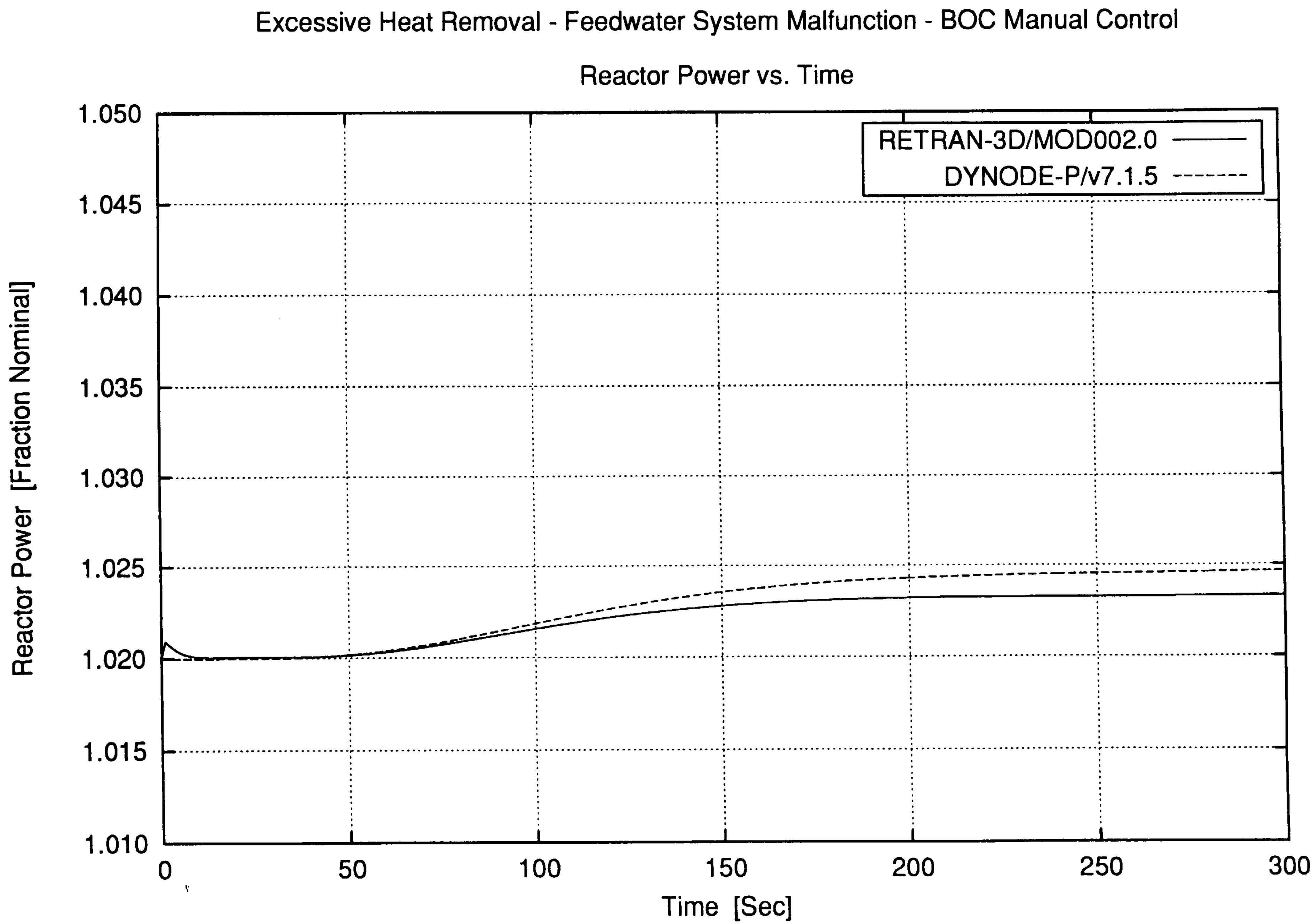

Excessive Heat Removal - Feedwater System Malfunction - BOC Manual Control
Reactor Power vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Reactor Power [Fraction Nominal]
1.050
1.045
1.040
1.035
1.030
1.025
1.020
1.015
1.010
0
50
100
150
200
250
300
Time [Sec]

Figure 3-1

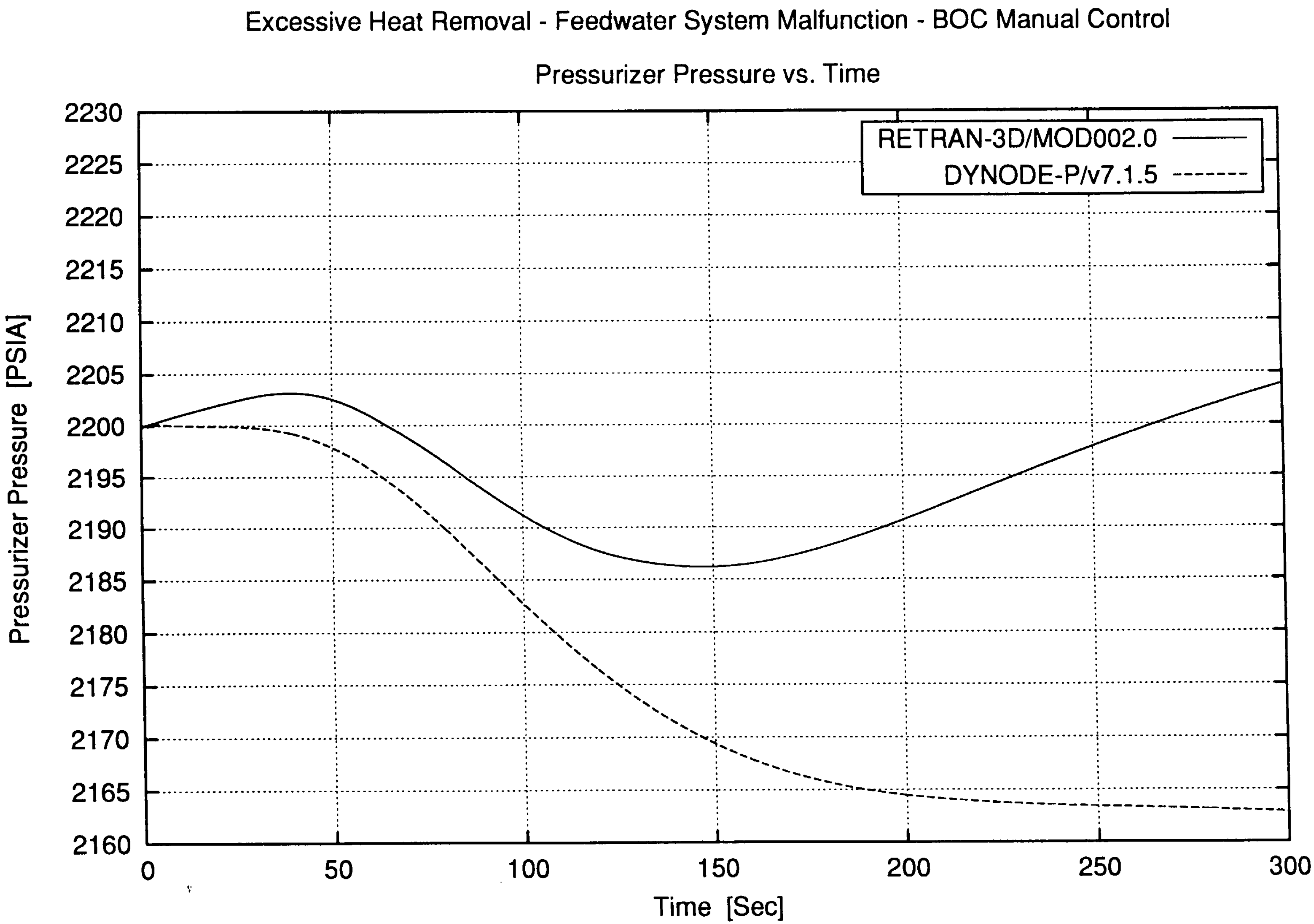

Excessive Heat Removal - Feedwater System Malfunction - BOC Manual Control
Pressurizer Pressure vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Pressurizer Pressure [PSIA]
2230
2225
2220
2215
2210
2205
2200
2195
2190
2185
2180
2175
2170
2165
2160
0
50
100
150
200
250
300
Time [Sec]

Figure 3-2

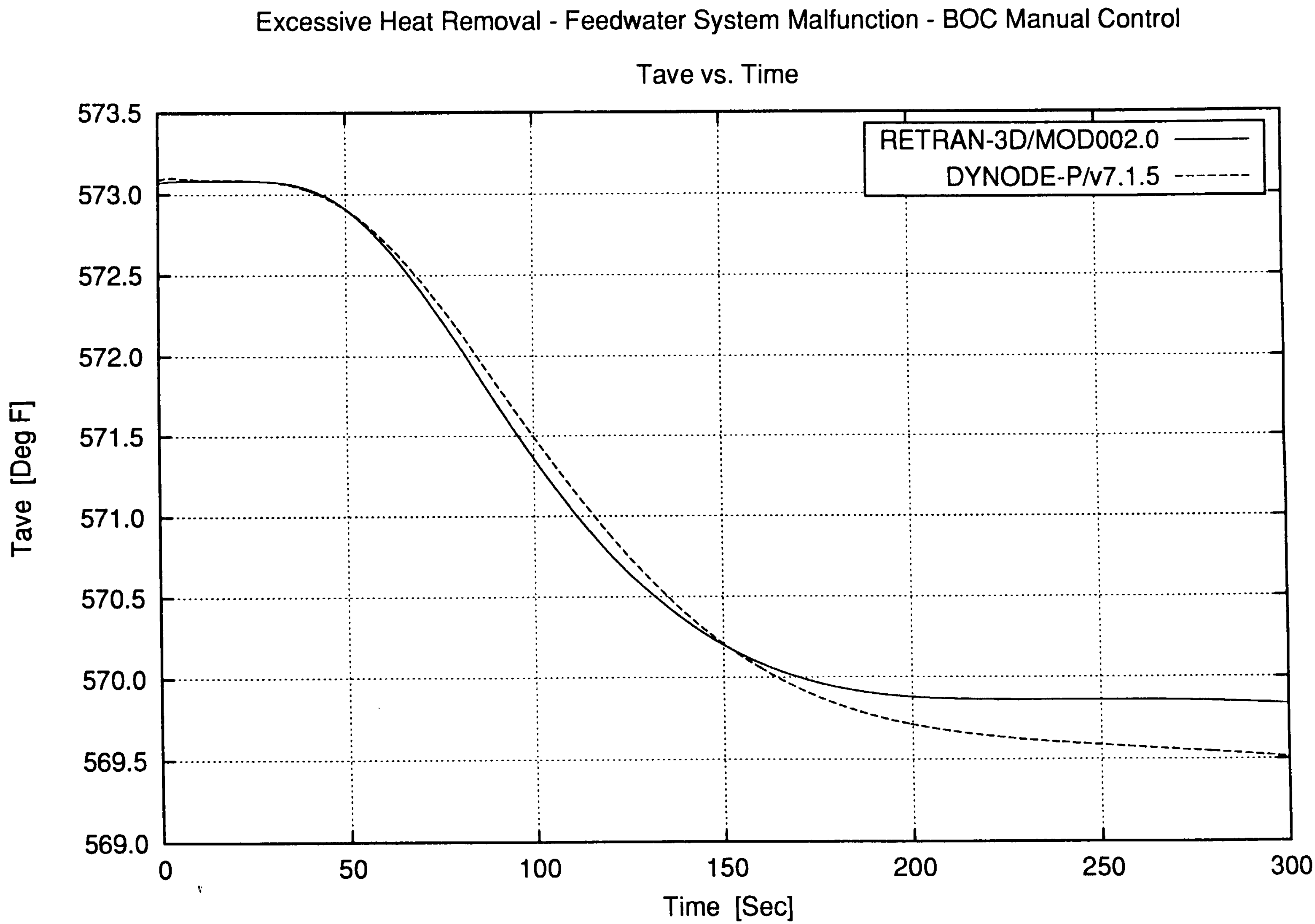
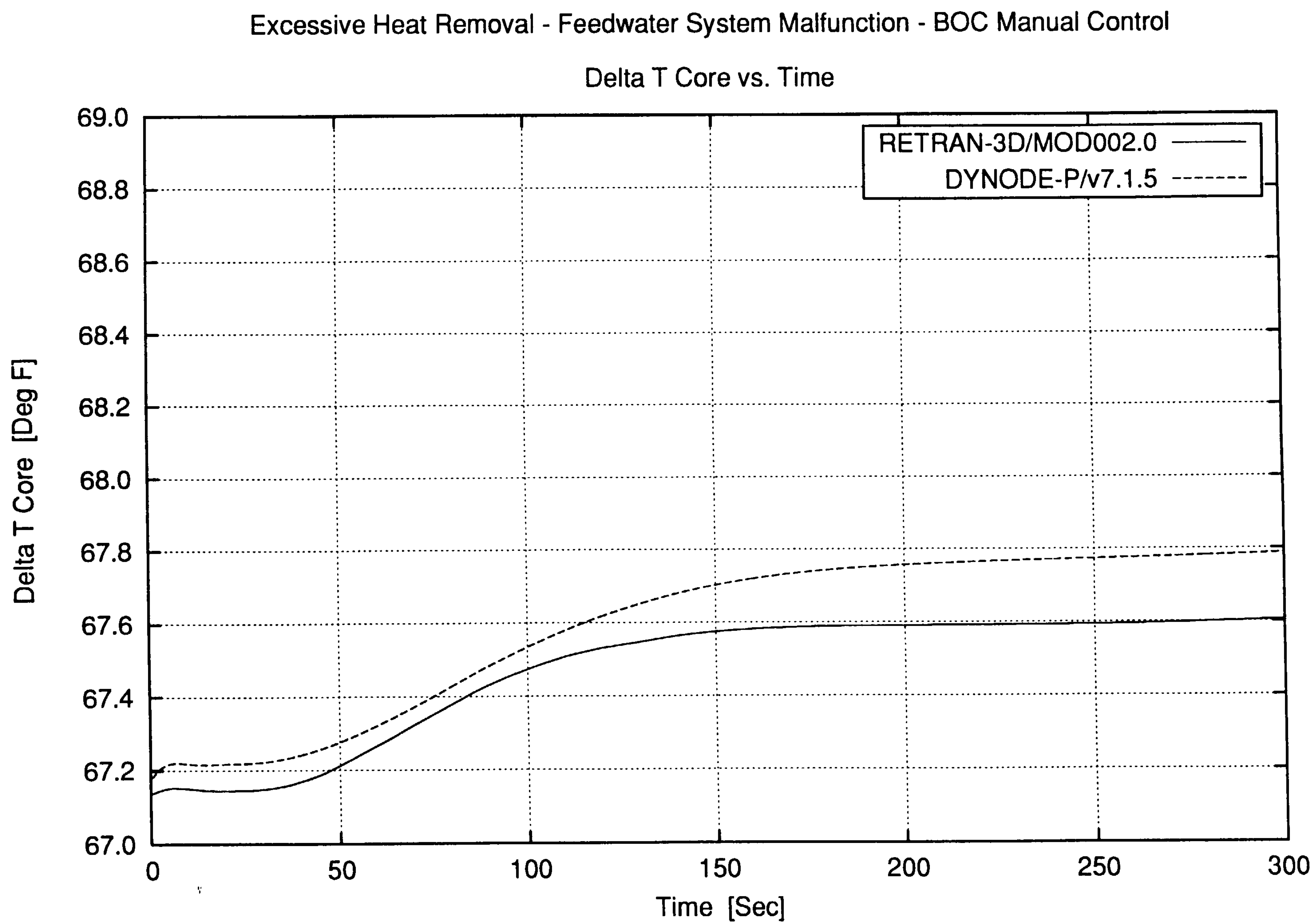
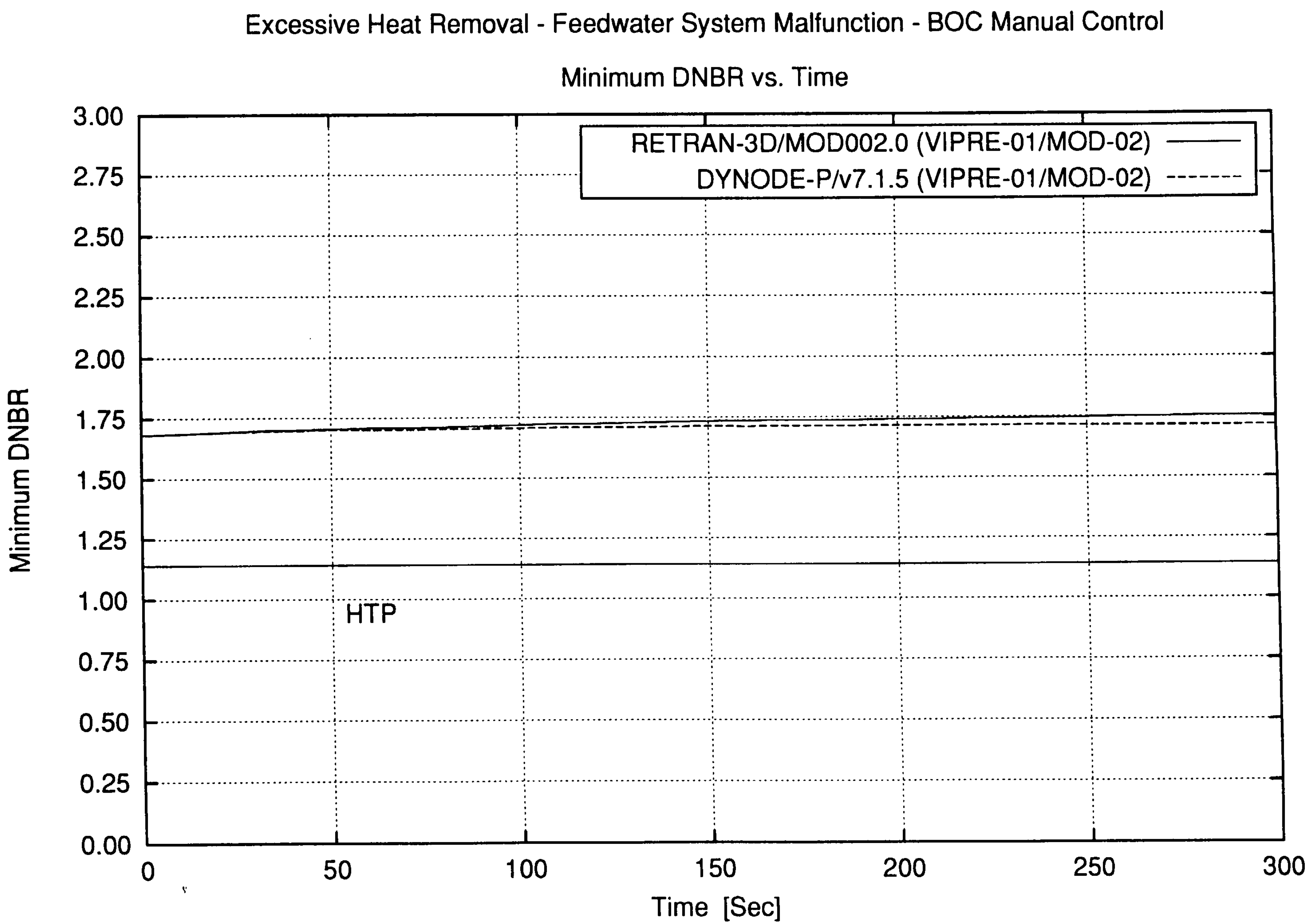

Excessive Heat Removal - Feedwater System Malfunction - BOC Manual Control
Tave vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Tave [Deg F]
573.5
573.0
572.5
572.0
571.5
571.0
570.5
570.0
569.5
569.0
0
50
100
150
200
250
300
Time [Sec]

Figure 3-3



Excessive Heat Removal - Feedwater System Malfunction - BOC Manual Control
Delta T Core vs. Time
Delta T Core [Deg F]
69.0
68.8
68.6
68.4
68.2
68.0
67.8
67.6
67.4
67.2
67.0
0
50
100
150
200
250
300
Time [Sec]
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5

Figure 3-4



Excessive Heat Removal - Feedwater System Malfunction - BOC Manual Control
Minimum DNBR vs. Time
RETRAN-3D/MOD002.0 (VIPRE-01/MOD-02)
DYNODE-P/v7.1.5 (VIPRE-01/MOD-02)
Minimum DNBR
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
HTP
0
50
100
150
200
250
300
Time [Sec]

Figure 3-5

Excessive Heat Removal - Feedwater System Malfunction - EOC Automatic Control

Reactor Power vs. Time

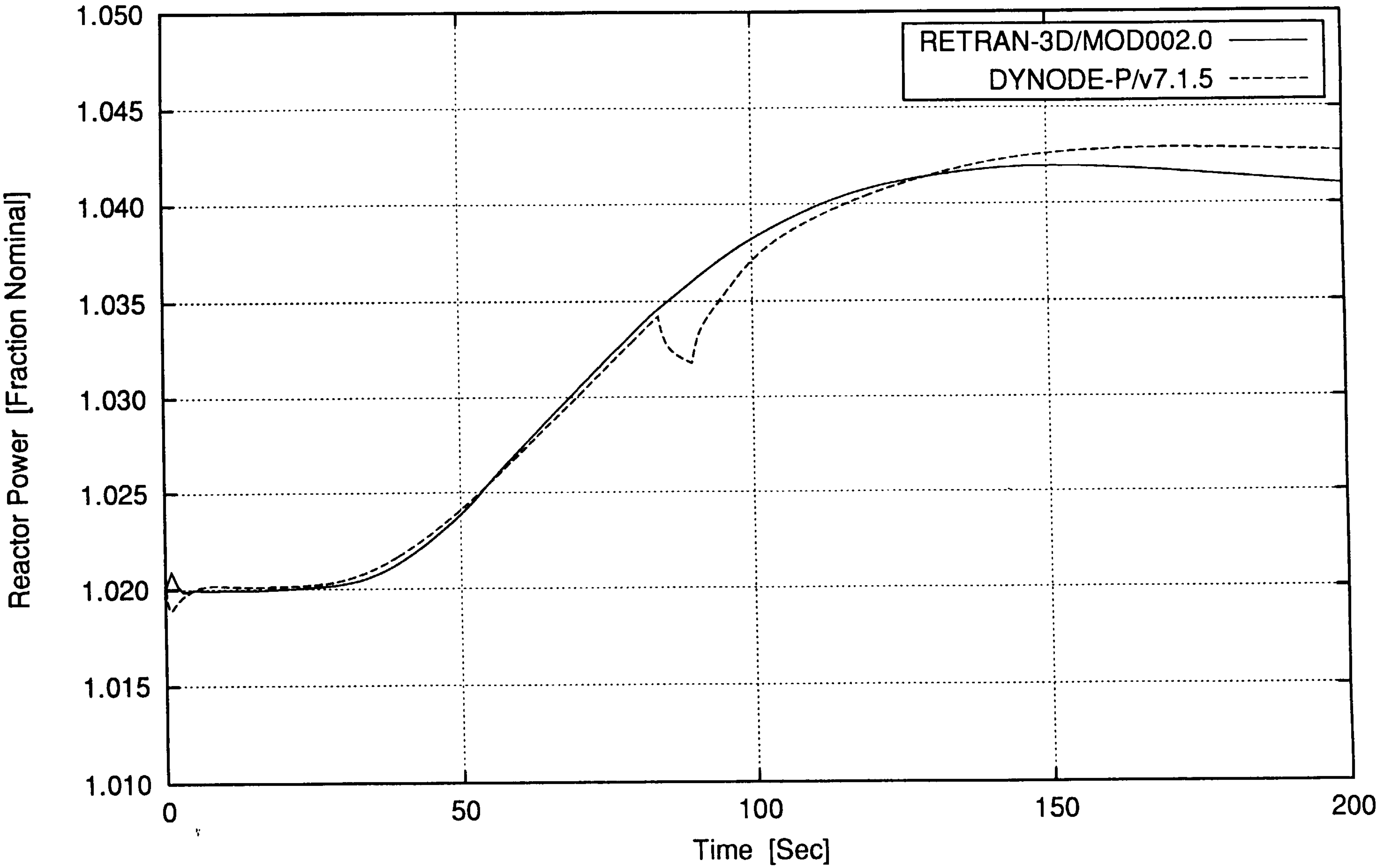
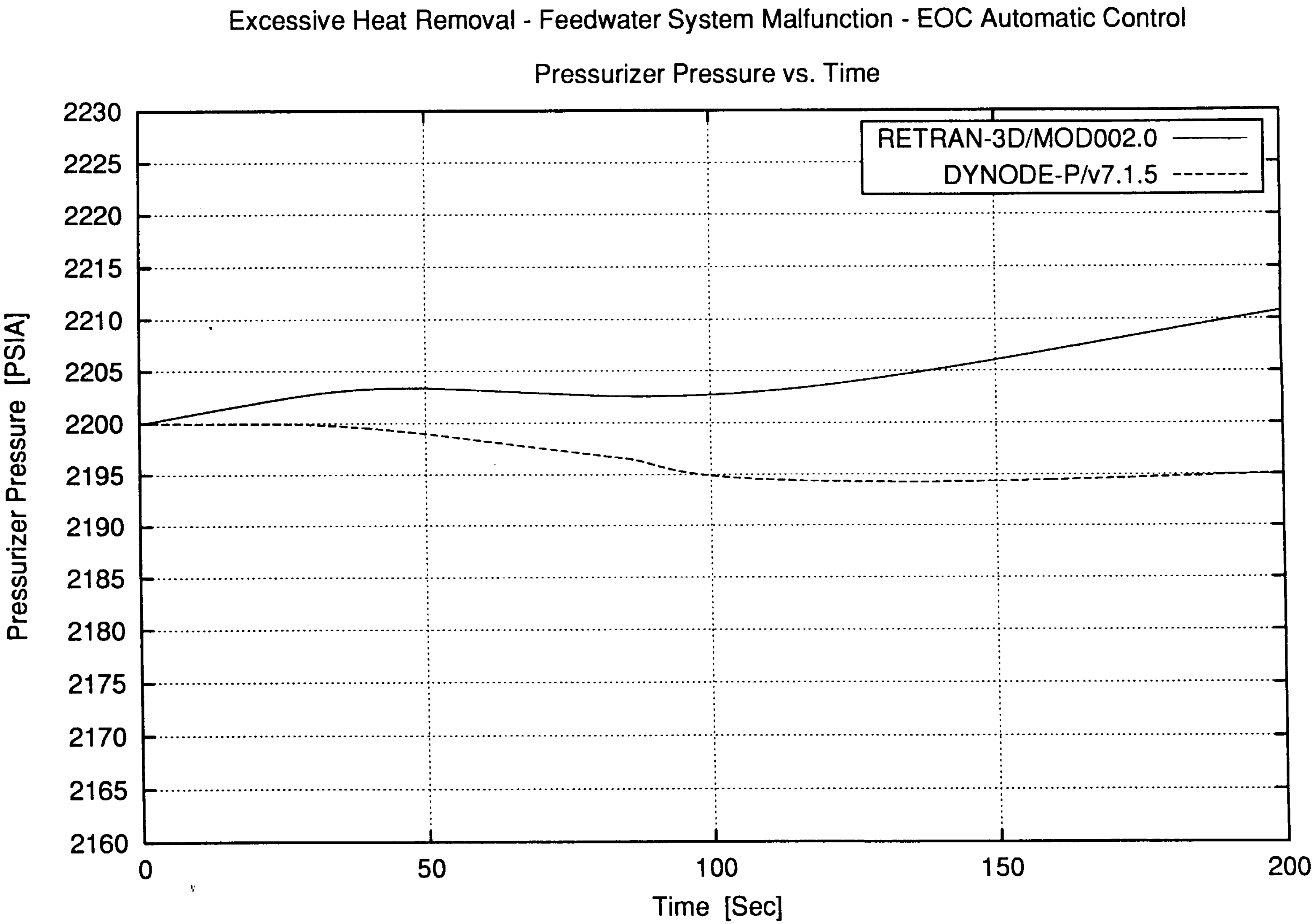


Figure 3-6



Excessive Heat Removal - Feedwater System Malfunction - EOC Automatic Control
Pressurizer Pressure vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Pressurizer Pressure [PSIA]
2230
2225
2220
2215
2210
2205
2200
2195
2190
2185
2180
2175
2170
2165
2160
0
50
100
150
200
Time [Sec]

Figure 3-7

Excessive Heat Removal - Feedwater System Malfunction - EOC Automatic Control

Tave vs. Time

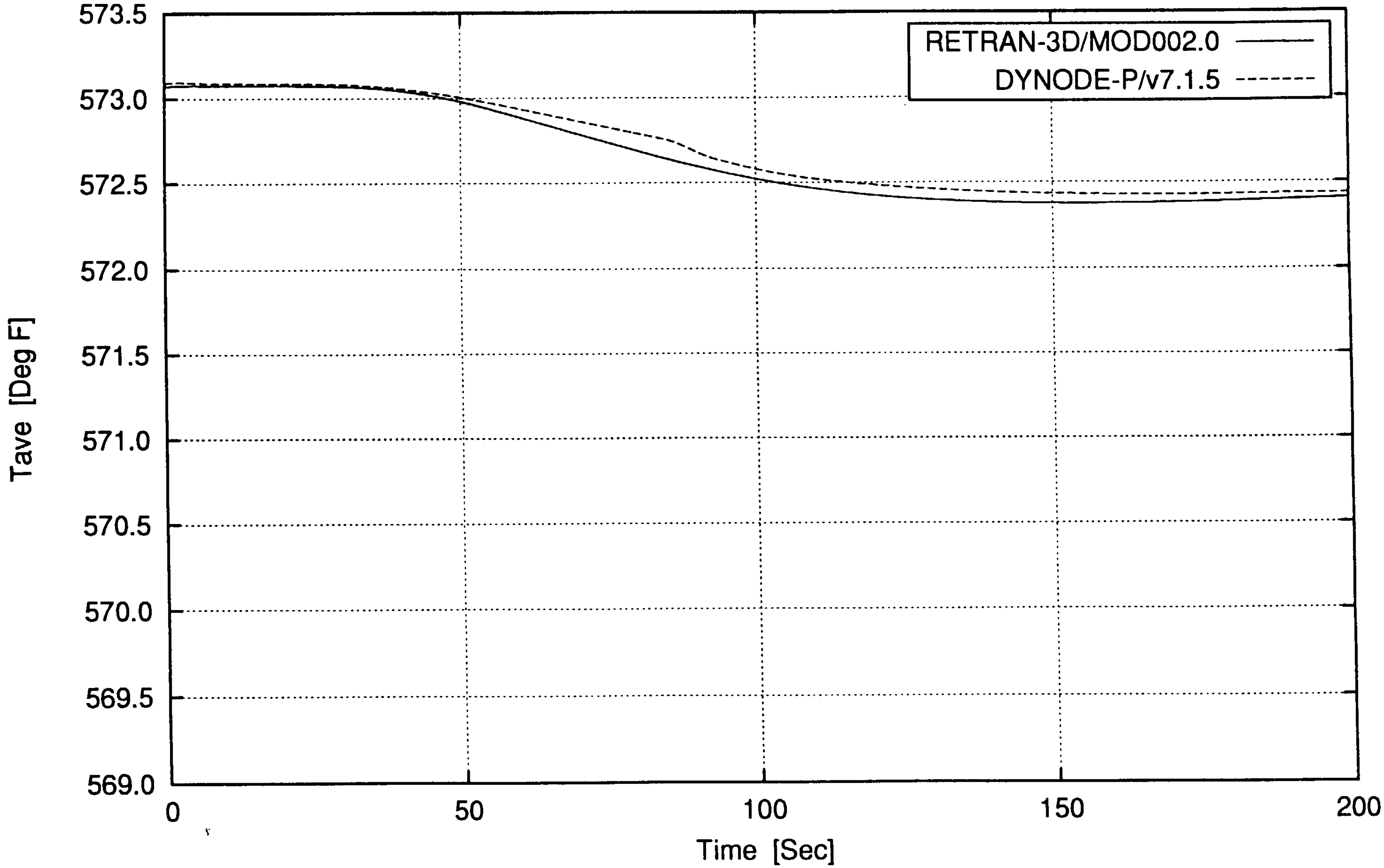


Figure 3-8

Excessive Heat Removal - Feedwater System Malfunction - EOC Automatic Control

Delta T Core vs. Time

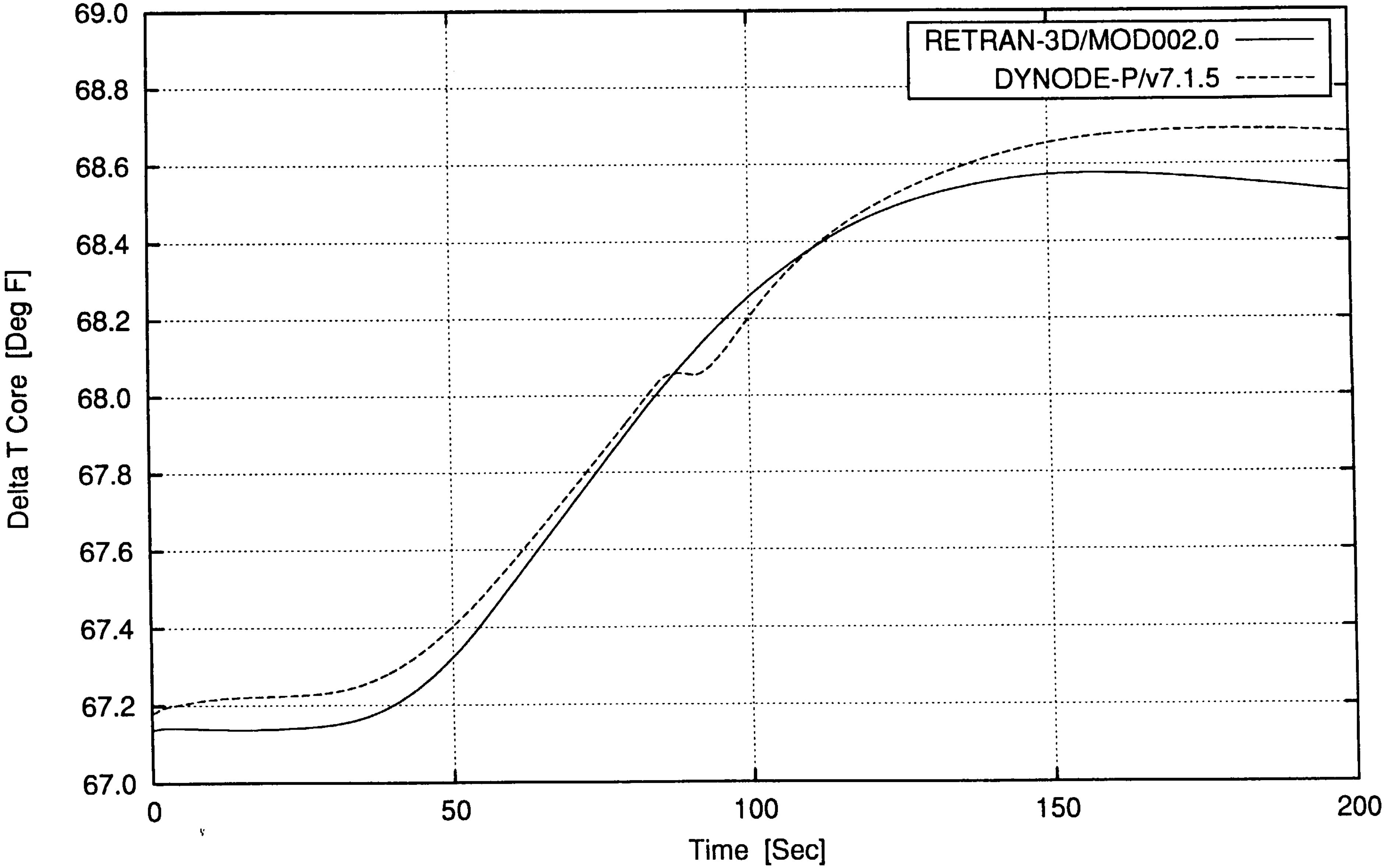
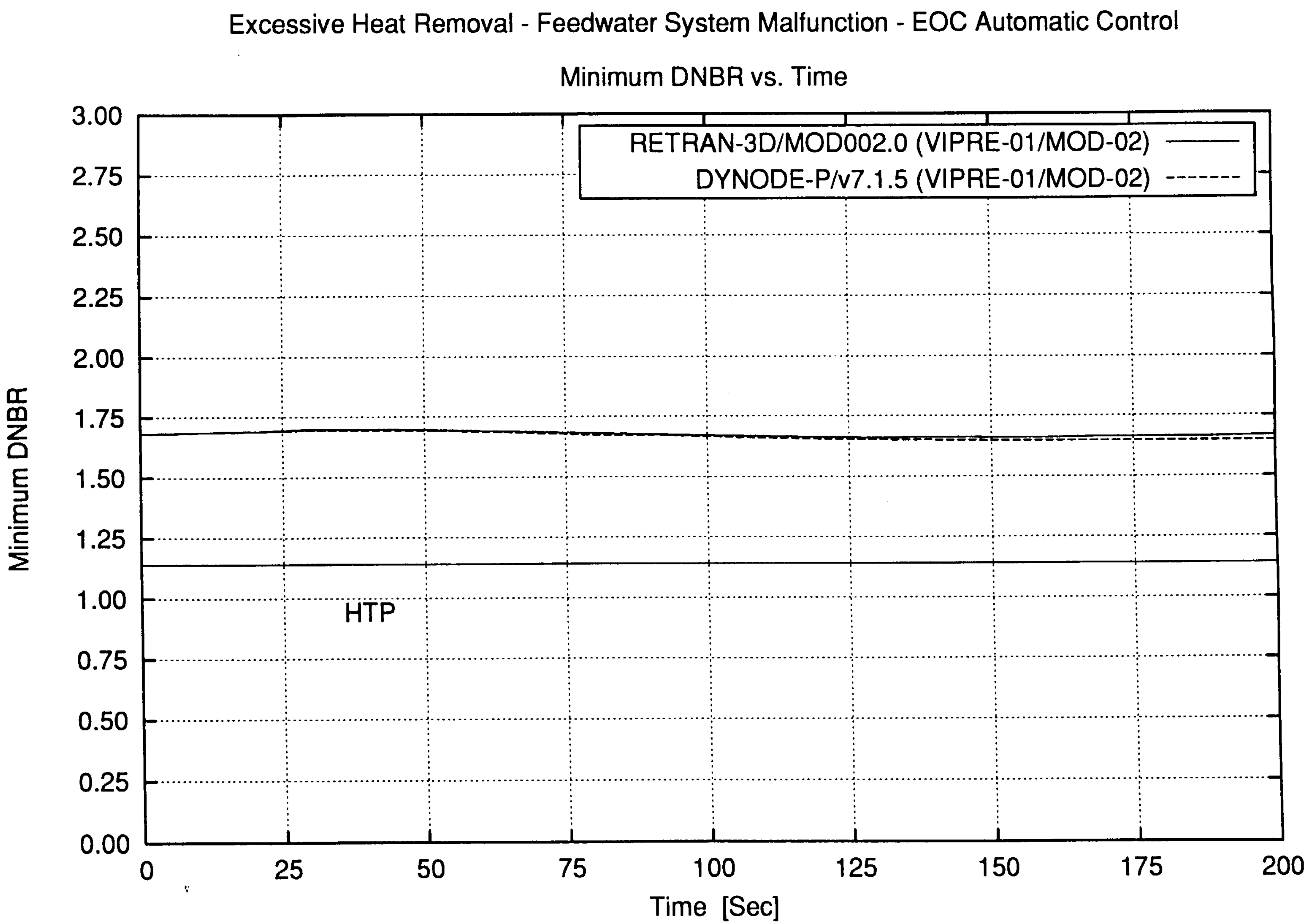


Figure 3-9



Excessive Heat Removal - Feedwater System Malfunction - EOC Automatic Control
Minimum DNBR vs. Time
RETRAN-3D/MOD002.0 (VIPRE-01/MOD-02)
DYNODE-P/v7.1.5 (VIPRE-01/MOD-02)
Minimum DNBR
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
HTP
0
25
50
75
100
125
150
175
200
Time [Sec]

Figure 3-10

Excessive Heat Removal - Feedwater System Malfunction - Opening of Regulating Valve

Reactor Power vs. Time

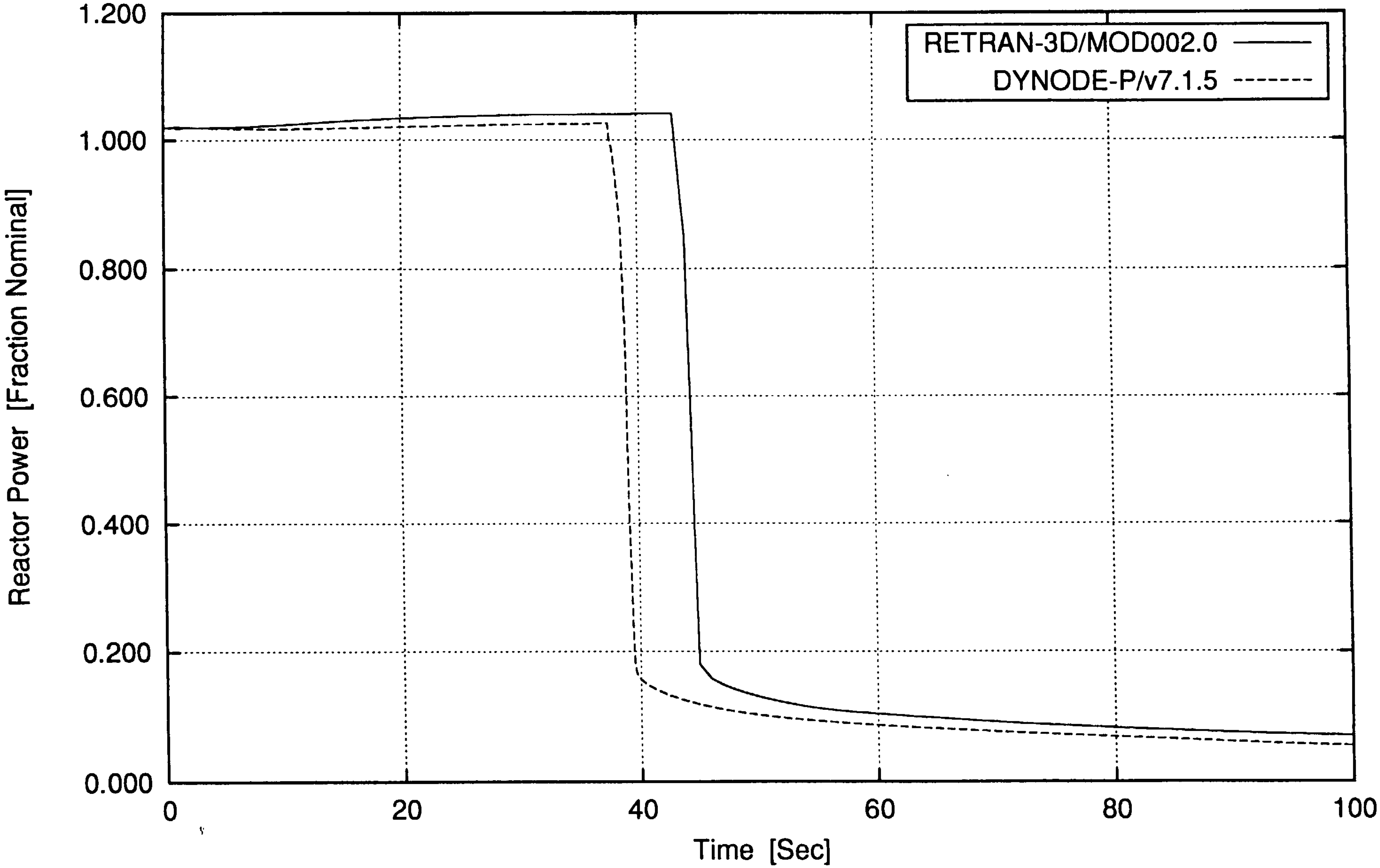
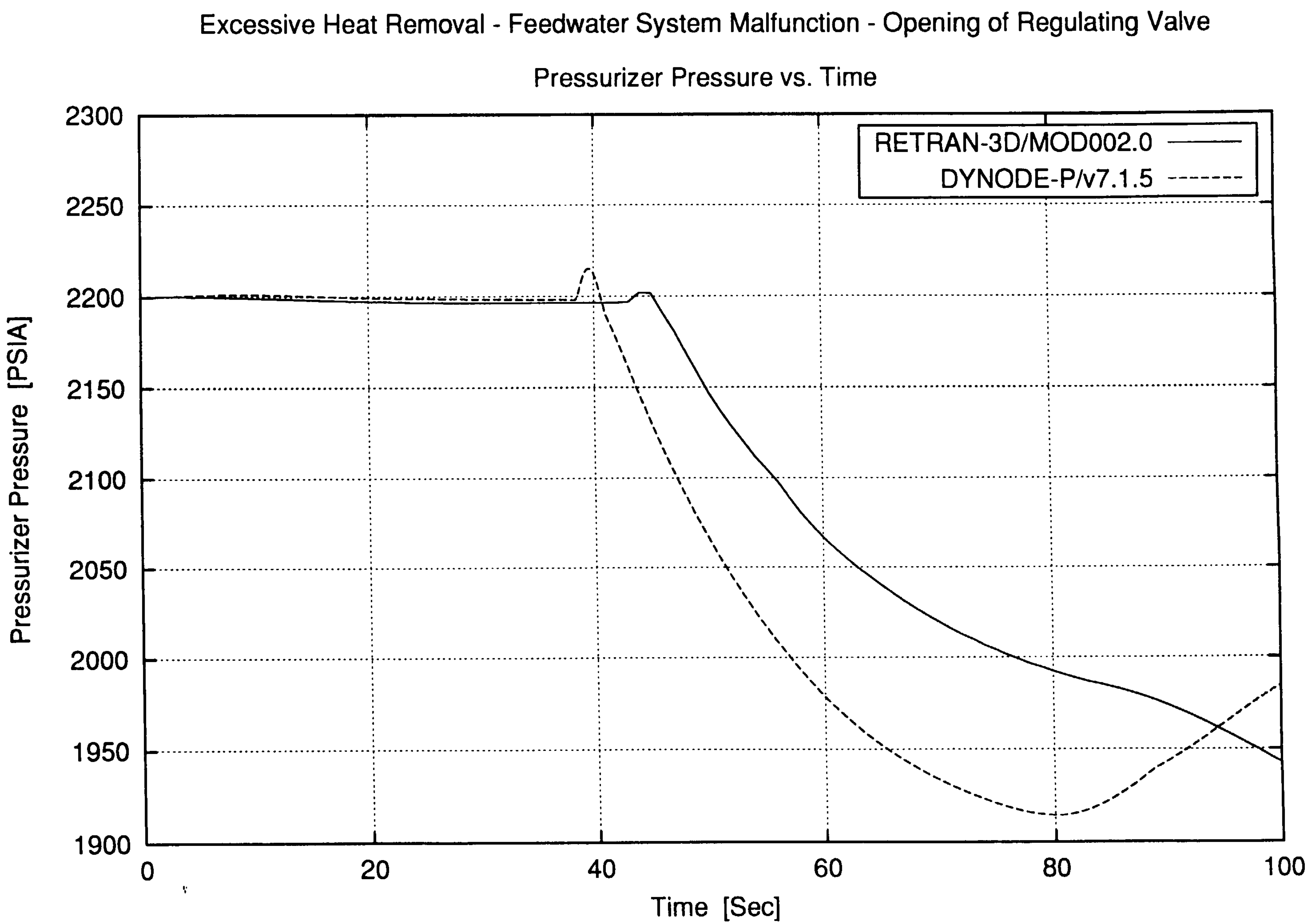
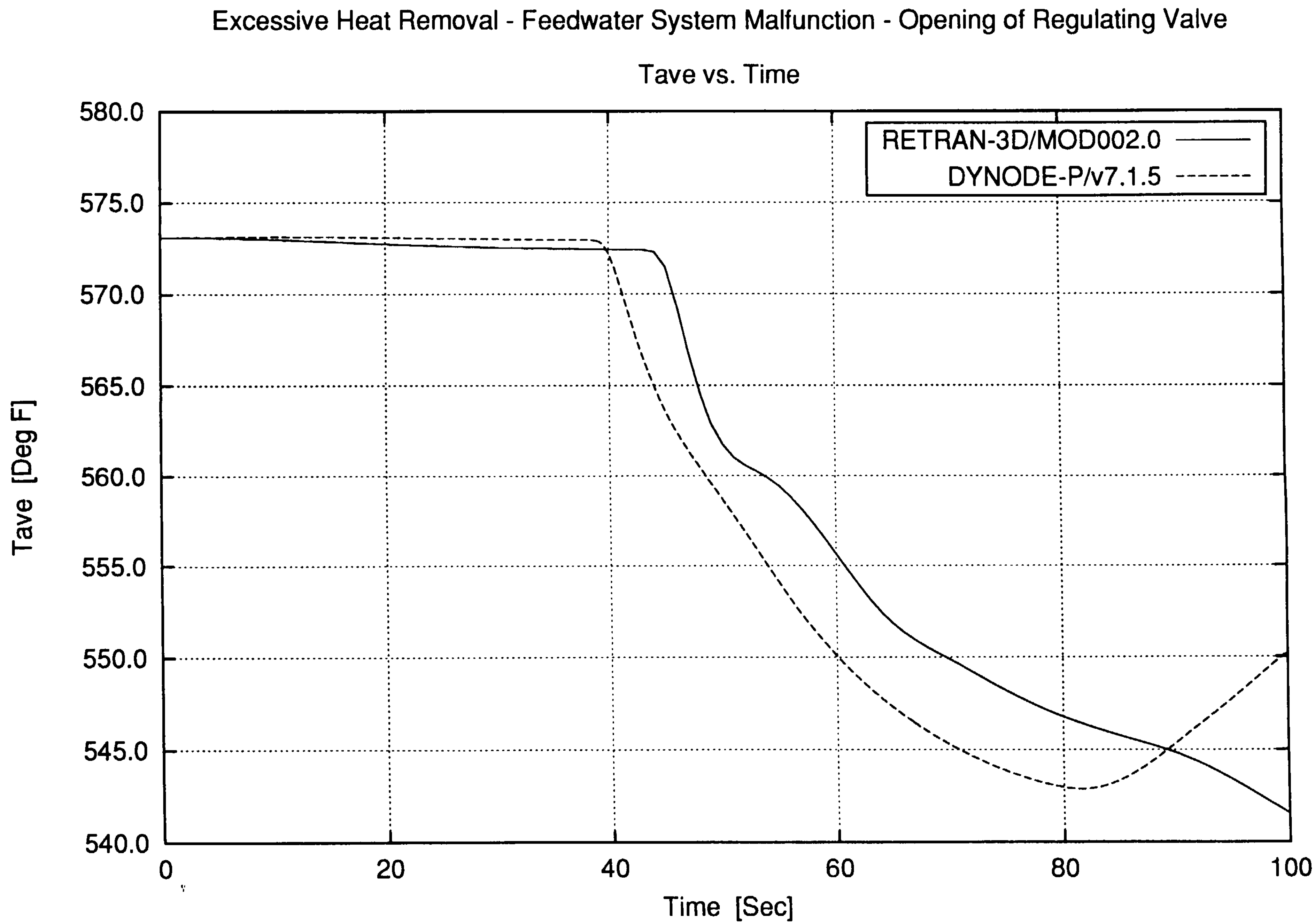


Figure 3-11



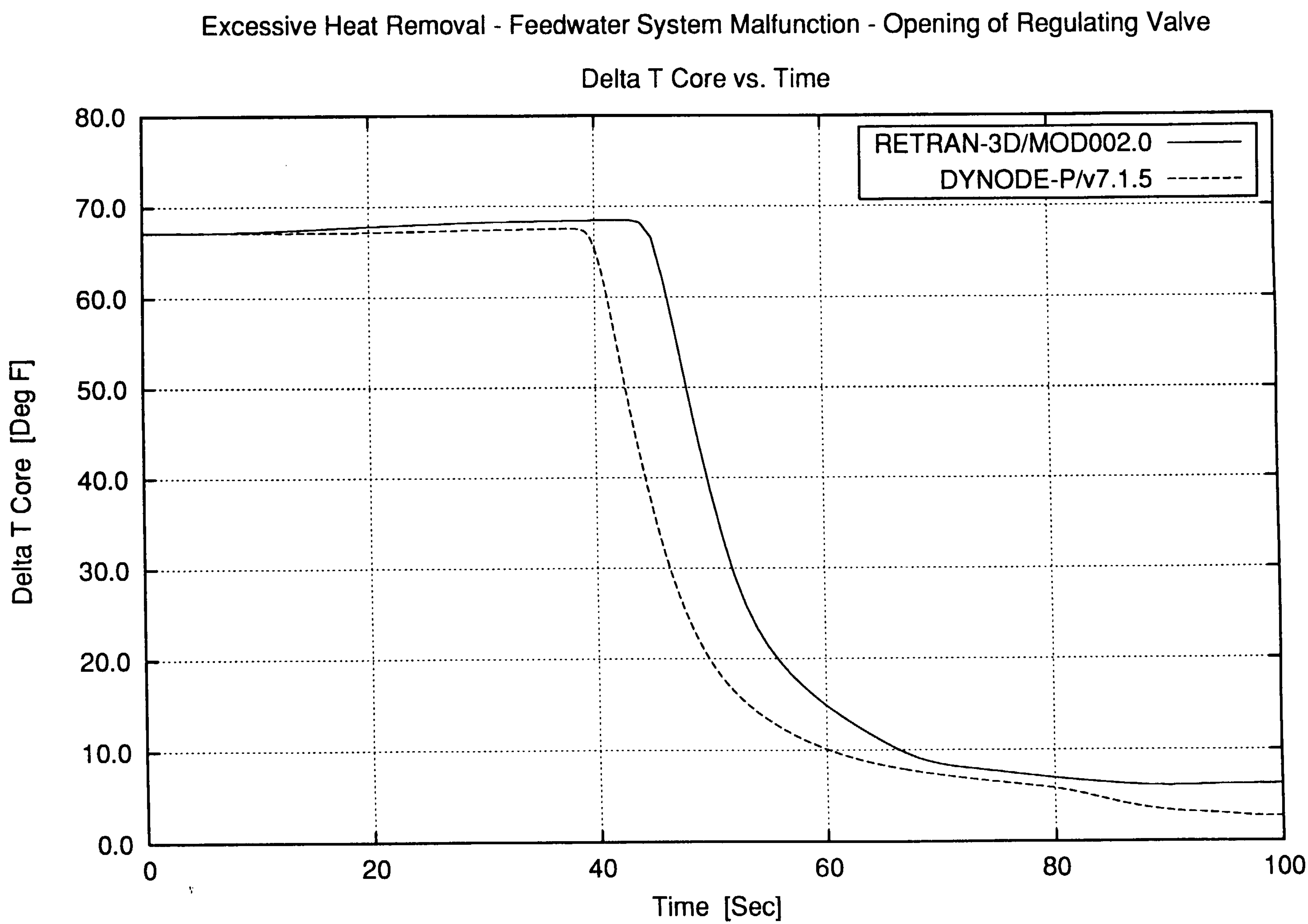
Excessive Heat Removal - Feedwater System Malfunction - Opening of Regulating Valve
Pressurizer Pressure vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Pressurizer Pressure [PSIA]
2300
2250
2200
2150
2100
2050
2000
1950
1900
0
20
40
60
80
100
Time [Sec]

Figure 3-12



Excessive Heat Removal - Feedwater System Malfunction - Opening of Regulating Valve
Tave vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
580.0
575.0
570.0
565.0
560.0
555.0
550.0
545.0
540.0
Tave [Deg F]
0
20
40
60
80
100
Time [Sec]

Figure 3-13



Excessive Heat Removal - Feedwater System Malfunction - Opening of Regulating Valve
Delta T Core vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Delta T Core [Deg F]
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
20
40
60
80
100
Time [Sec]

Figure 3-14

4. Excessive Load Increase

BOC Manual Control

Figure 4-1 shows the reactor power versus time. The two codes agree to within 0.5%.

Figure 4-2 shows the pressurizer pressure versus time. The results are almost identical.

Figure 4-3 shows the core ΔT versus time. The results are almost identical between the two codes.

Figure 4-4 shows the MDNBR versus time. The results are almost identical between the two codes.

EOC Manual Control

Figure 4-5 shows the reactor power versus time. The two codes agree to within 0.5%.

Figure 4-6 shows the pressurizer pressure versus time. The two codes agree to within 20 Psi.

Figure 4-7 shows the core ΔT versus time. The results are almost identical between the two codes.

Figure 4-8 shows the MDNBR versus time. The results are almost identical between the two codes.

BOC Automatic Control

Figure 4-9 shows the reactor power versus time. After steady-state is achieved, the two codes agree to within 1.2%.

Figure 4-10 shows the pressurizer pressure versus time. The results are almost identical between the two codes.

Figure 4-11 shows the core ΔT versus time. The RETRAN ΔT settles to a slightly higher value because of the slightly higher power.

Figure 4-12 shows T_{ave} versus time. The two codes agree to within 0.5° F.

Figure 4-13 shows the MDNBR versus time. The results are almost identical between the two codes.

EOC Automatic Control

Figure 4-14 shows the reactor power versus time. The two codes agree to within 1.5%.

Figure 4-15 shows the pressurizer pressure versus time. The two codes agree to within 30 Psi.

Figure 4-16 shows the core ΔT versus time. The RETRAN ΔT settles to a slightly higher value because of the slightly higher power.

Figure 4-17 shows T_{ave} versus time. The two codes agree to within 0.5°F.

Figure 4-18 shows the MDNBR versus time. The results are almost identical between the two codes.

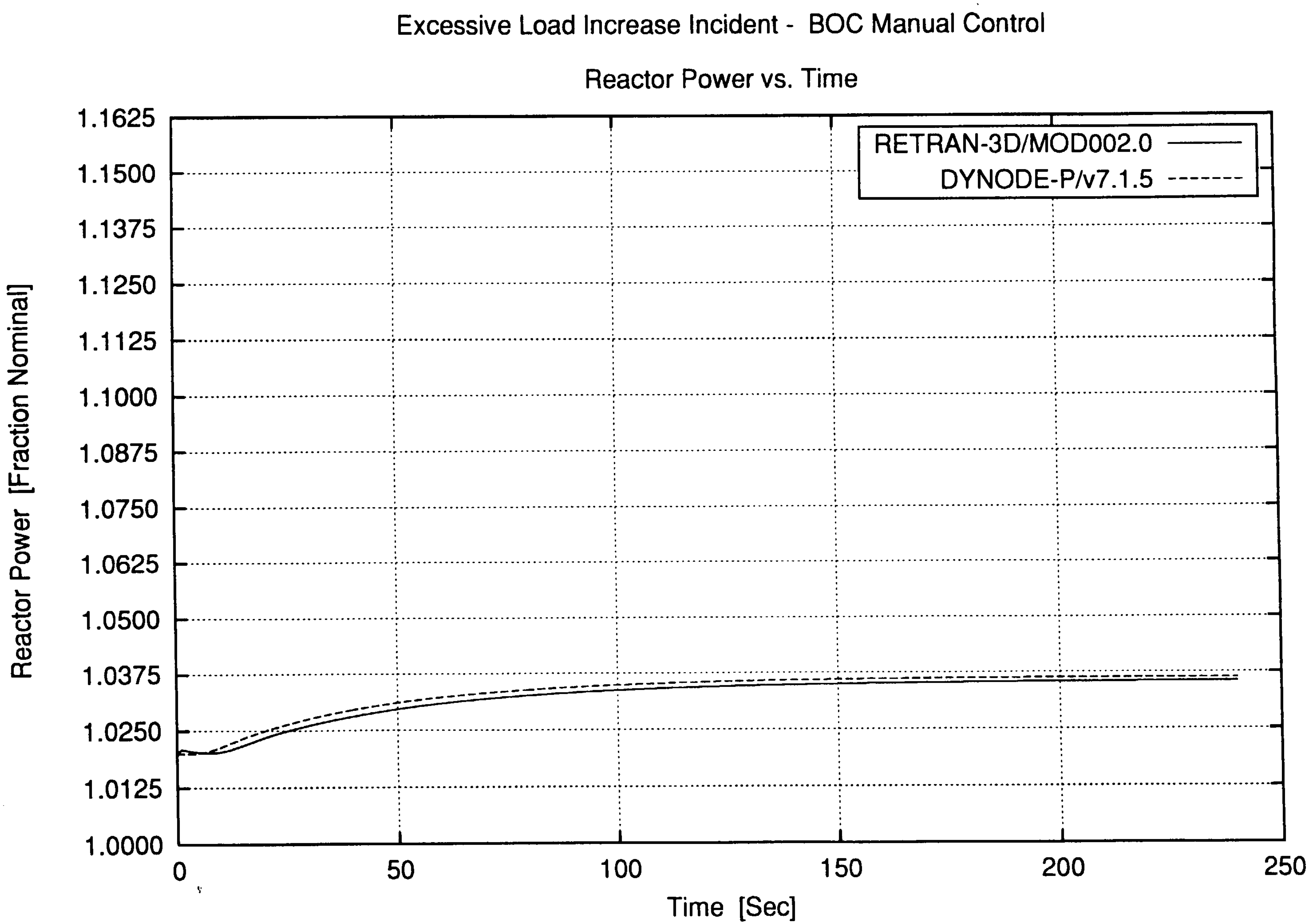
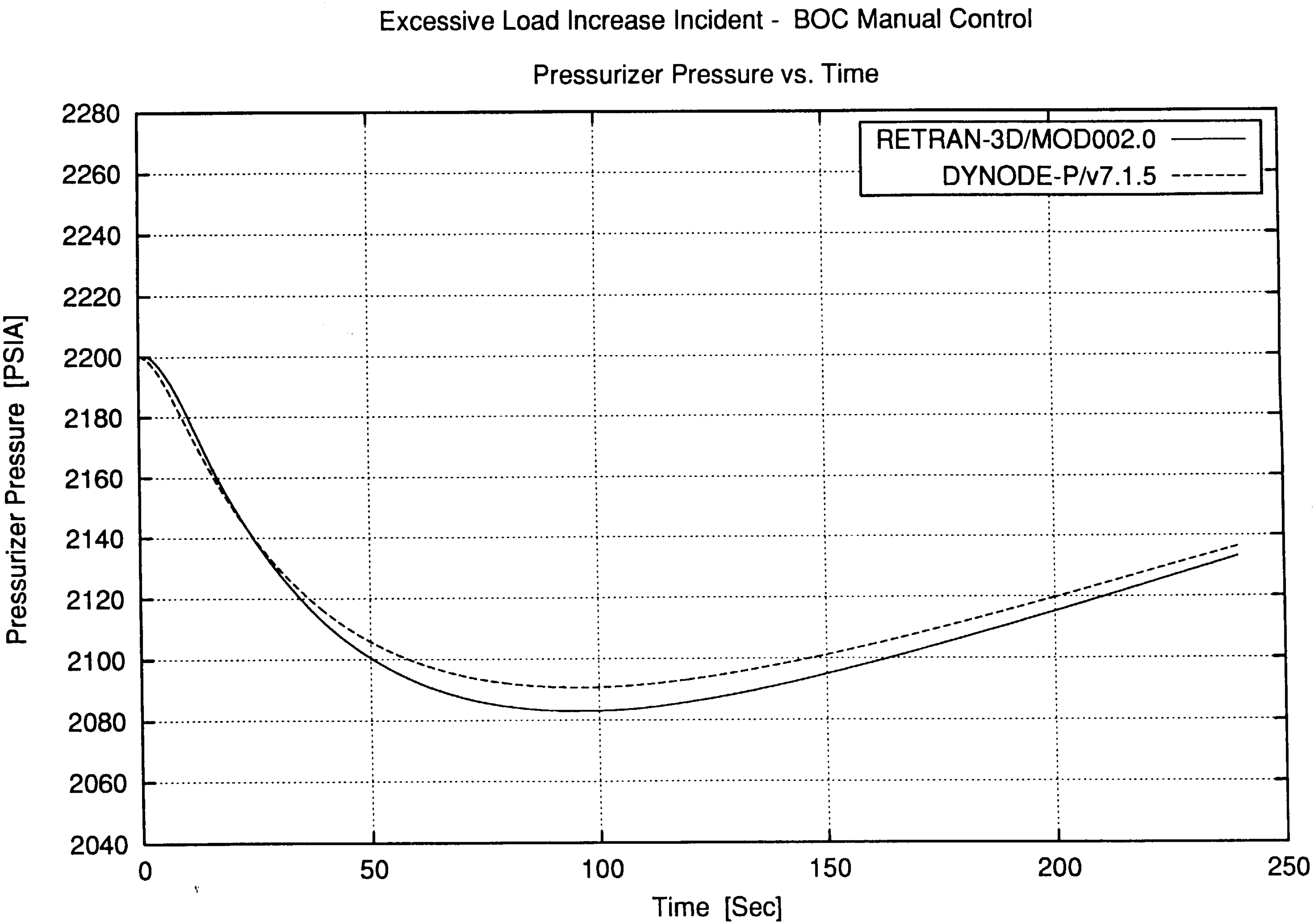

Excessive Load Increase Incident - BOC Manual Control
Reactor Power vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Reactor Power [Fraction Nominal]
1.1625
1.1500
1.1375
1.1250
1.1125
1.1000
1.0875
1.0750
1.0625
1.0500
1.0375
1.0250
1.0125
1.0000
0
50
100
150
200
250
Time [Sec]

Figure 4-1



Excessive Load Increase Incident - BOC Manual Control
Pressurizer Pressure vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Pressurizer Pressure [PSIA]
2280
2260
2240
2220
2200
2180
2160
2140
2120
2100
2080
2060
2040
0
50
100
150
200
250
Time [Sec]

Figure 4-2

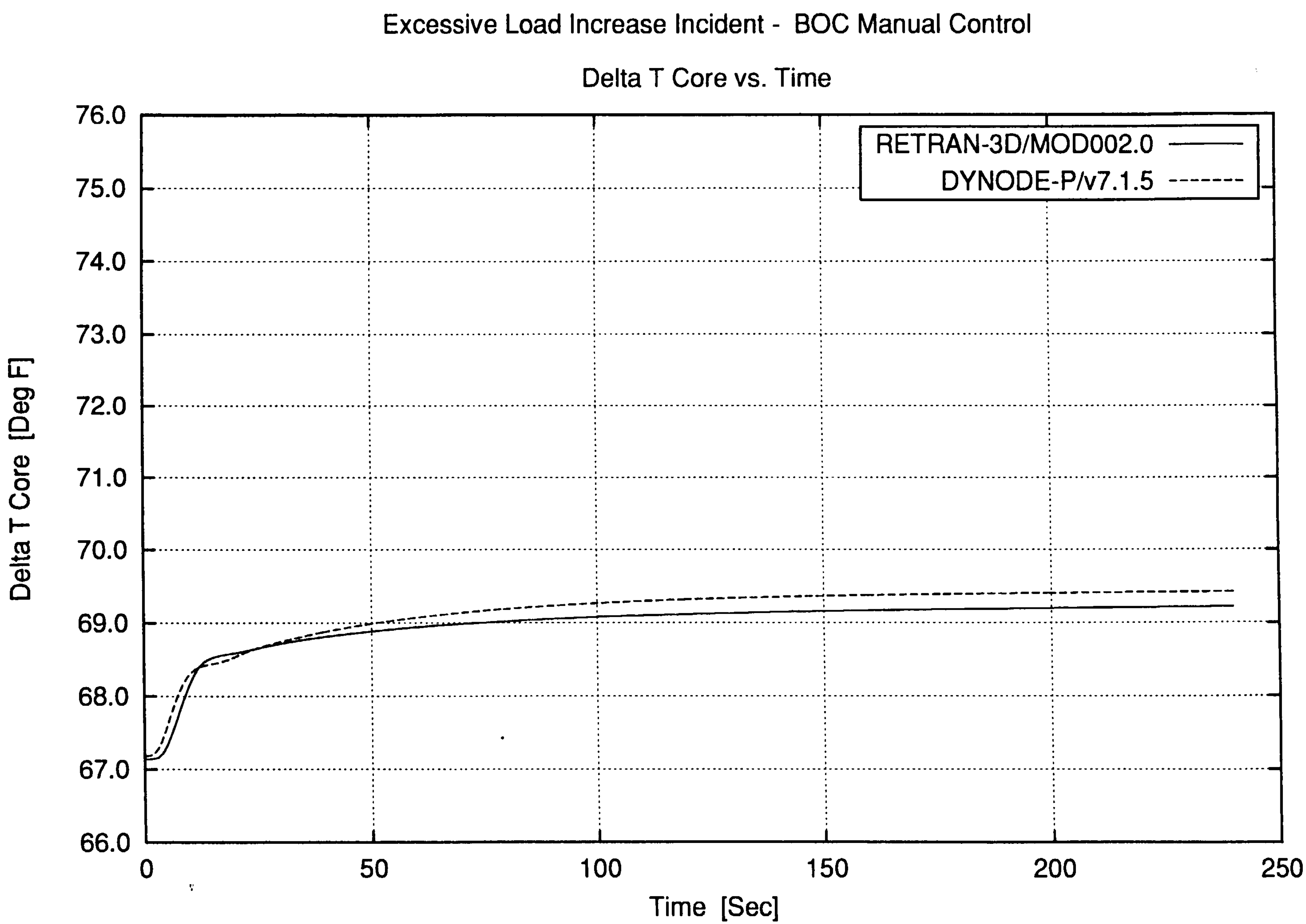

Excessive Load Increase Incident - BOC Manual Control
Delta T Core vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Delta T Core [Deg F]
76.0
75.0
74.0
73.0
72.0
71.0
70.0
69.0
68.0
67.0
66.0
0
50
100
150
200
250
Time [Sec]

Figure 4-3

Excessive Load Increase Incident - BOC Manual Control

Minimum DNBR vs. Time

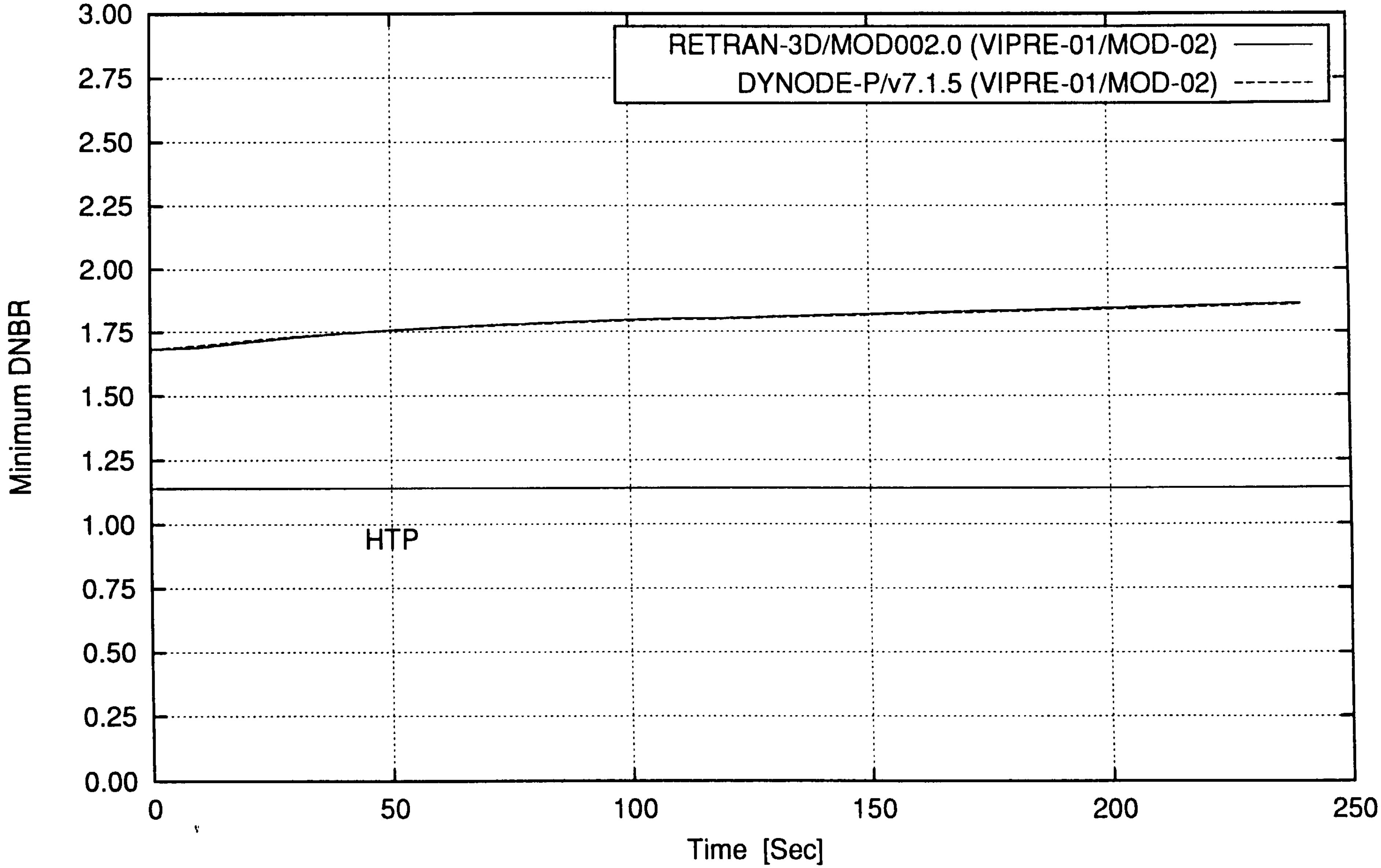


Figure 4-4

Excessive Load Increase Incident - EOC Manual Control

Reactor Power vs. Time

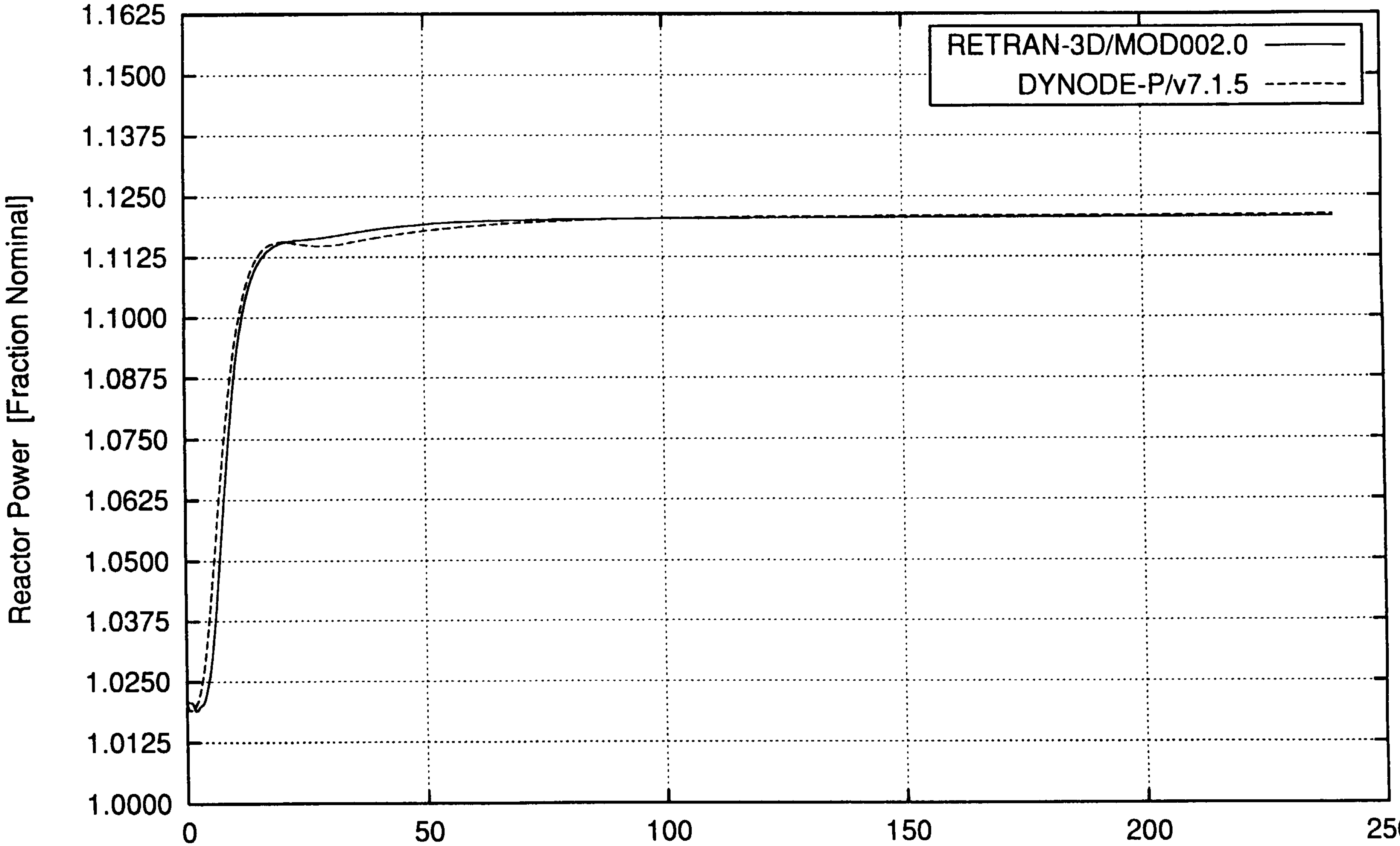


Figure 4-5

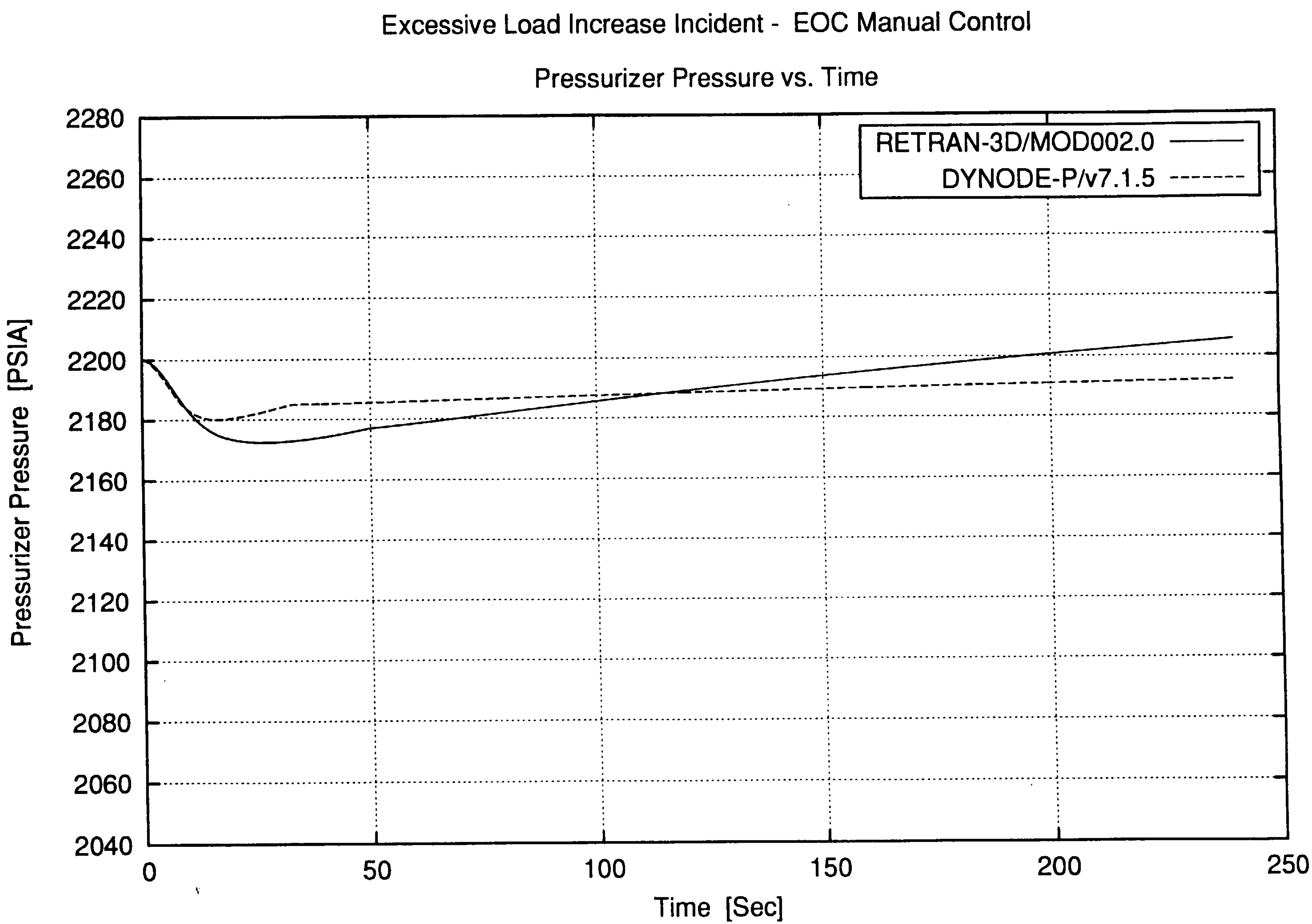

Excessive Load Increase Incident - EOC Manual Control
Pressurizer Pressure vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Pressurizer Pressure [PSIA]
2280
2260
2240
2220
2200
2180
2160
2140
2120
2100
2080
2060
2040
0
50
100
150
200
250
Time [Sec]

Figure 4-6

Excessive Load Increase Incident - EOC Manual Control

Delta T Core vs. Time

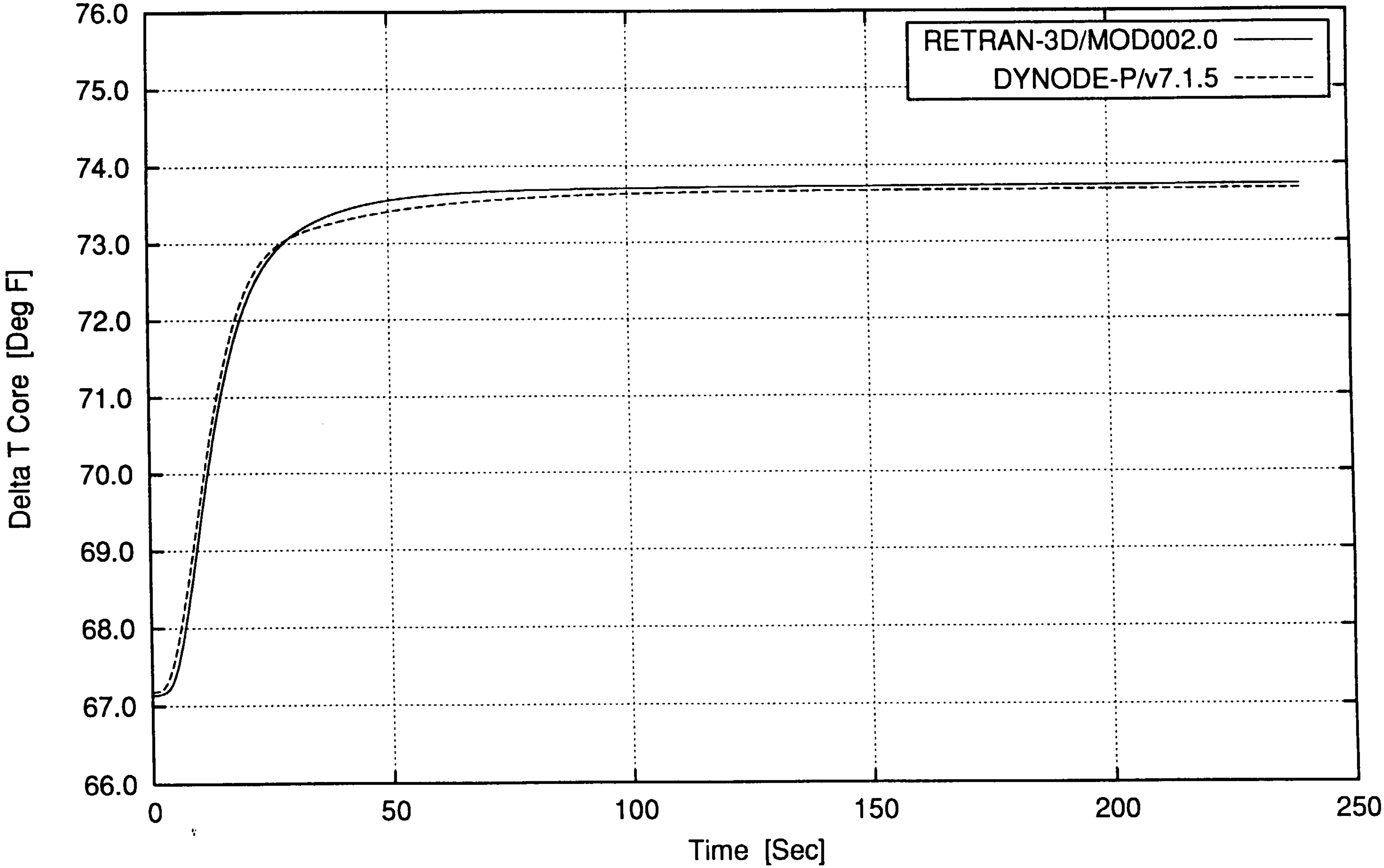


Figure 4-7

Excessive Load Increase Incident - EOC Manual Control

Minimum DNBR vs. Time

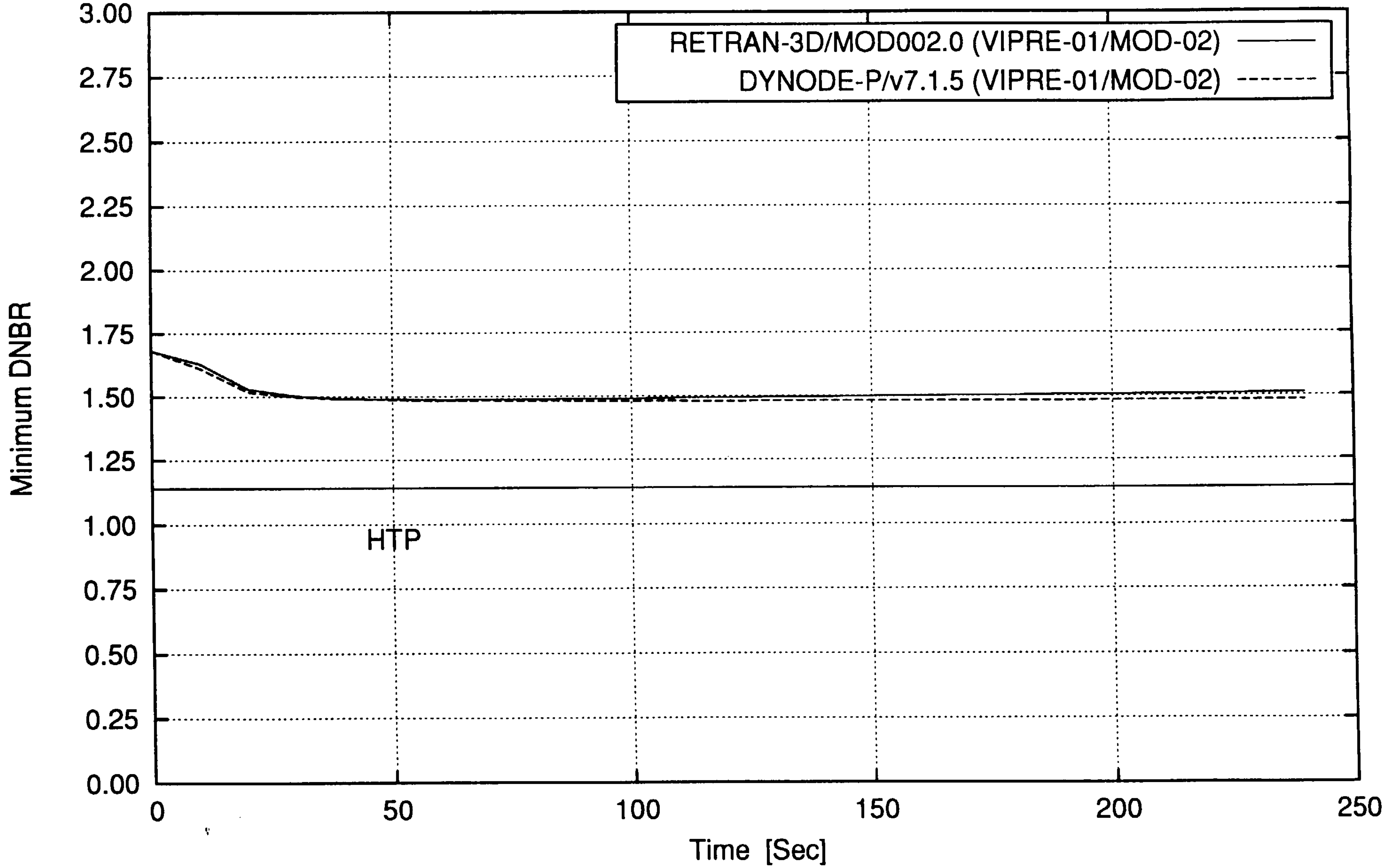


Figure 4-8

Excessive Load Increase Incident - BOC Auto Control

Reactor Power vs. Time

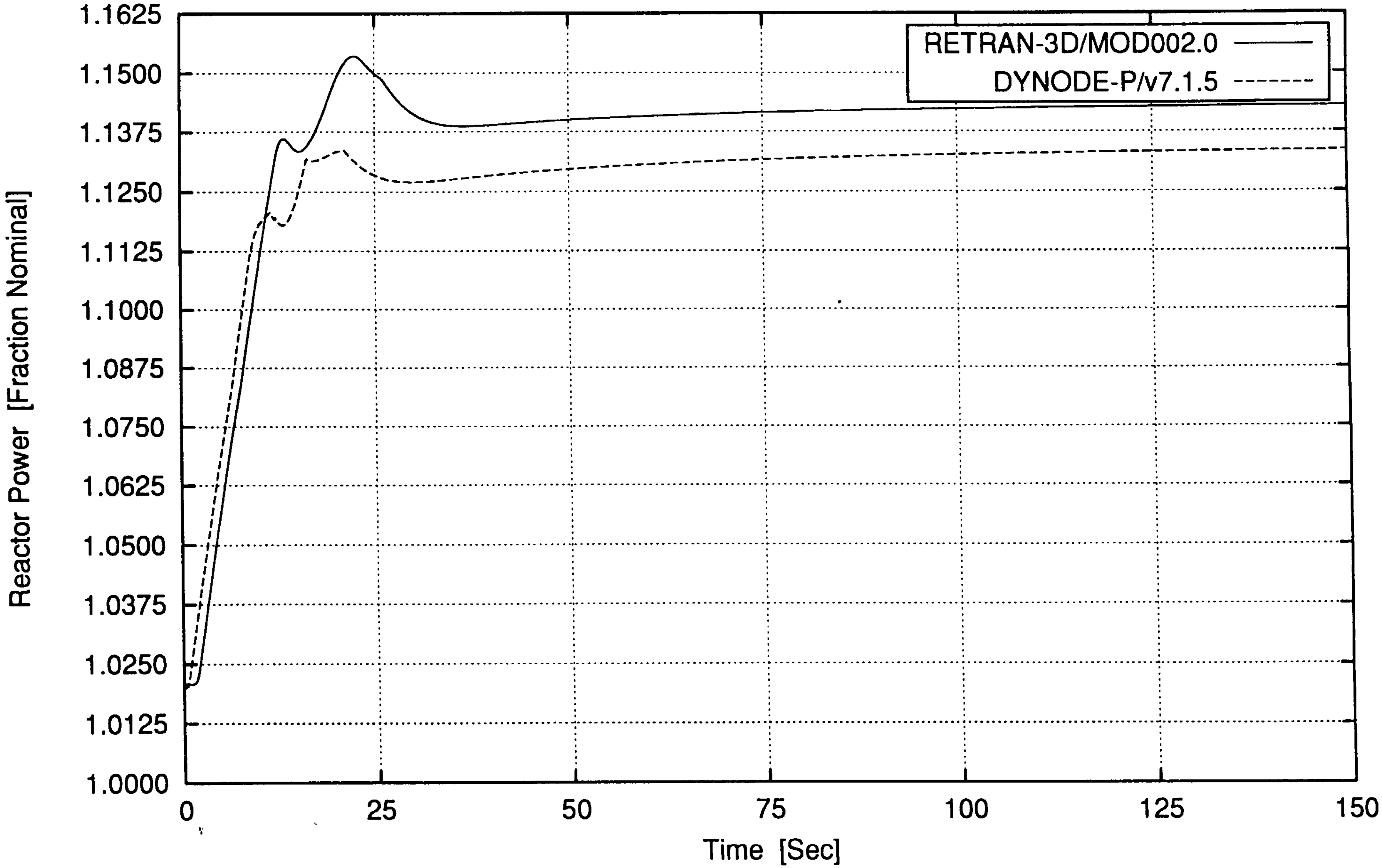
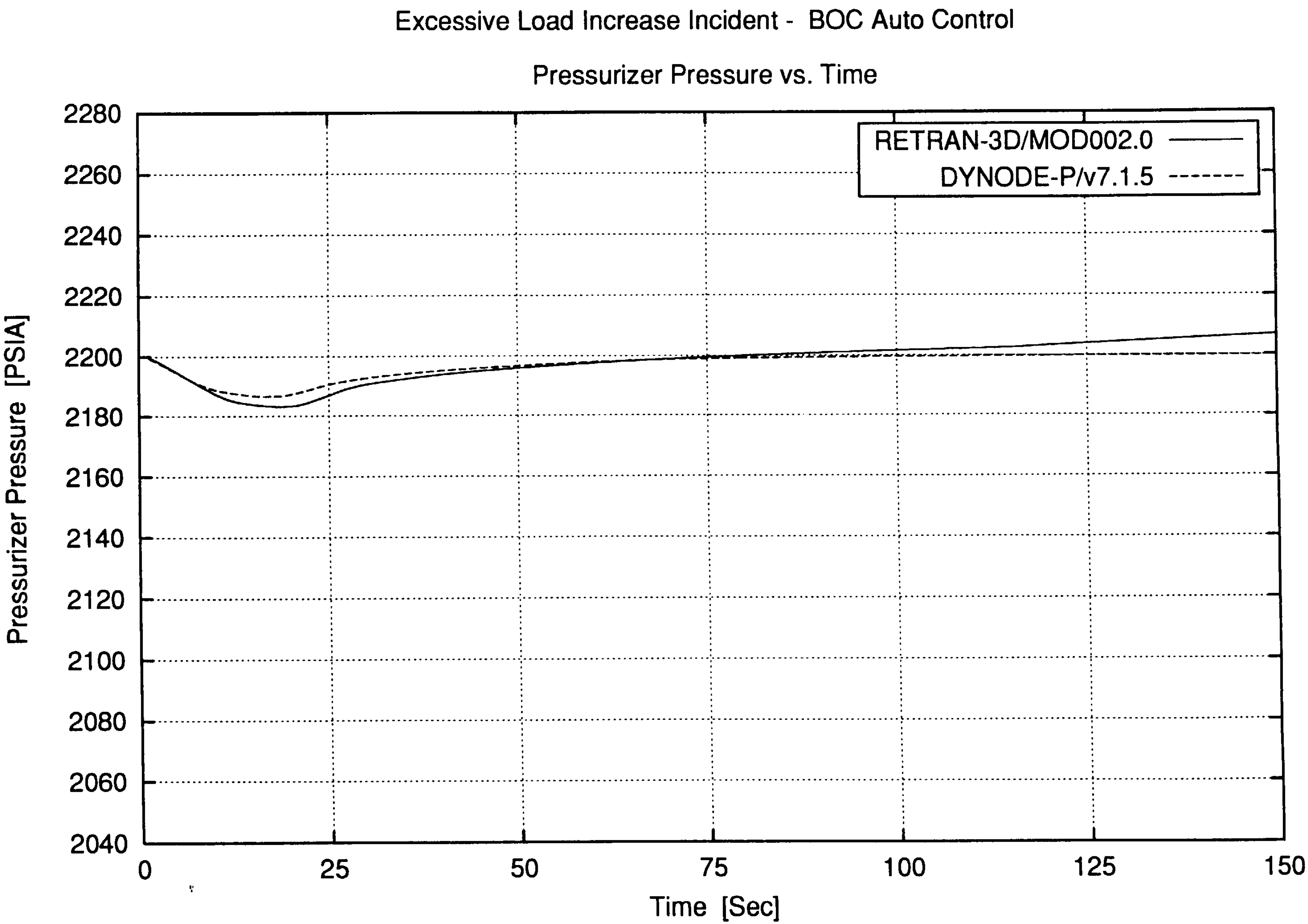


Figure 4-9



Excessive Load Increase Incident - BOC Auto Control
Pressurizer Pressure vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Pressurizer Pressure [PSIA]
2280
2260
2240
2220
2200
2180
2160
2140
2120
2100
2080
2060
2040
0
25
50
75
100
125
150
Time [Sec]

Figure 4-10

Excessive Load Increase Incident - BOC Auto Control

Delta T Core vs. Time

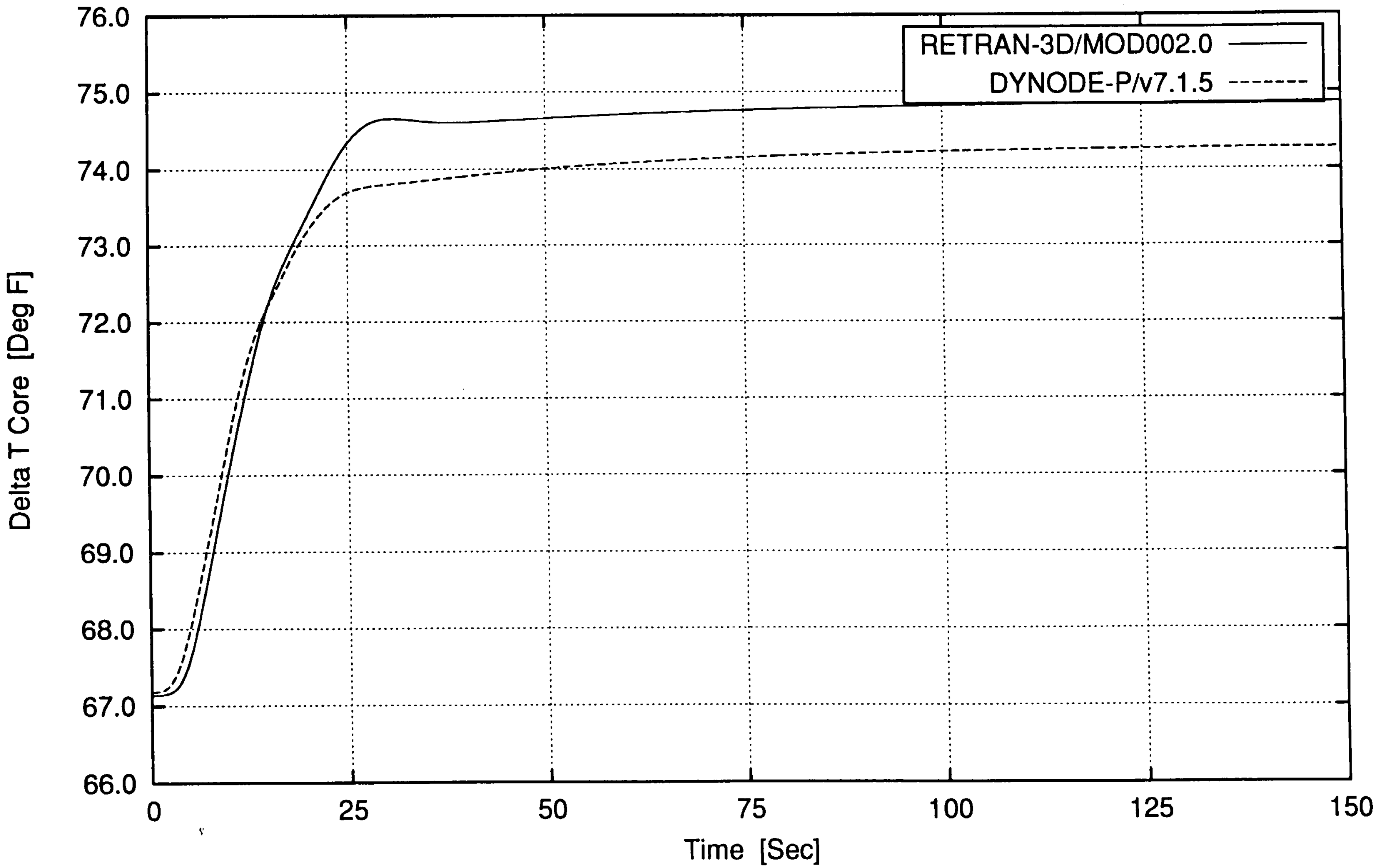


Figure 4-11

Excessive Load Increase Incident - BOC Auto Control

Tave vs. Time

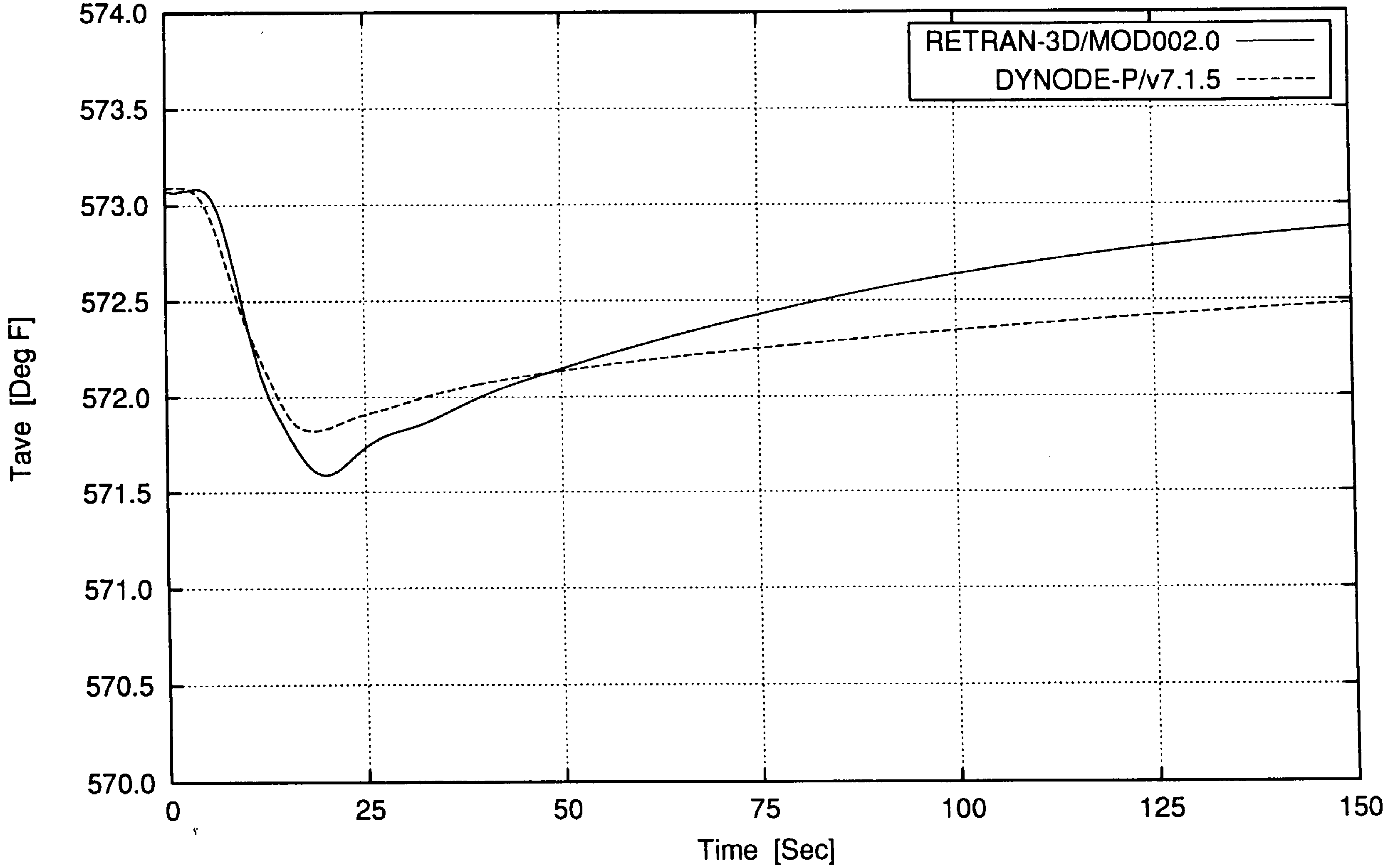


Figure 4-12

Excessive Load Increase Incident - BOC Auto Control

Minimum DNBR vs. Time

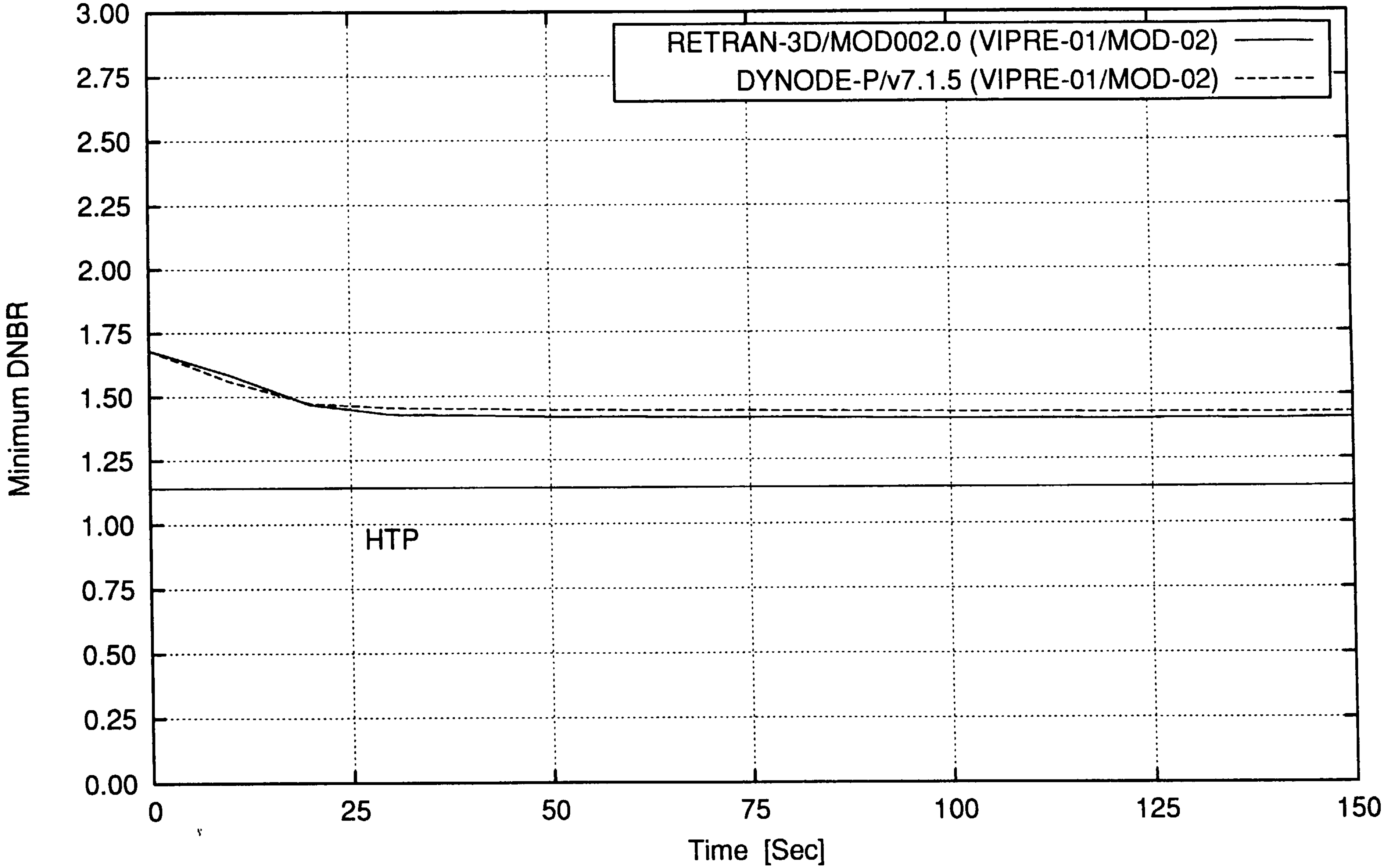


Figure 4-13

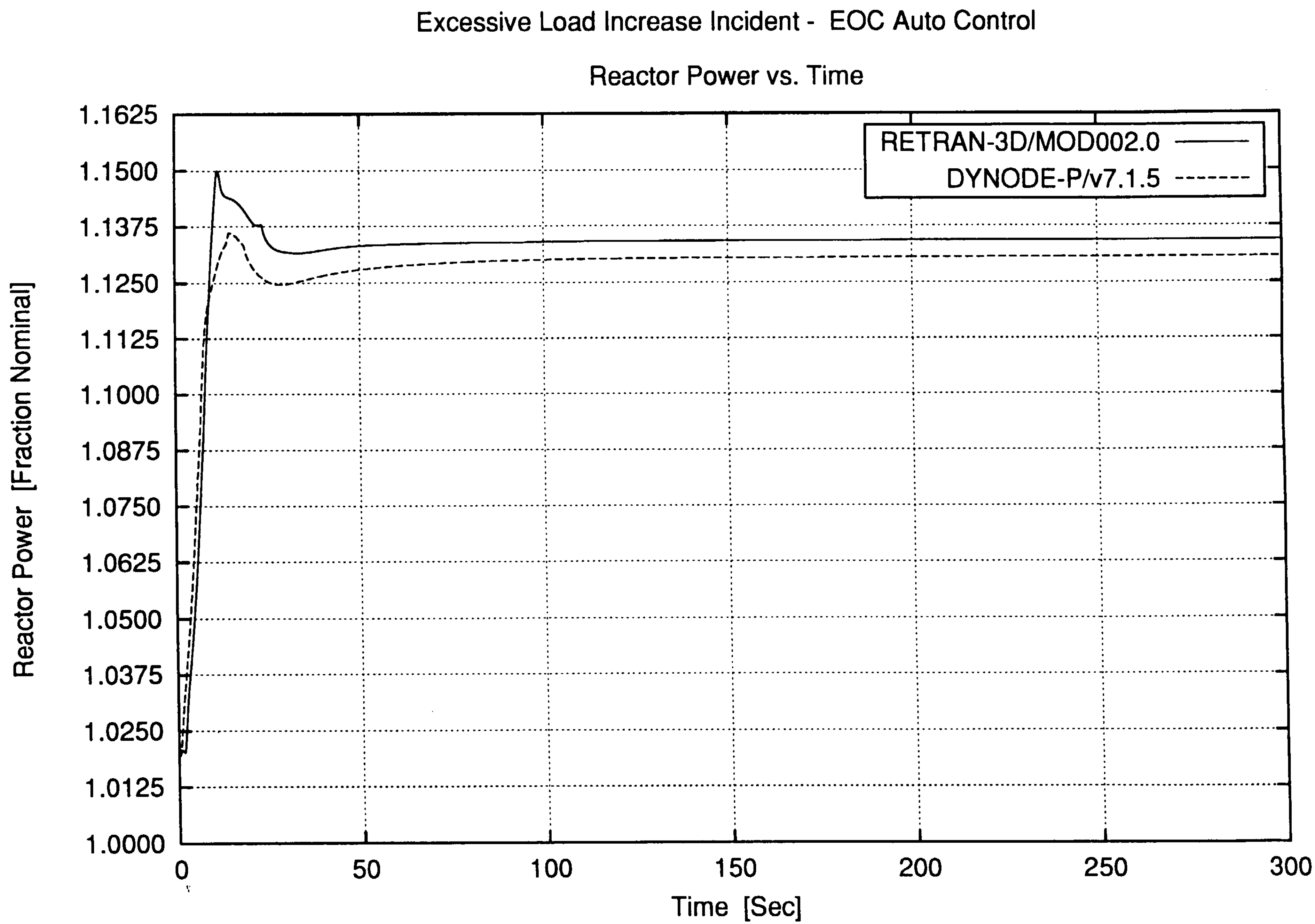

Excessive Load Increase Incident - EOC Auto Control
Reactor Power vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Reactor Power [Fraction Nominal]
1.1625
1.1500
1.1375
1.1250
1.1125
1.1000
1.0875
1.0750
1.0625
1.0500
1.0375
1.0250
1.0125
1.0000
0
50
100
150
200
250
300
Time [Sec]

Figure 4-14

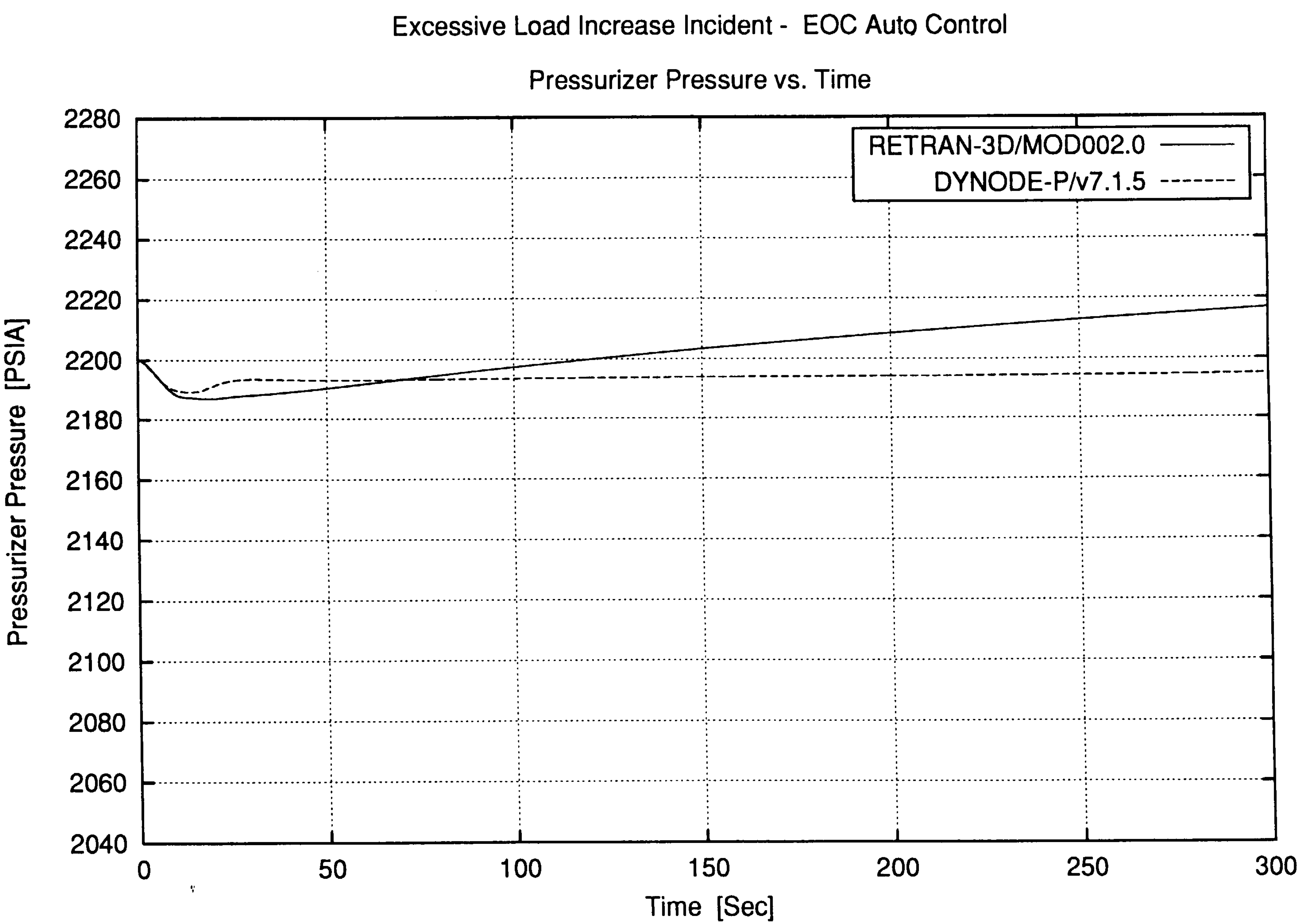

Excessive Load Increase Incident - EOC Auto Control
Pressurizer Pressure vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Pressurizer Pressure [PSIA]
2280
2260
2240
2220
2200
2180
2160
2140
2120
2100
2080
2060
2040
0
50
100
150
200
250
300
Time [Sec]

Figure 4-15

Excessive Load Increase Incident - EOC Auto Control

Delta T Core vs. Time

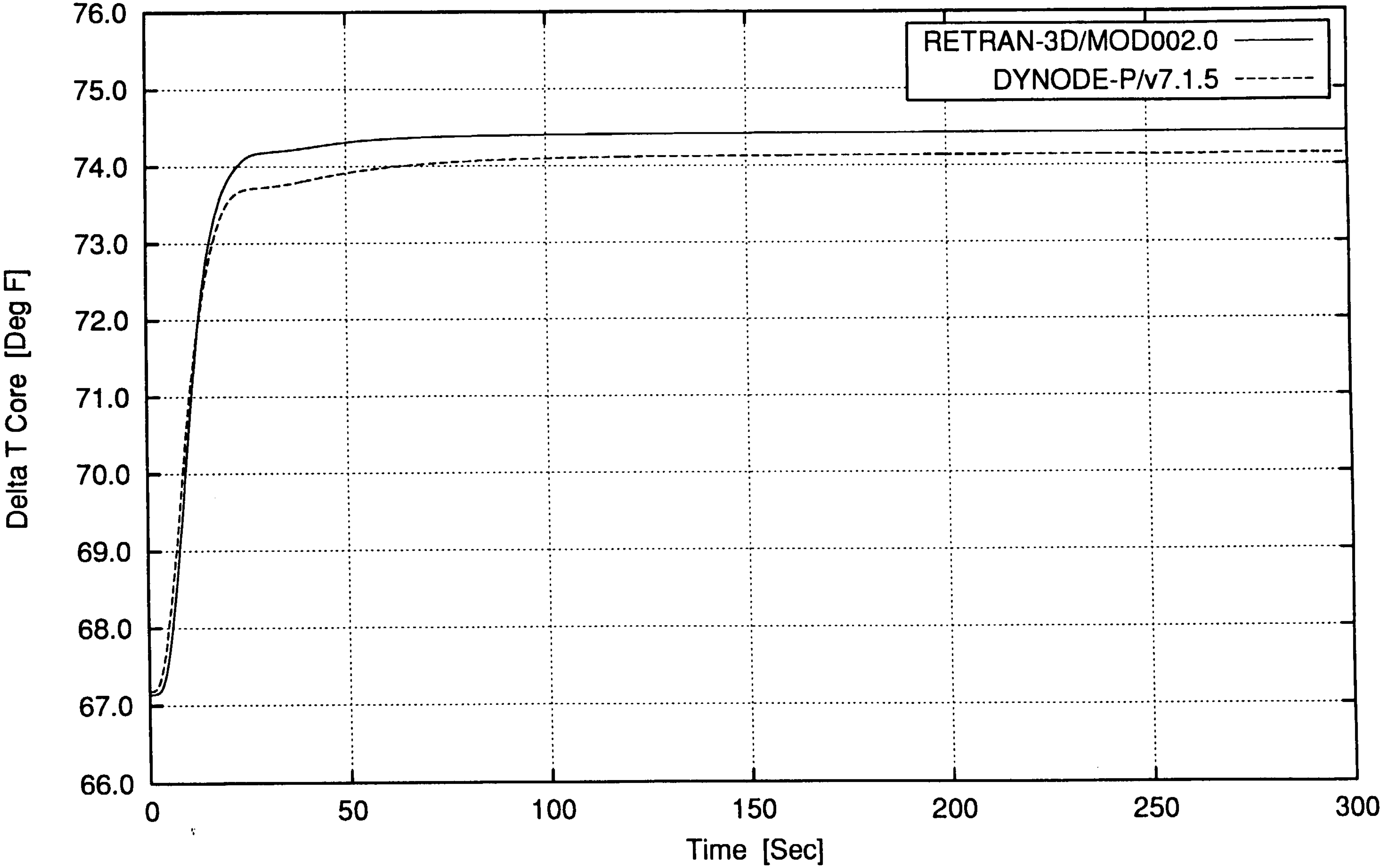
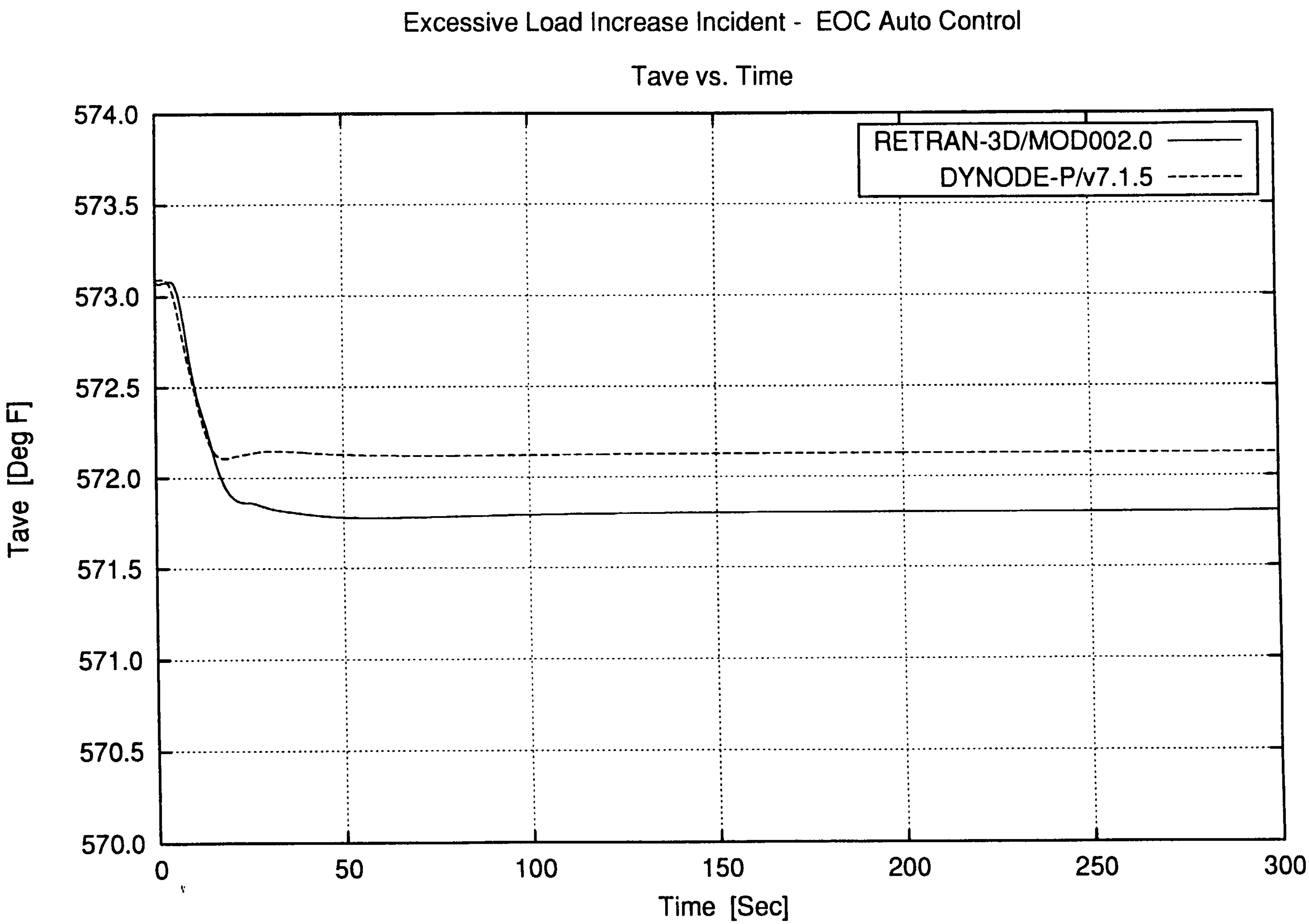


Figure 4-16



Excessive Load Increase Incident - EOC Auto Control
Tave vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
574.0
573.5
573.0
572.5
572.0
571.5
571.0
570.5
570.0
Tave [Deg F]
0
50
100
150
200
250
300
Time [Sec]

Figure 4-17

Excessive Load Increase Incident - EOC Auto Control

Minimum DNBR vs. Time

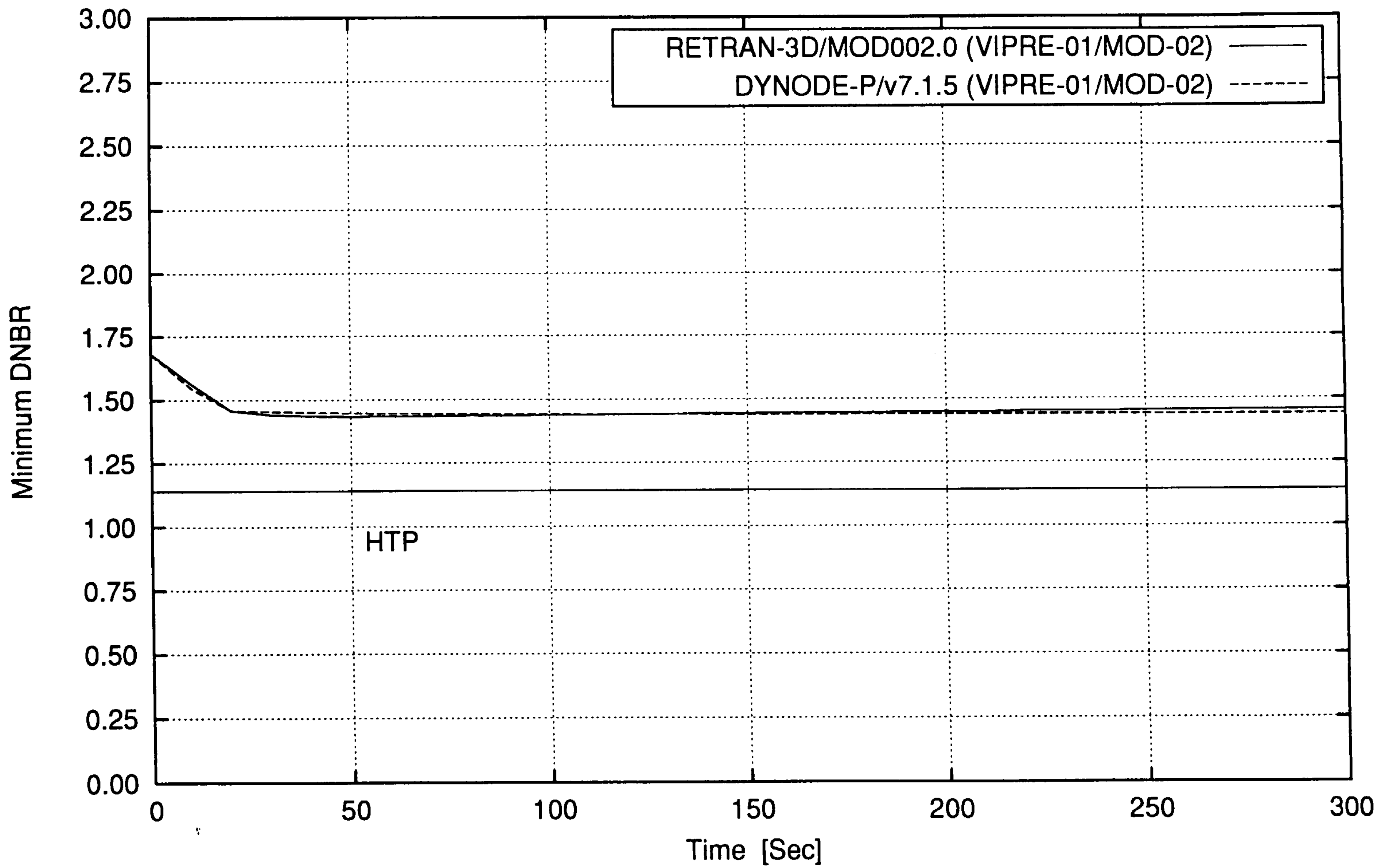


Figure 4-18

5. Loss of Reactor Coolant Flow

Two Pump Trip

Figure 5-1 shows the core flow versus time. The results are almost identical between the two codes.

Figure 5-2 shows reactor power versus time. The results are almost identical between the two codes.

Figure 5-3 shows core heat flux versus time. The results are within 5% between the two codes.

Figure 5-4 shows the MDNBR versus time. The results are almost identical between the two codes.

Underfrequency Trip

Figure 5-5 shows the core flow versus time. Core flow is almost identical between the two codes.

Figure 5-6 shows reactor power versus time. Power is almost identical between the two codes. In both codes, the reactor trip is on low reactor coolant flow.

Figure 5-7 shows core heat flux versus time. Heat flux agrees to within 5% between the two codes except for about the last 1/2 second for which the difference is only slightly greater than 5%.

Figure 5-8 shows the MDNBR versus time. The results up to the time of MDNBR are almost identical between the two codes.

Locked Rotor

Figure 5-9 shows the core flow versus time. Core flow is fairly consistent between the two codes. The flow settles to a slightly higher value in RETRAN, but the difference is not enough to have a major impact on the results.

Figure 5-10 shows core heat flux versus time. The increases at 0.5 and 1.2 seconds in RETRAN are non-physical and are due to heat transfer regime changes. At 0.5 seconds the middle core node moves from the single-phase liquid region to the fully developed nucleate boiling region. DYNODE models the core as twelve heat transfer regions instead of just three, so the curve is smoother. In both codes the reactor trip is on low reactor coolant flow.

Figure 5-11 shows pressurizer pressure versus time. The greater heat flux in RETRAN, due in part to the heat transfer regime changes discussed above, causes a faster rate of heat addition and larger total amount of heat to be deposited in the primary side leading to a greater rise in pressure.

Figure 5-12 shows the MDNBR versus time. The greater heat flux in RETRAN (see above) causes a lower MDNBR. Note that for the Locked Rotor accident, a lower MDNBR translates into a lower allowable $F_{\Delta H}$ value (see Table 8 of Section III.8) for the given MDNBR limit and does not represent an MDNBR violation.

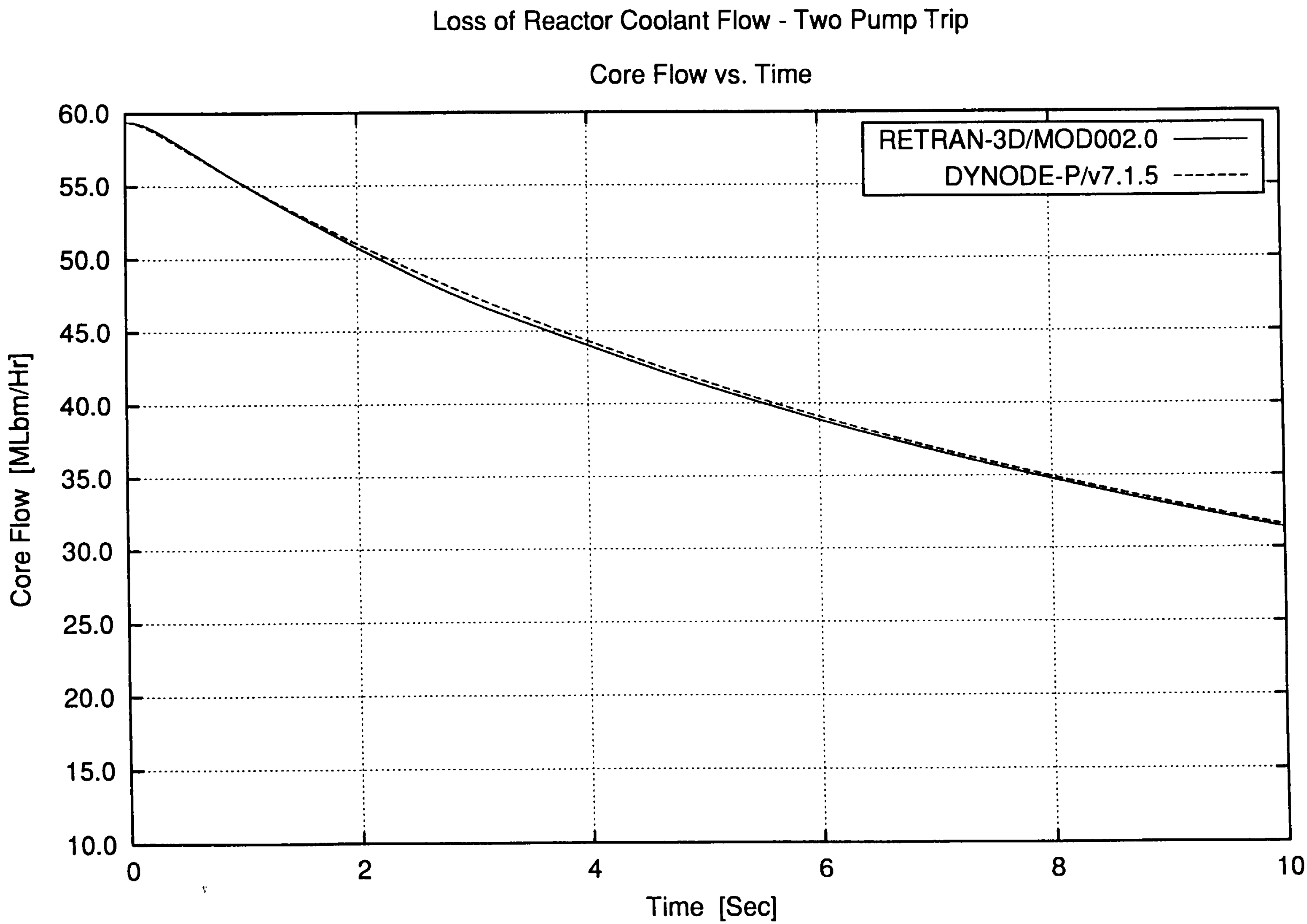
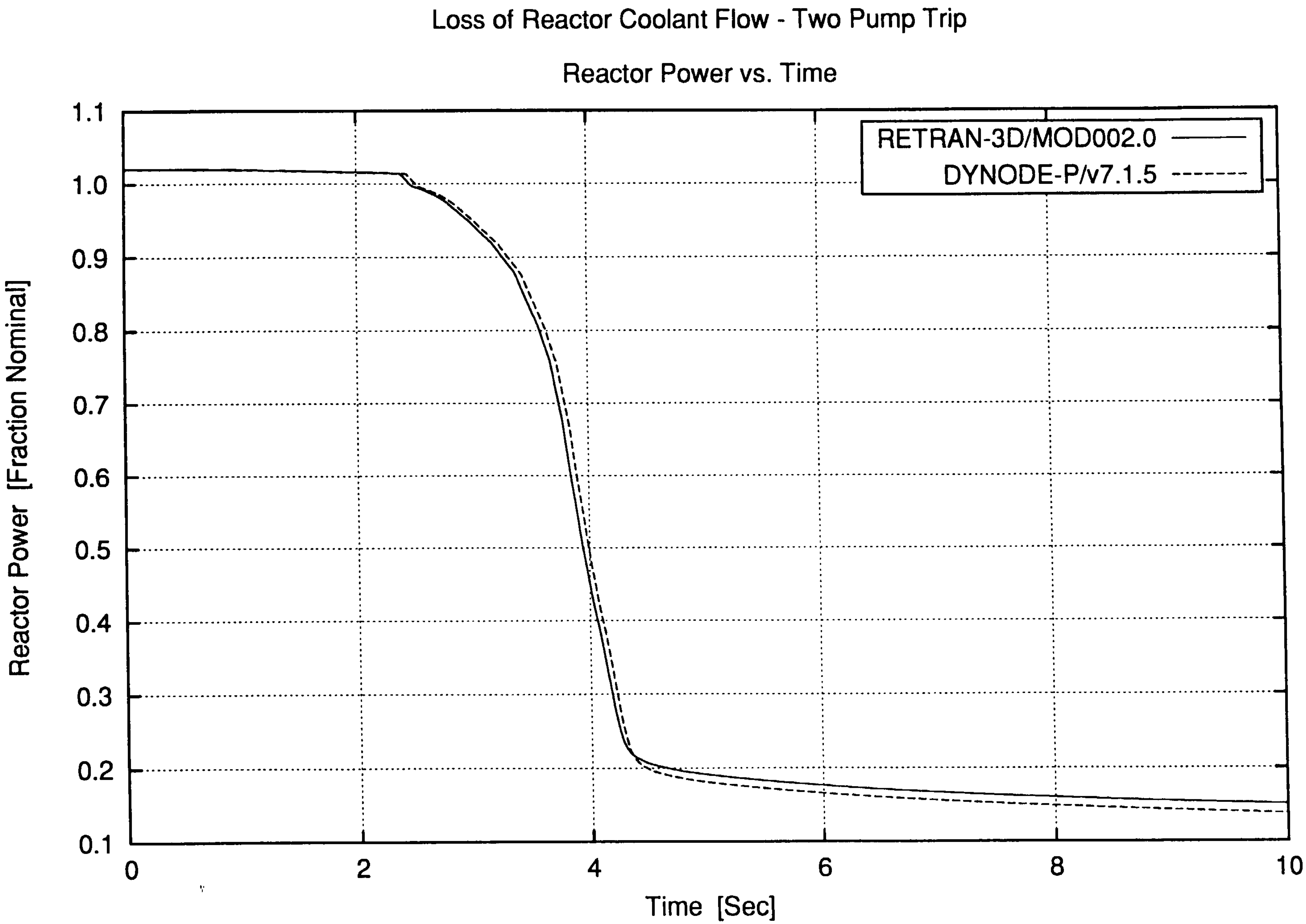

Loss of Reactor Coolant Flow - Two Pump Trip
Core Flow vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Core Flow [MLbm/Hr]
Time [Sec]
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
0
2
4
6
8
10

Figure 5-1



Loss of Reactor Coolant Flow - Two Pump Trip
Reactor Power vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Reactor Power [Fraction Nominal]
Time [Sec]
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
4
6
8
10

Figure 5-2

Loss of Reactor Coolant Flow - Two Pump Trip

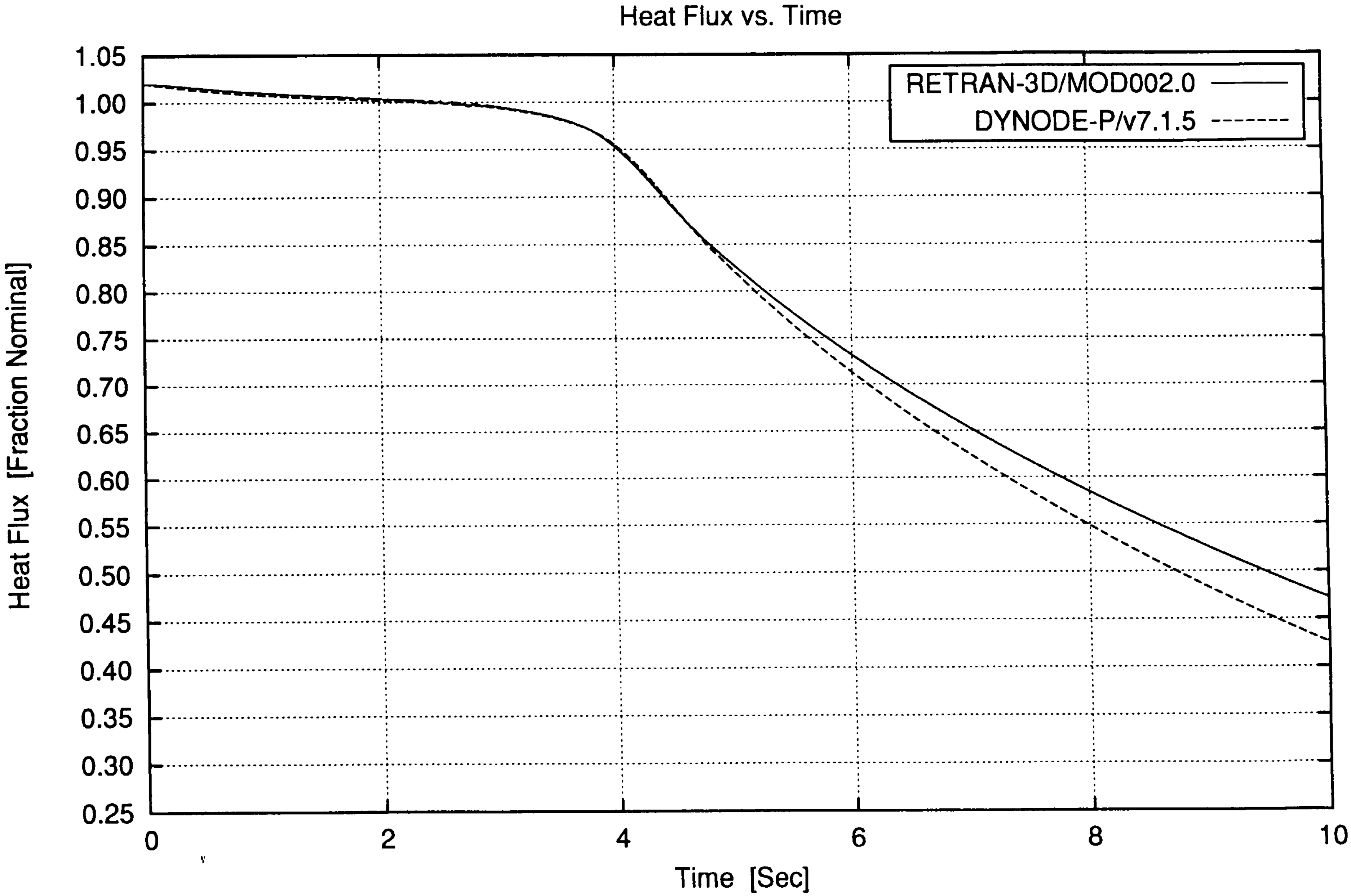


Figure 5-3

Loss of Reactor Coolant Flow - Two Pump Trip

Minimum DNBR vs. Time

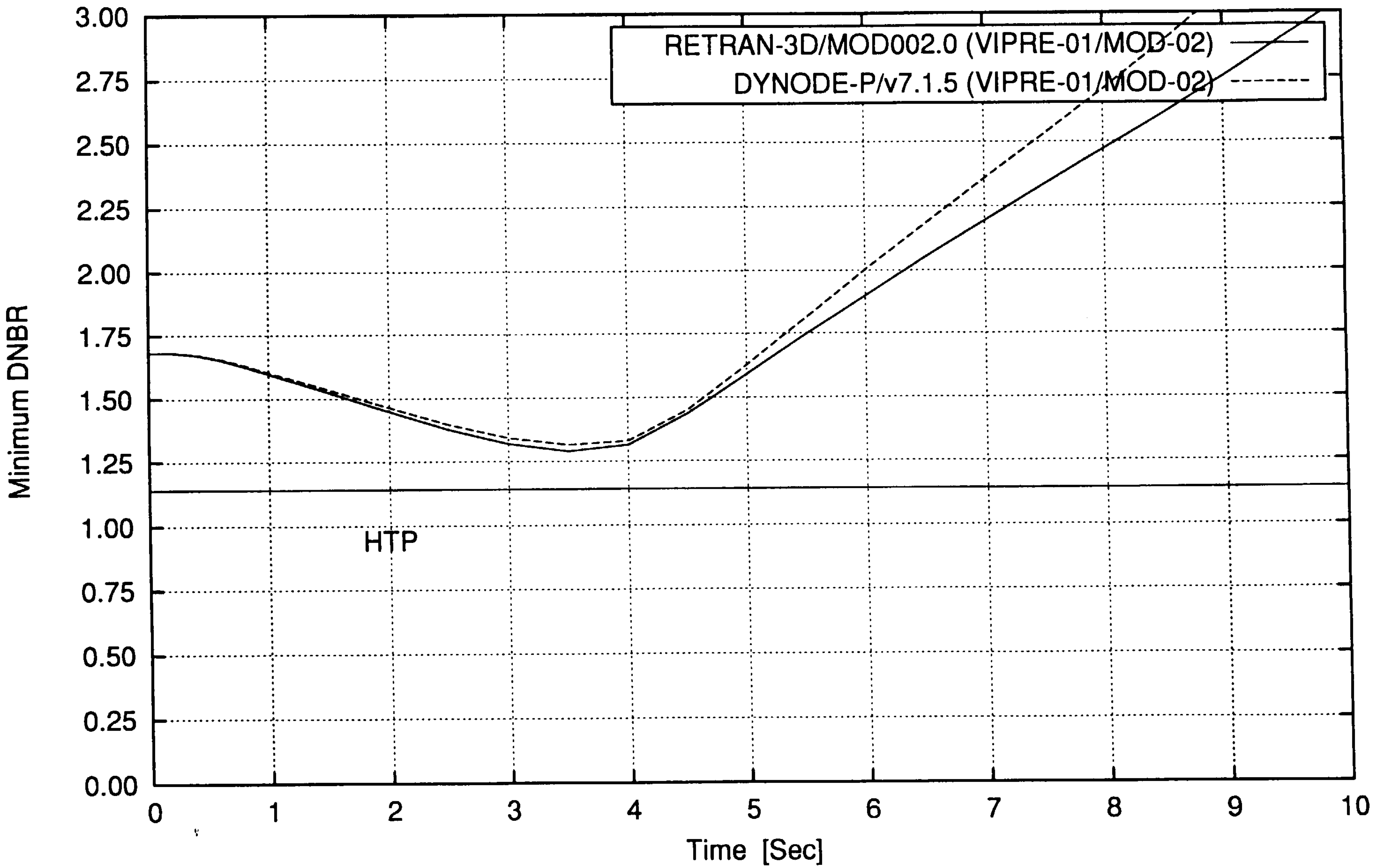
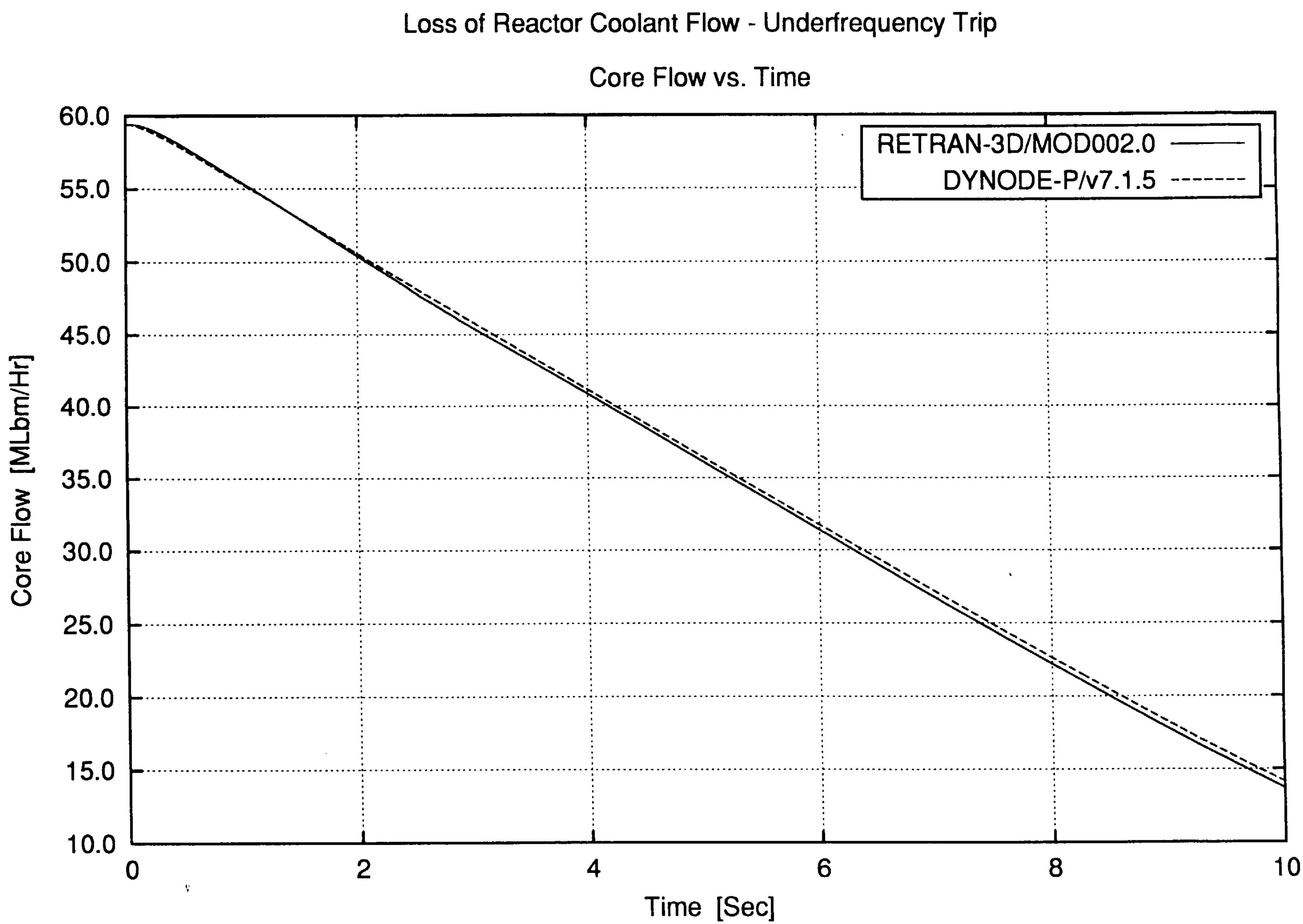


Figure 5-4



Loss of Reactor Coolant Flow - Underfrequency Trip
Core Flow vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Core Flow [MLbm/Hr]
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
0
2
4
6
8
10
Time [Sec]

Figure 5-5

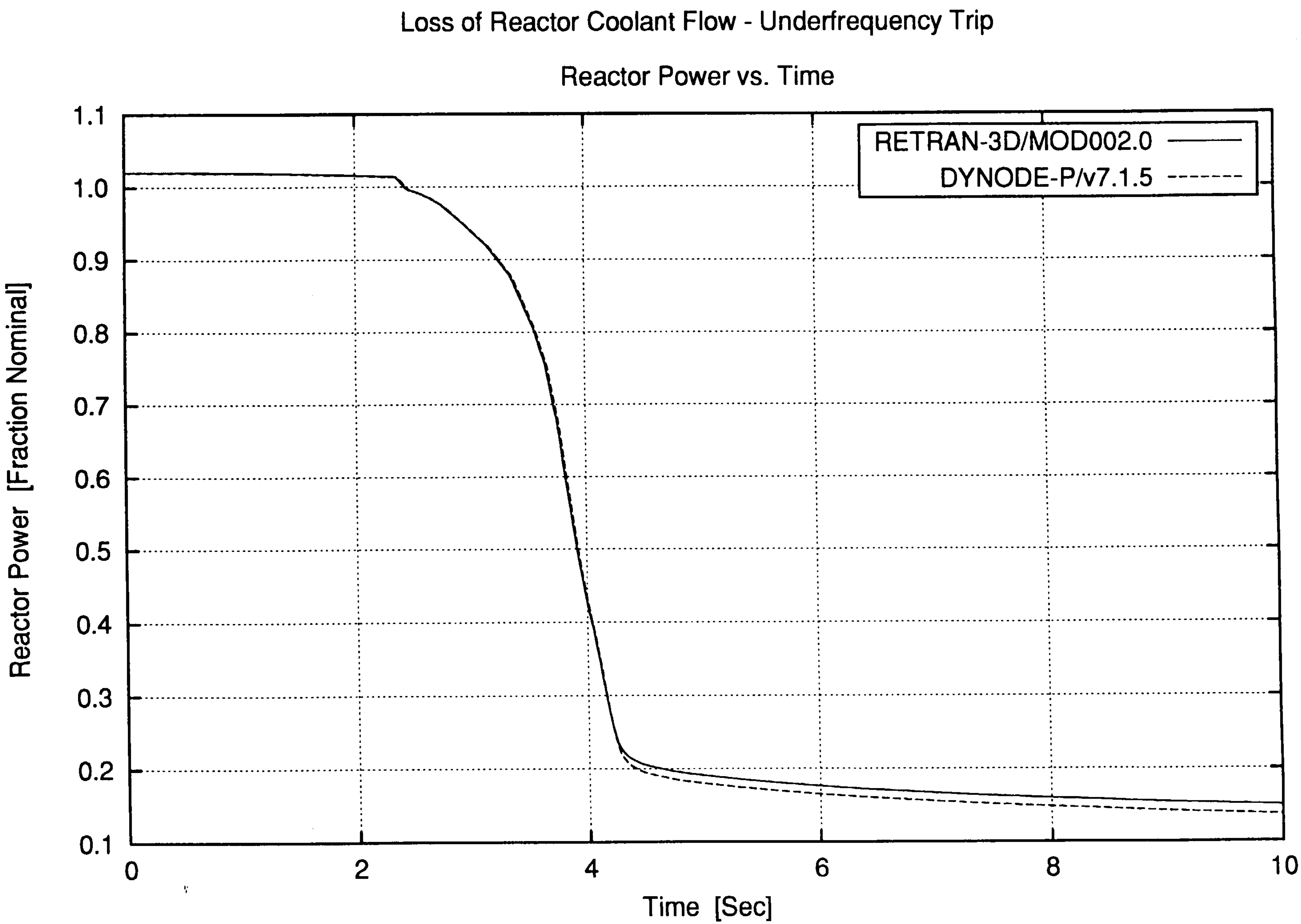

Loss of Reactor Coolant Flow - Underfrequency Trip
Reactor Power vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Reactor Power [Fraction Nominal]
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
4
6
8
10
Time [Sec]

Figure 5-6

Loss of Reactor Coolant Flow - Underfrequency Trip

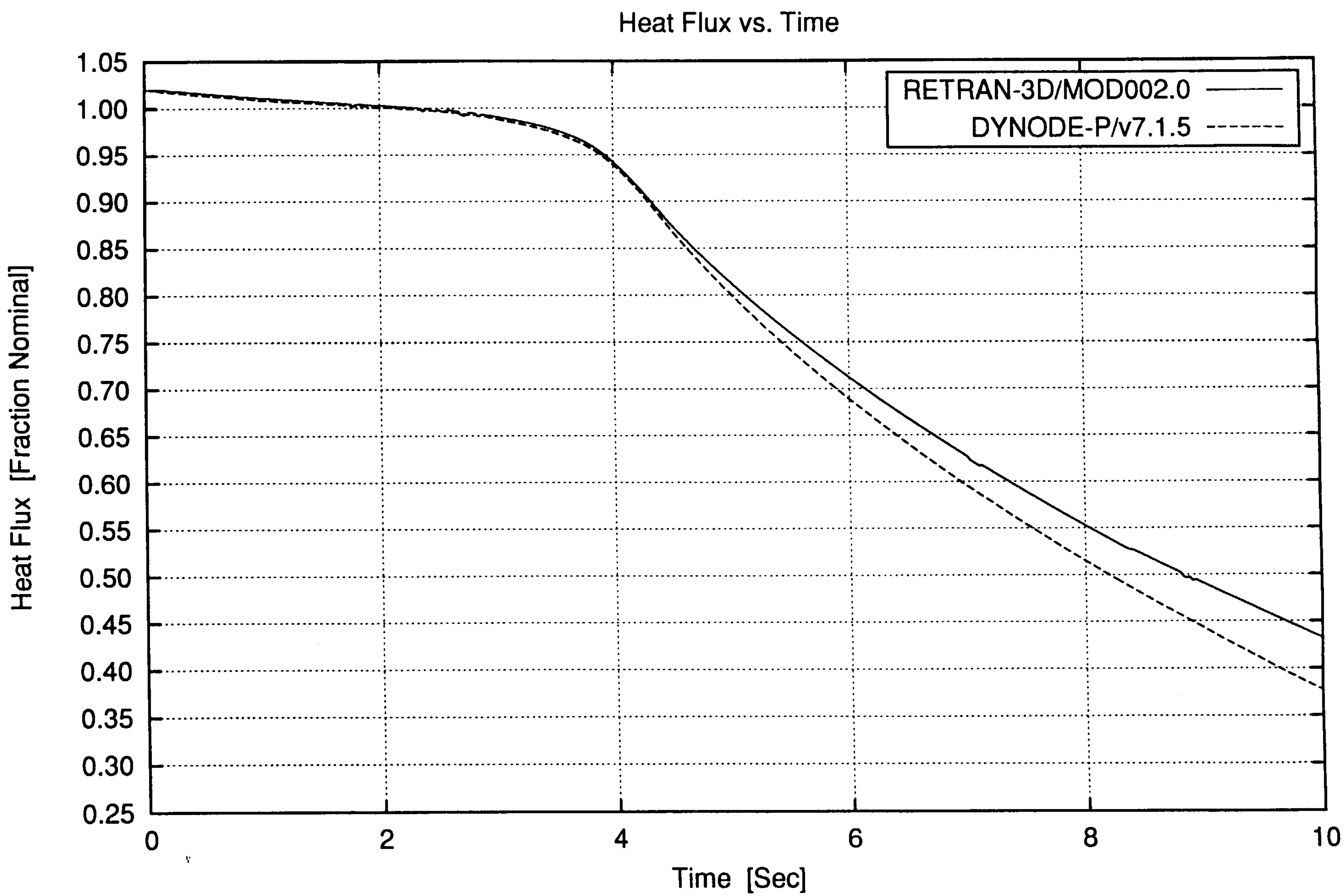


Figure 5-7

Loss of Reactor Coolant Flow - Underfrequency Trip

Minimum DNBR vs. Time

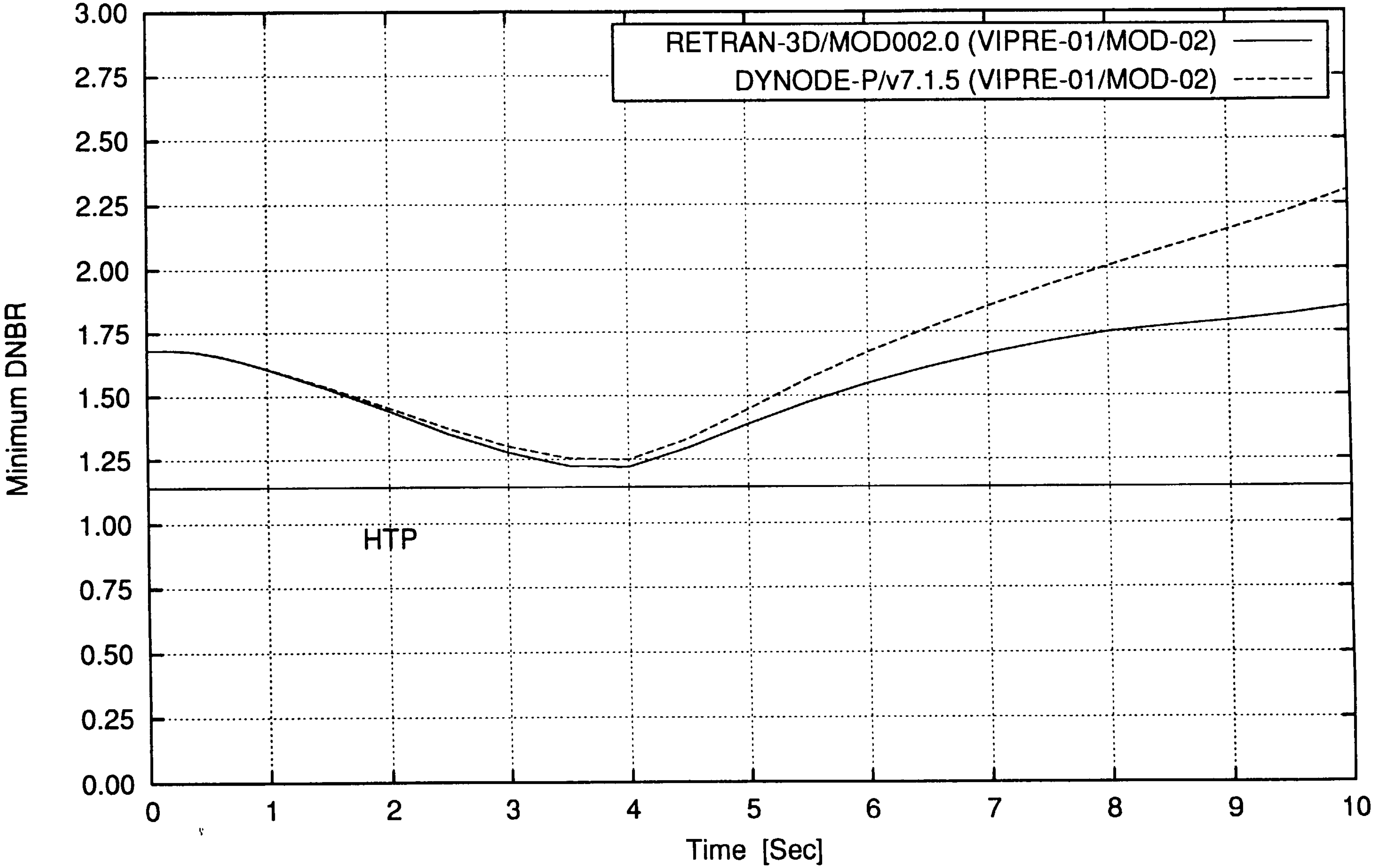


Figure 5-8

Loss of Reactor Coolant Flow - Locked Rotor

Core Flow vs. Time

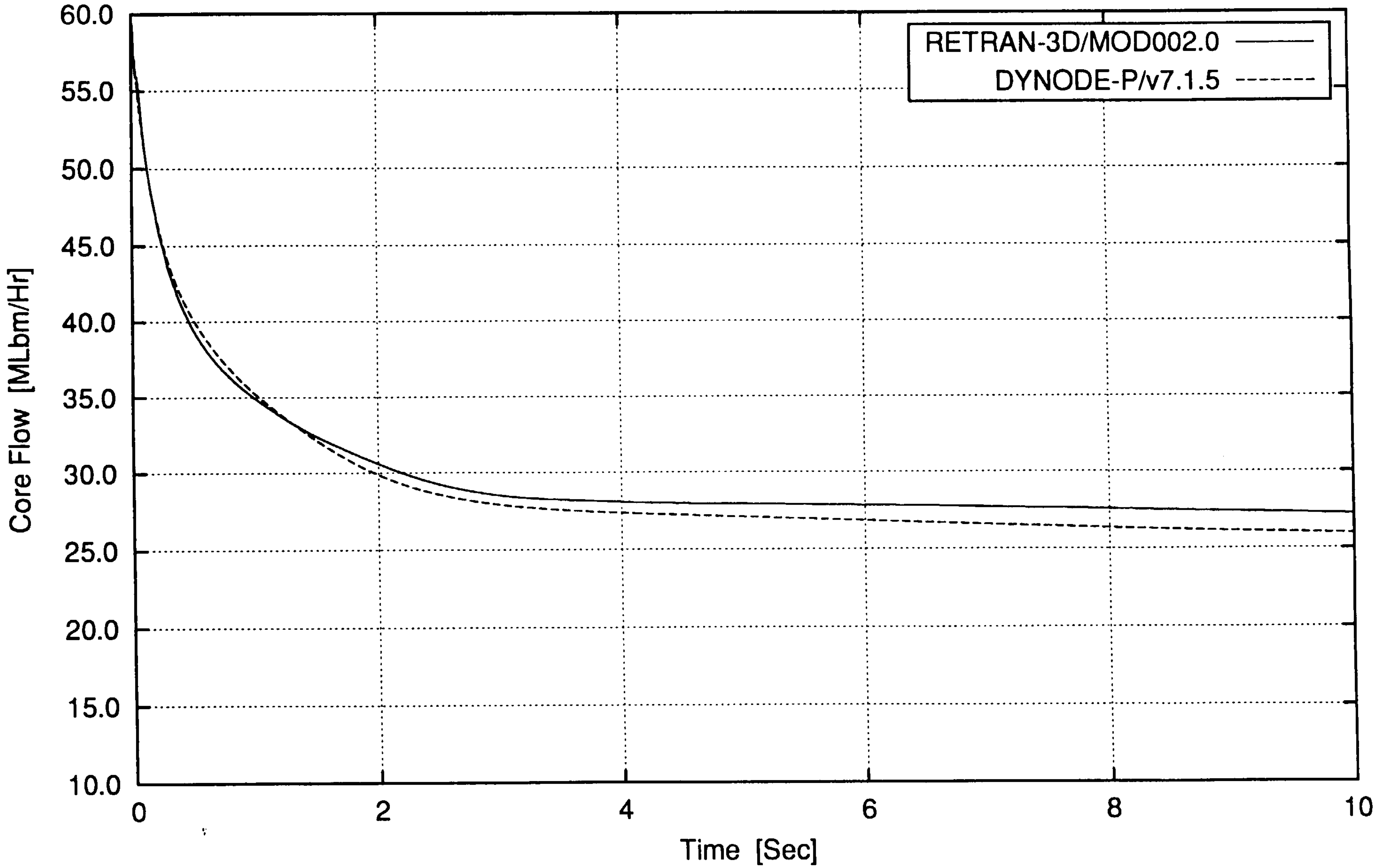
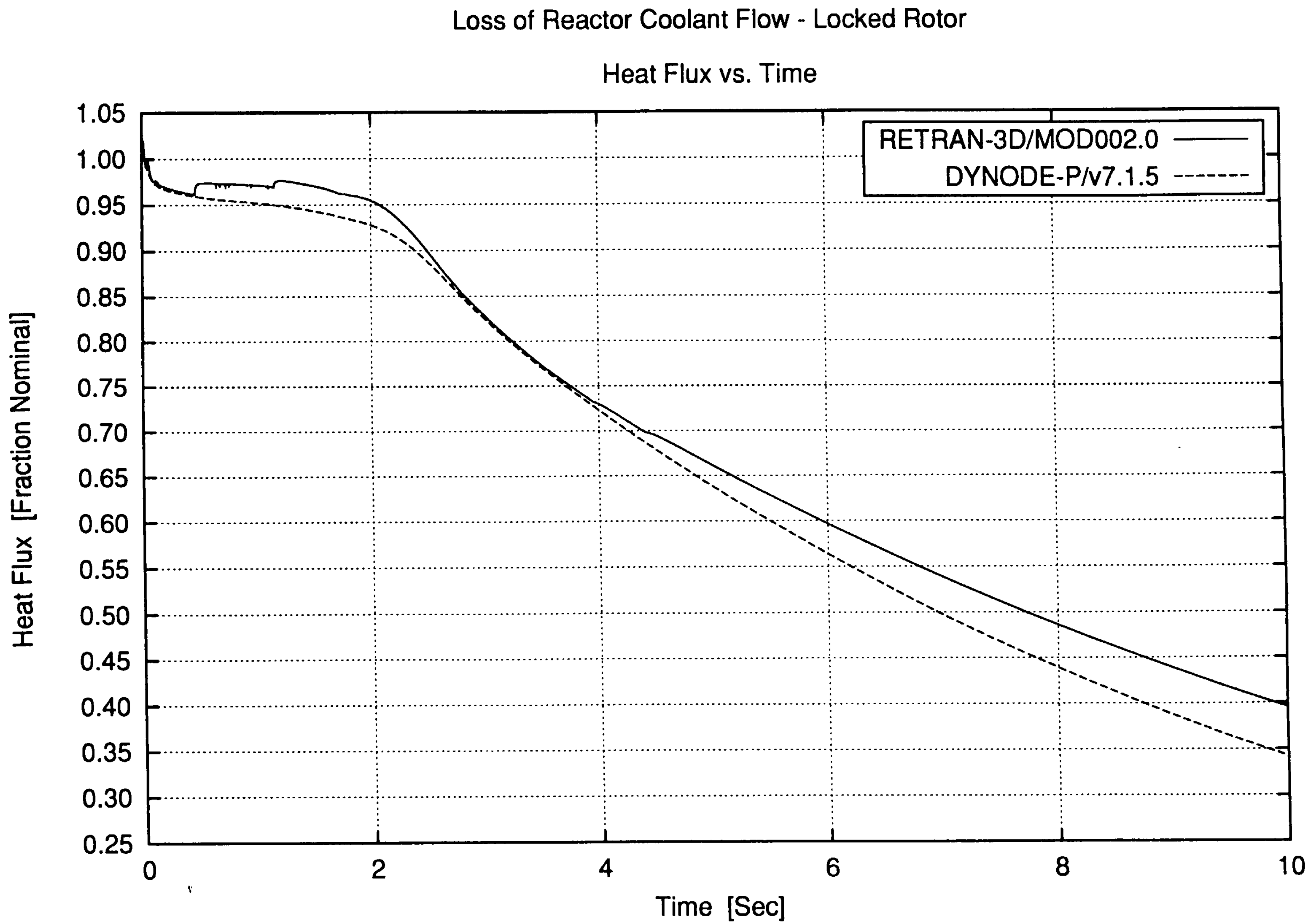


Figure 5-9


Loss of Reactor Coolant Flow - Locked Rotor
Heat Flux vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Heat Flux [Fraction Nominal]
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0
2
4
6
8
10
Time [Sec]
Figure 5-10

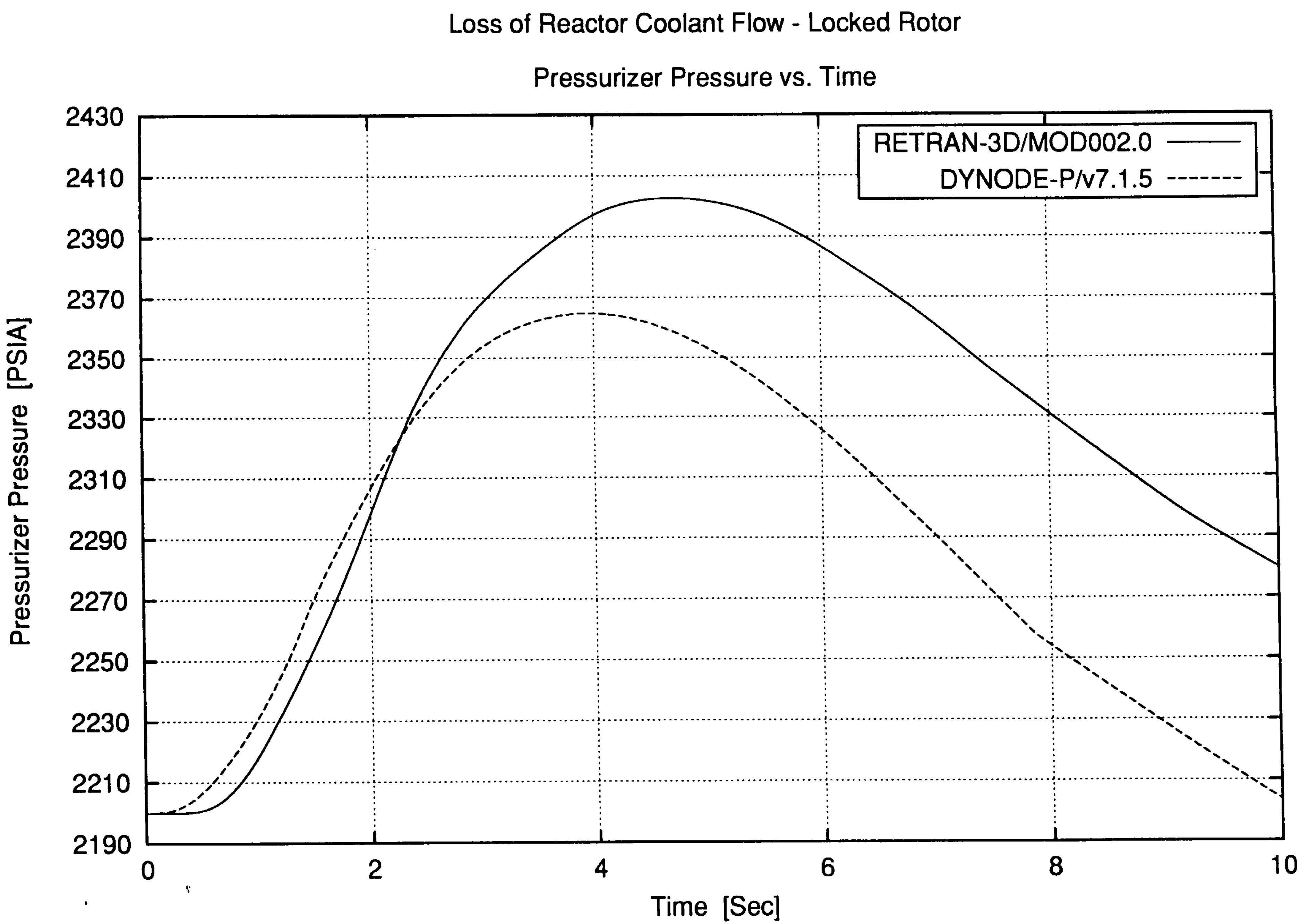
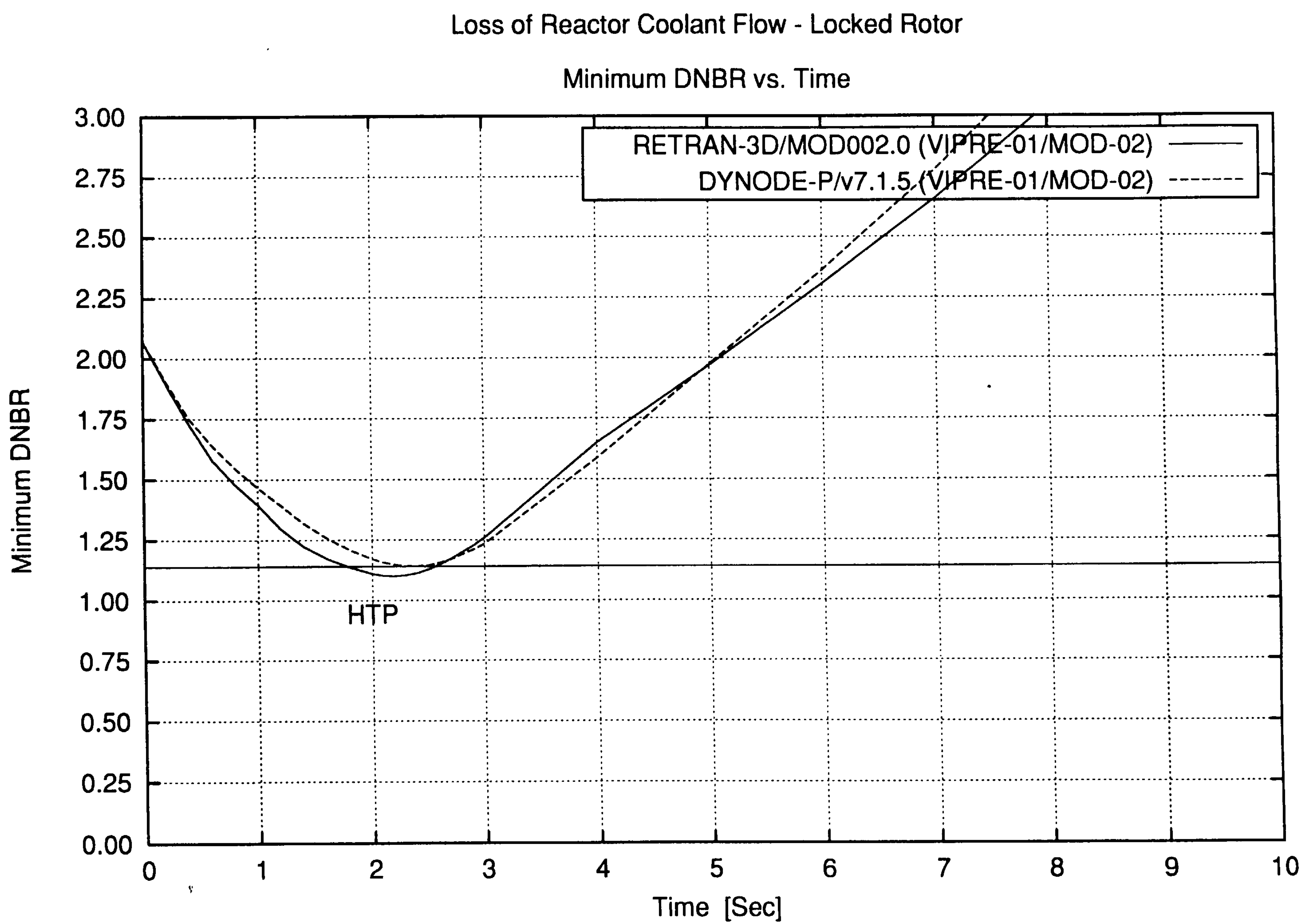

Loss of Reactor Coolant Flow - Locked Rotor
Pressurizer Pressure vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Pressurizer Pressure [PSIA]
2430
2410
2390
2370
2350
2330
2310
2290
2270
2250
2230
2210
2190
0
2
4
6
8
10
Time [Sec]

Figure 5-11



Loss of Reactor Coolant Flow - Locked Rotor
Minimum DNBR vs. Time
RETRAN-3D/MOD002.0 (VIPRE-01/MOD-02)
DYNODE-P/v7.1.5 (VIPRE-01/MOD-02)
Minimum DNBR
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
HTP
0
1
2
3
4
5
6
7
8
9
10
Time [Sec]

Figure 5-12

6. Loss of Load

BOC Automatic Control

Figure 6-1 shows reactor power versus time. The results are nearly identical except that the reactor trip on high pressurizer pressure occurs 1.4 seconds earlier in RETRAN than in DYNODE due to the faster pressure increase.

Figure 6-2 shows T_{inlet} versus time. At about 2 seconds, T_{inlet} increases more slowly in RETRAN than in DYNODE. This is due to the finer nodalization in the RETRAN steam generator. This nodalization takes into account the fact that water in the bottom of the cold leg side of the tubes (which is the first to enter the core) is heated by the bottom of the steam generator riser (which is the last part to be affected by the transient). Two seconds later, however, the increase is greater, because the water that had been in contact with the upper riser nodes now begins to enter the core.

Figure 6-3 shows the pressurizer pressure versus time. The pressure increase is greater in RETRAN because of differences in the steam generator models. The faster rise in T_{inlet} between 5 and 10 seconds results in a greater pressure increase.

Figure 6-4 shows pressurizer level versus time. The differences are due to the differences in T_{inlet}.

Figure 6-5 shows the MDNBR versus time. RETRAN has a slightly higher MDNBR trend due to the higher pressure. Since both codes predict an increasing MDNBR, the minimum is at time 0 and is therefore identical between the two codes.

EOC Automatic Control

Figure 6-6 shows reactor power versus time. The power decrease is slower in RETRAN than DYNODE because the T_{inlet} transient is slower resulting in later negative reactivity insertion. For all but about 5-10 seconds of the transient, the power differences are within 5%.

Figure 6-7 shows T_{inlet} versus time. As explained for the BOC automatic control case above, the T_{inlet} difference is due to differences in steam generator models.

Figure 6-8 shows the pressurizer pressure versus time. As explained for the BOC automatic control case above, the pressure increase is greater in RETRAN because of differences in the steam generator models. This increase is enough to cause a reactor trip on high pressurizer pressure, but the trip is disabled in RETRAN, in order to match DYNODE thermal-hydraulically.

Figure 6-9 shows pressurizer level versus time. The differences are due to the differences in T_{inlet}.

Figure 6-10 shows the MDNBR versus time. The results are very similar until about 15-20 seconds, at which point the faster rate of pressure decrease in RETRAN causes the MDNBR to increase less quickly.

BOC Manual Control

Figure 6-11 shows reactor power versus time. The results are identical between the two codes.

Figure 6-12 shows T_{inlet} versus time. As explained for the BOC automatic control case above, the T_{inlet} difference is due to differences in steam generator models.

Figure 6-13 shows the pressurizer pressure versus time. As explained for the BOC automatic control case above, the pressure increase is faster in RETRAN because of differences in the steam generator models.

Figure 6-14 shows pressurizer level versus time. The differences are due to the differences in T_{inlet}.

Figure 6-15 shows the MDNBR versus time. RETRAN has a slightly higher MDNBR trend due to the higher pressure. Since both codes predict an increasing MDNBR, the minimum is at time 0 and is therefore identical between the two codes.

EOC Manual Control

Figure 6-16 shows reactor power versus time. The power decrease is slower in RETRAN than DYNODE because the T_{inlet} transient is slower resulting in later negative reactivity insertion. The reactor trip on high pressurizer pressure is earlier in RETRAN due to faster pressure increase.

Figure 6-17 shows T_{inlet} versus time. As explained for the BOC automatic control case above, the T_{inlet} difference is due to differences in steam generator models.

Figure 6-18 shows the pressurizer pressure versus time. As explained for the BOC automatic control case above, the pressure increase is greater in RETRAN because of differences in the steam generator models.

Figure 6-19 shows pressurizer level versus time. The differences are due to the differences in T_{inlet}.

Figure 6-20 shows the MDNBR versus time. RETRAN has a slightly higher MDNBR trend after 10 seconds due to the higher pressure. Since both codes predict an increasing MDNBR, the minimum is at time 0 and is therefore identical between the two codes.

Loss of External Electric Load - BOC Automatic Control

Reactor Power vs. Time

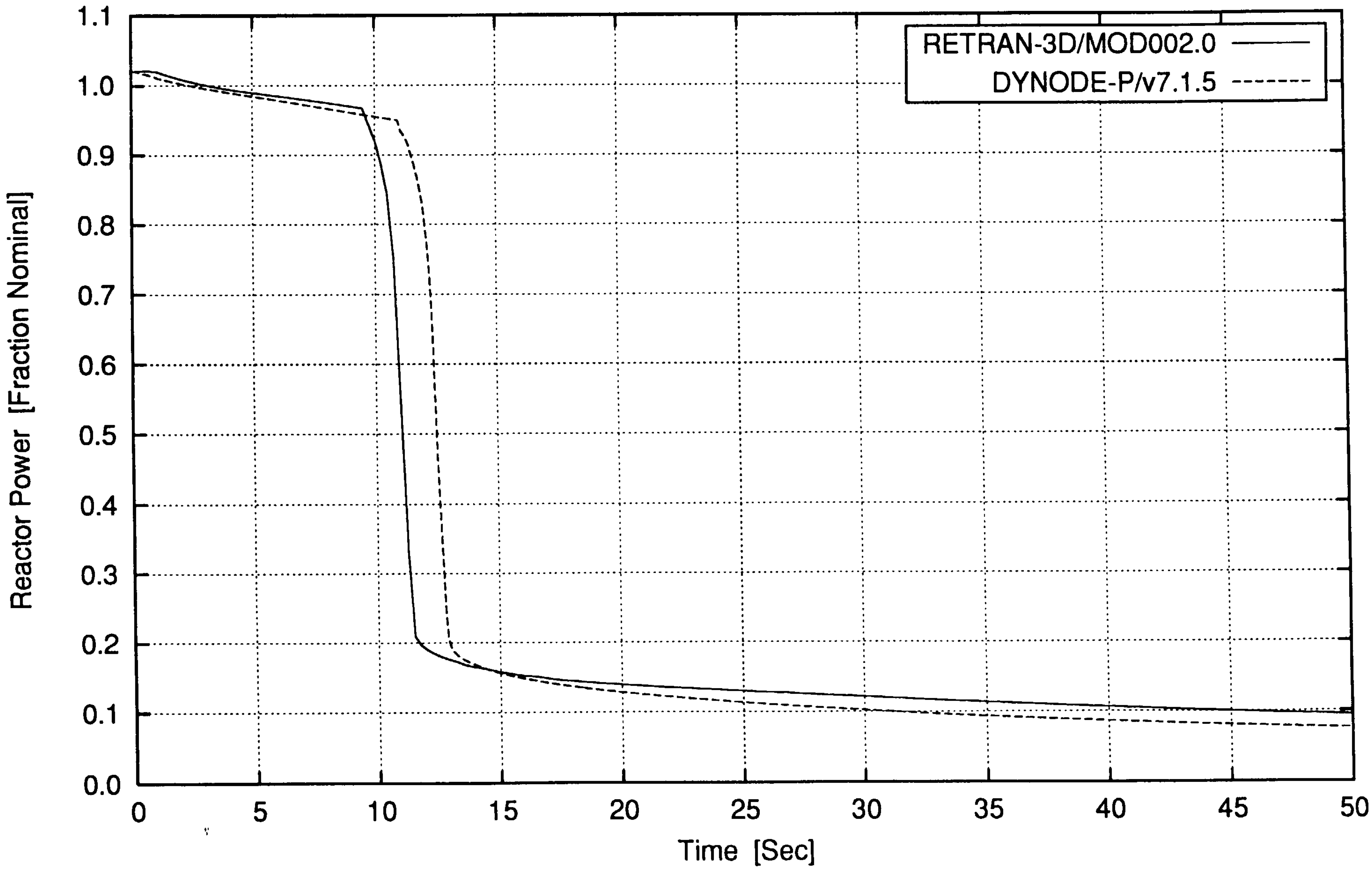


Figure 6-1

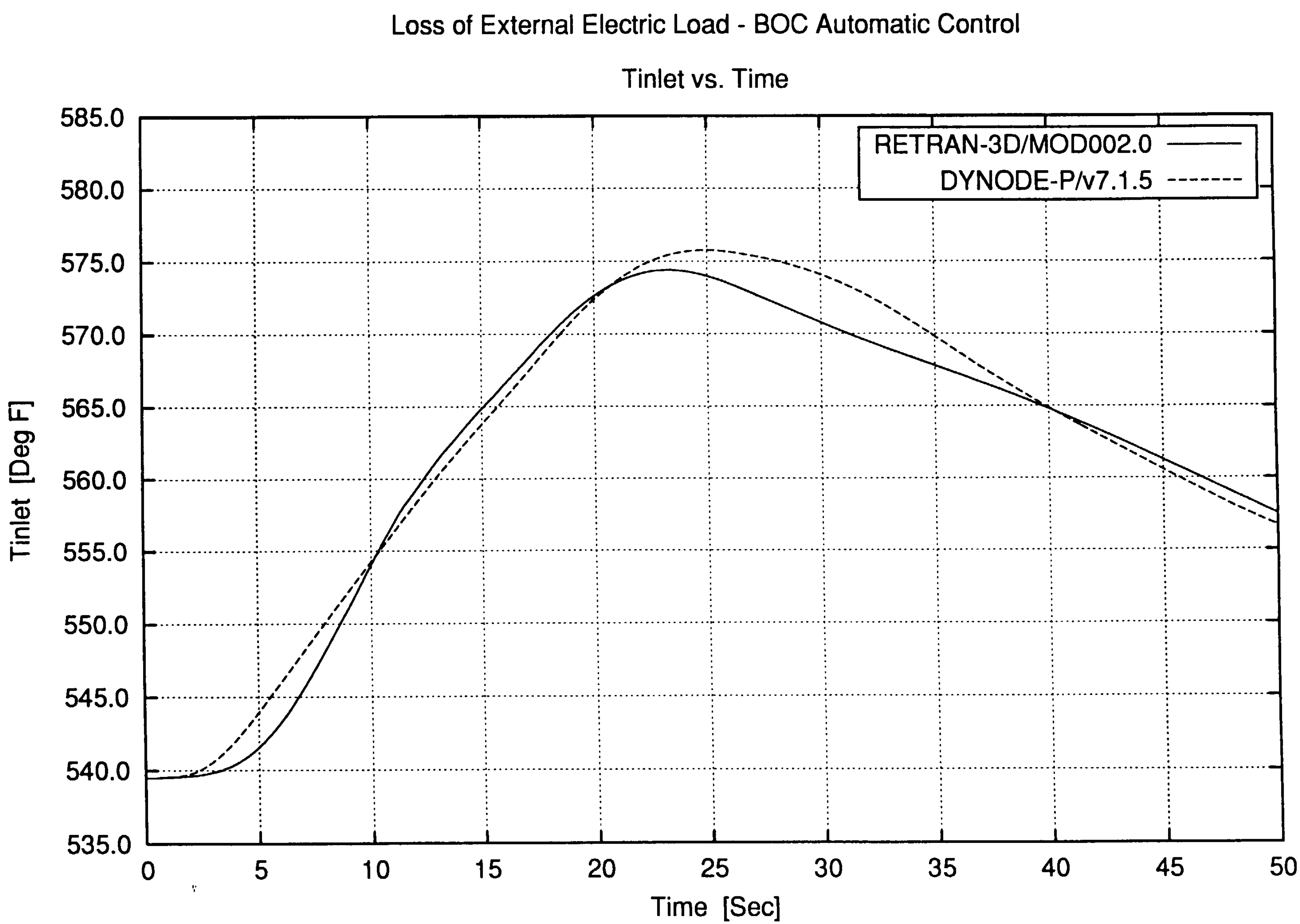
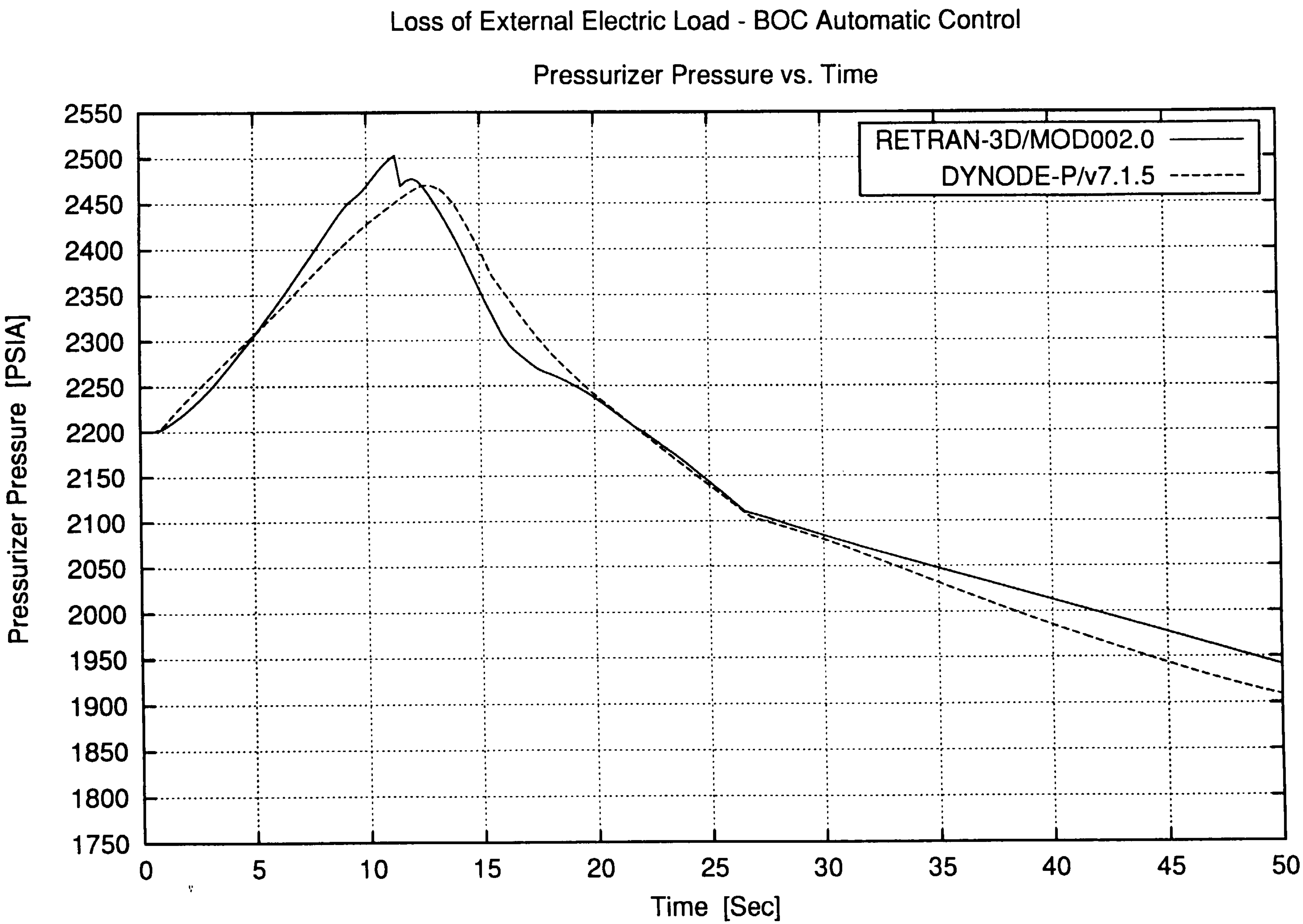
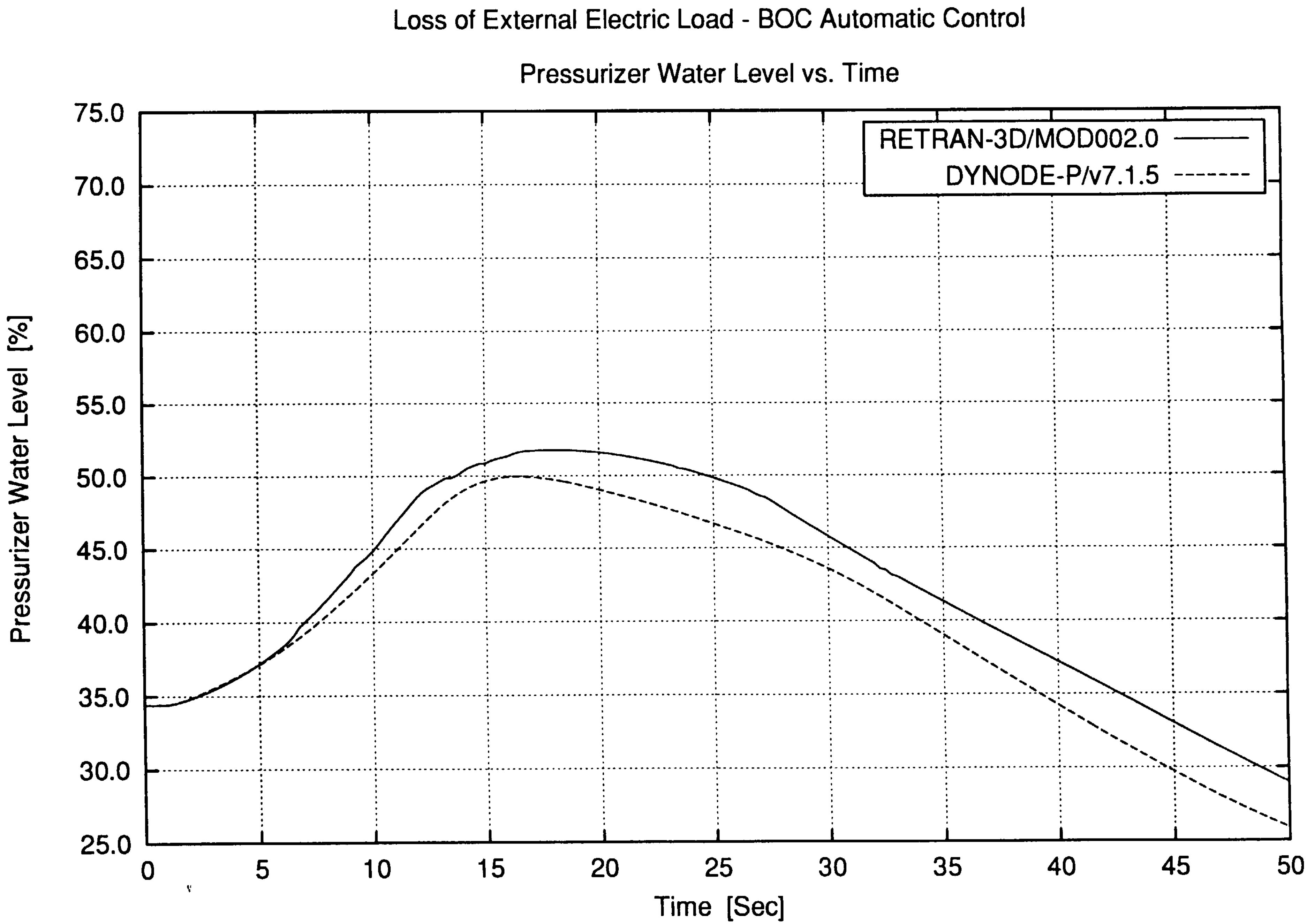

Loss of External Electric Load - BOC Automatic Control
Tinlet vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Tinlet [Deg F]
585.0
580.0
575.0
570.0
565.0
560.0
555.0
550.0
545.0
540.0
535.0
0
5
10
15
20
25
30
35
40
45
50
Time [Sec]

Figure 6-2



Loss of External Electric Load - BOC Automatic Control
Pressurizer Pressure vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Pressurizer Pressure [PSIA]
2550
2500
2450
2400
2350
2300
2250
2200
2150
2100
2050
2000
1950
1900
1850
1800
1750
0
5
10
15
20
25
30
35
40
45
50
Time [Sec]

Figure 6-3



Loss of External Electric Load - BOC Automatic Control
Pressurizer Water Level vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Pressurizer Water Level [%]
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
0
5
10
15
20
25
30
35
40
45
50
Time [Sec]

Figure 6-4

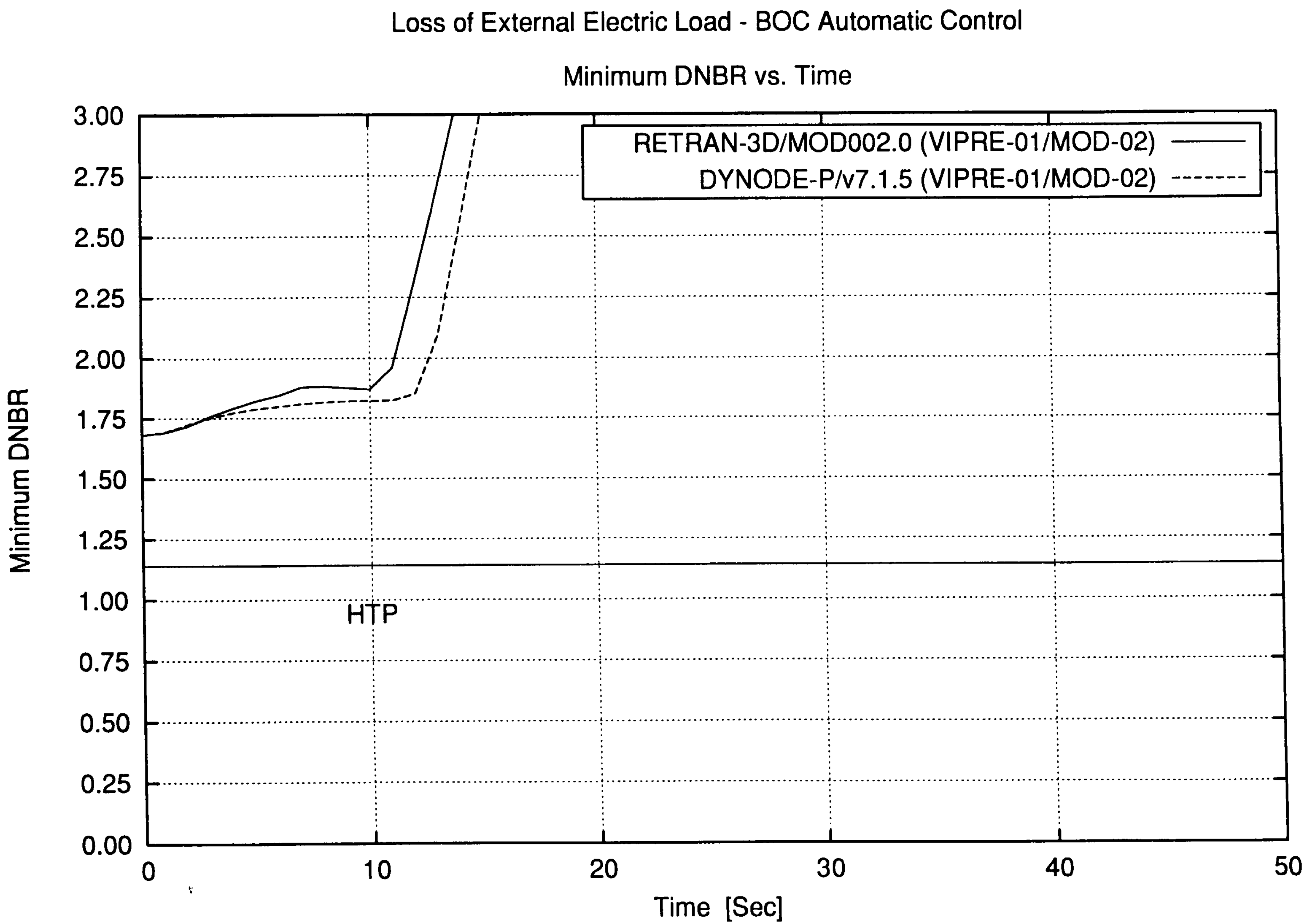
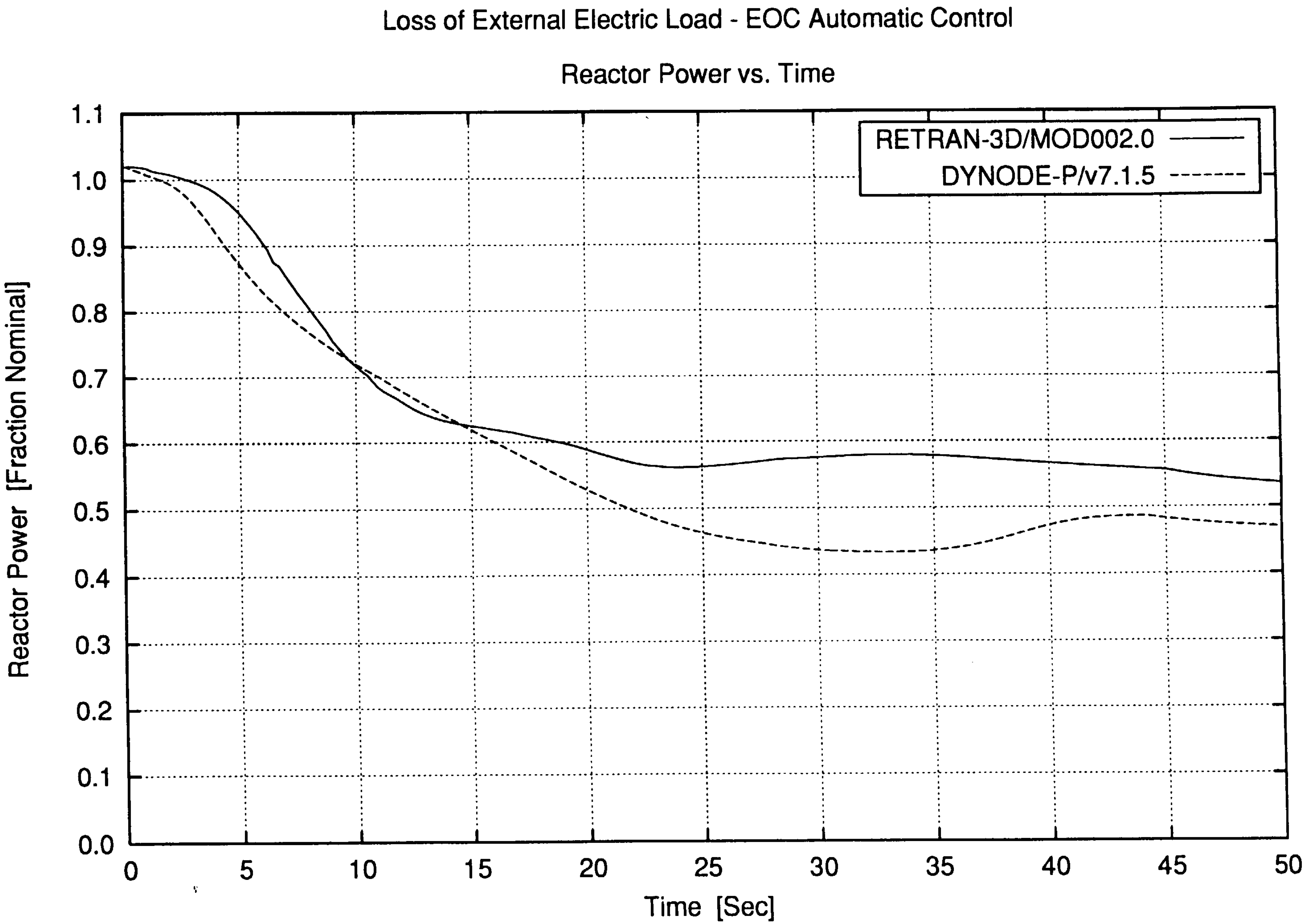
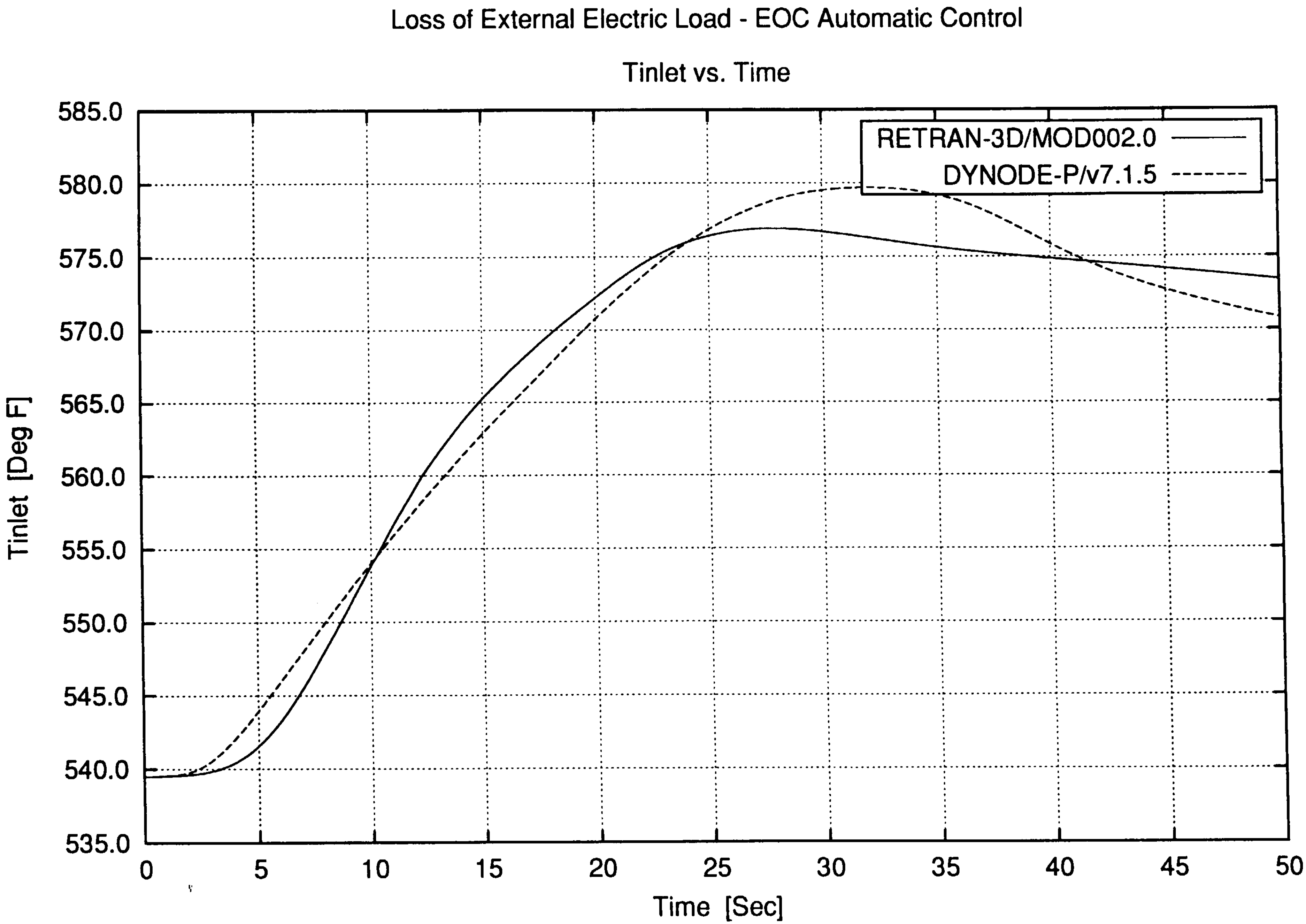

Loss of External Electric Load - BOC Automatic Control
Minimum DNBR vs. Time
RETRAN-3D/MOD002.0 (VIPRE-01/MOD-02)
DYNODE-P/v7.1.5 (VIPRE-01/MOD-02)
HTP
Minimum DNBR
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
10
20
30
40
50
Time [Sec]

Figure 6-5



Loss of External Electric Load - EOC Automatic Control
Reactor Power vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Reactor Power [Fraction Nominal]
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
45
50
Time [Sec]

Figure 6-6



Loss of External Electric Load - EOC Automatic Control
Tinlet vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
585.0
580.0
575.0
570.0
565.0
560.0
555.0
550.0
545.0
540.0
535.0
Tinlet [Deg F]
0
5
10
15
20
25
30
35
40
45
50
Time [Sec]

Figure 6-7

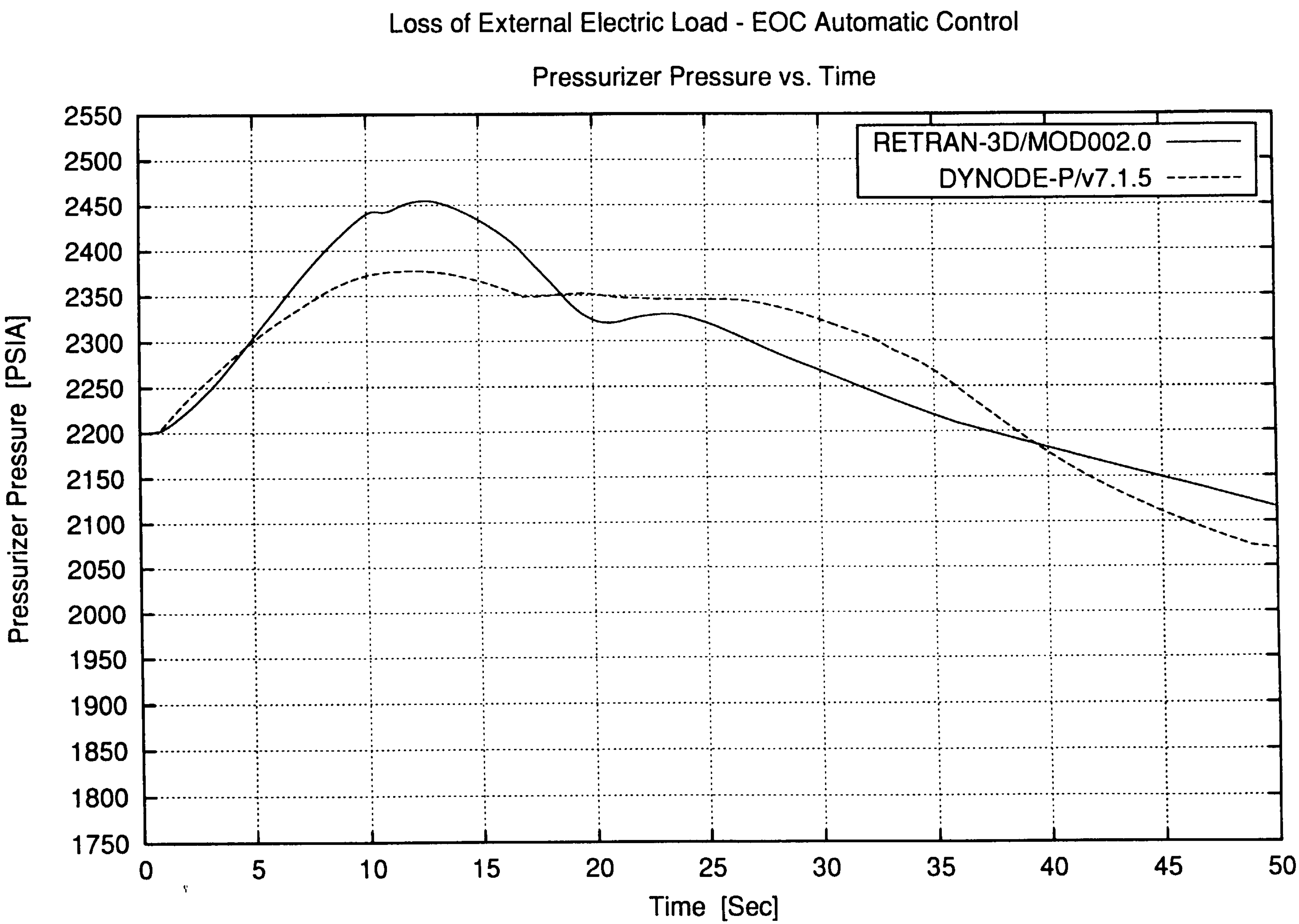

Loss of External Electric Load - EOC Automatic Control
Pressurizer Pressure vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Pressurizer Pressure [PSIA]
2550
2500
2450
2400
2350
2300
2250
2200
2150
2100
2050
2000
1950
1900
1850
1800
1750
0
5
10
15
20
25
30
35
40
45
50
Time [Sec]

Figure 6-8

Loss of External Electric Load - EOC Automatic Control

Pressurizer Water Level vs. Time

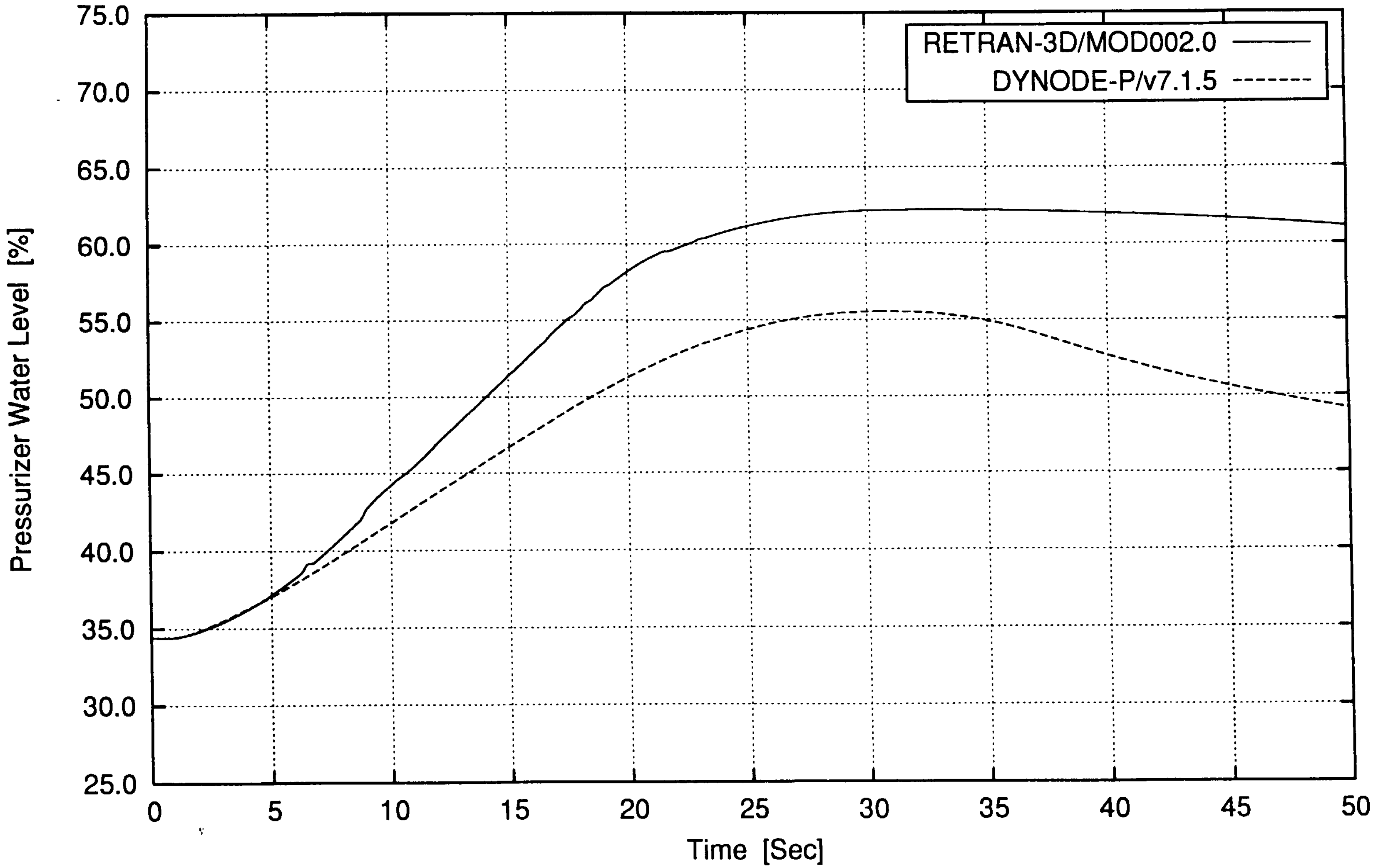


Figure 6-9

Loss of External Electric Load - EOC Automatic Control

Minimum DNBR vs. Time

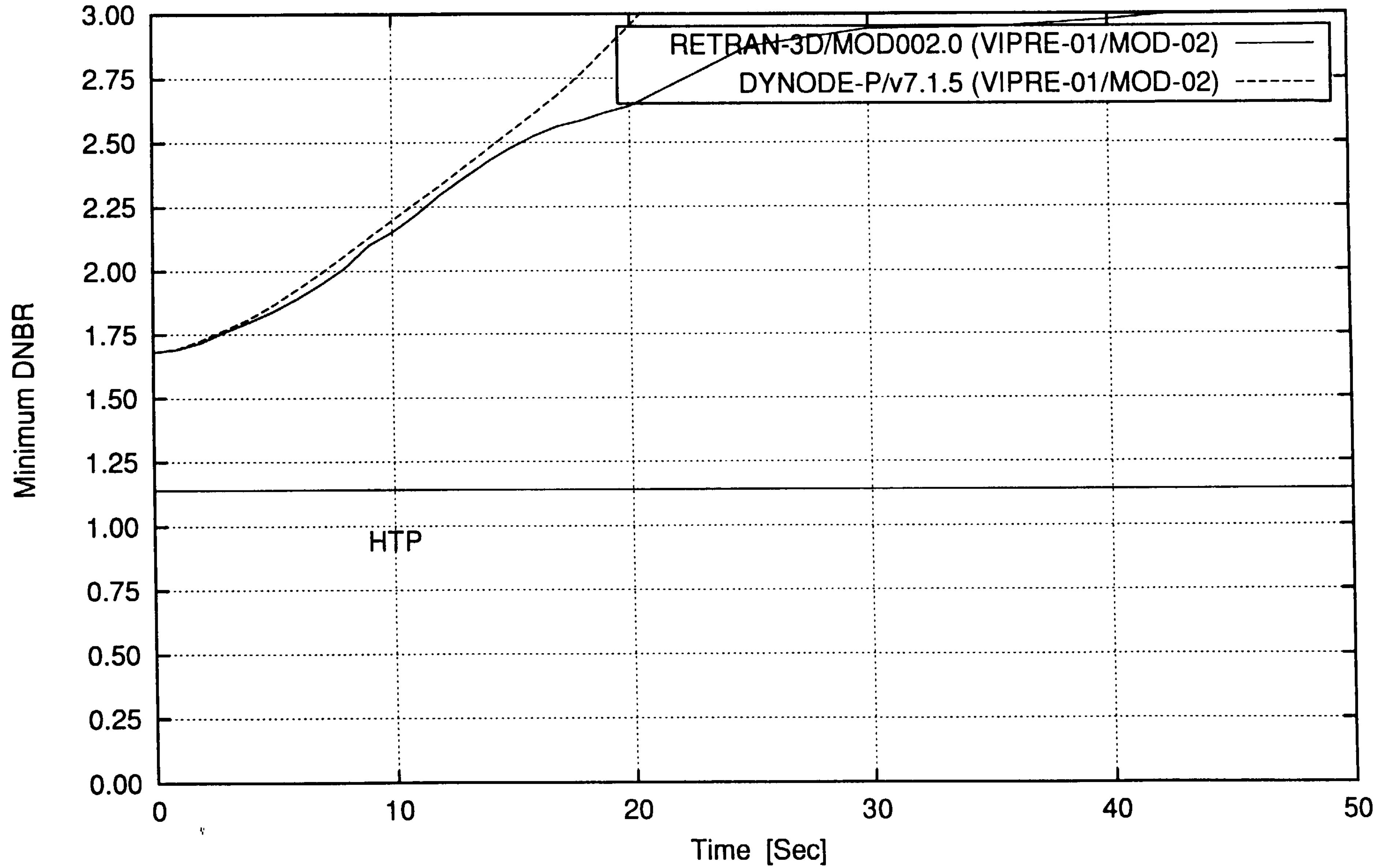


Figure 6-10

Loss of External Electric Load - BOC Manual Control

Reactor Power vs. Time

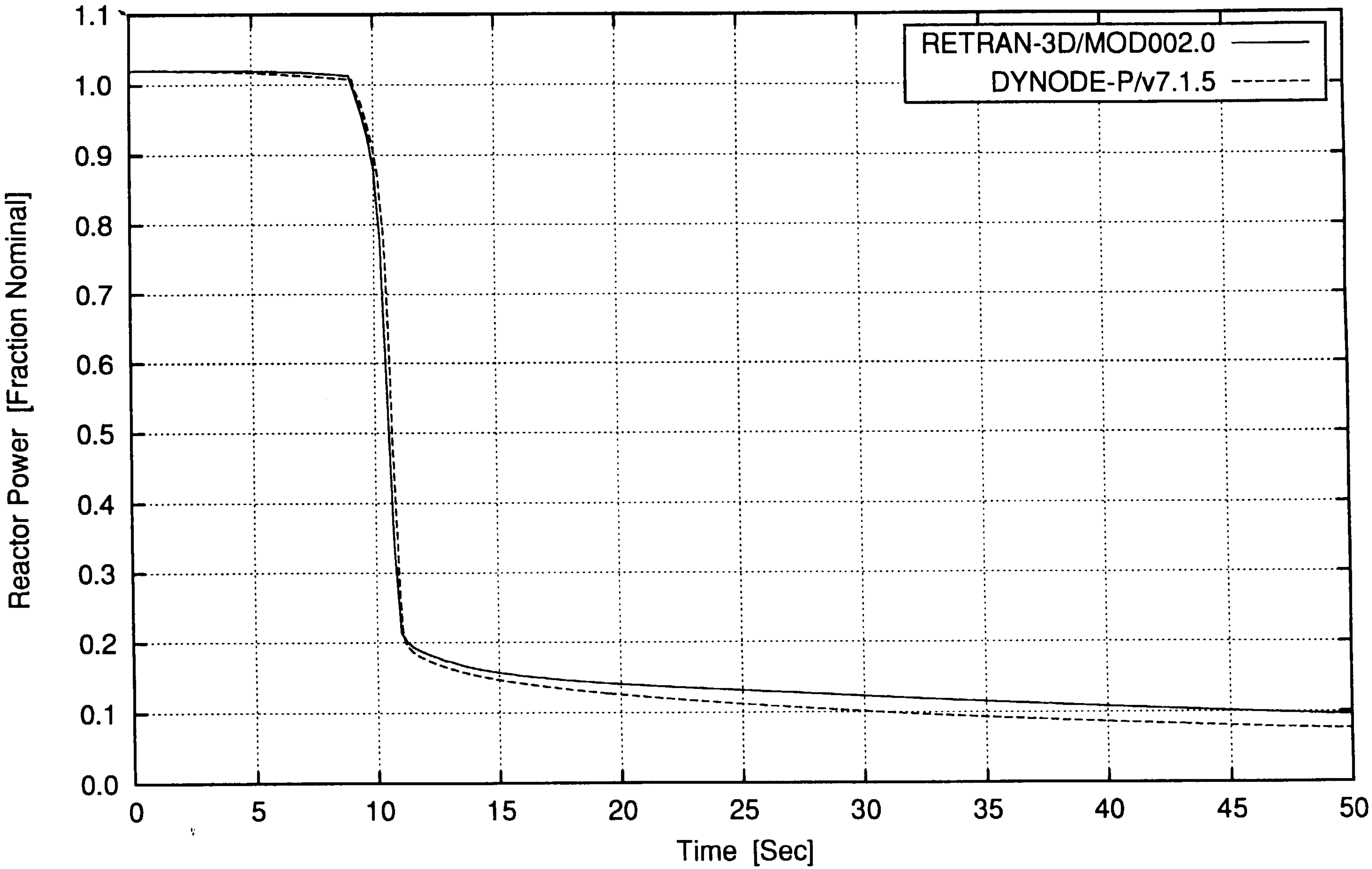


Figure 6-11

Loss of External Electric Load - BOC Manual Control

Tinlet vs. Time

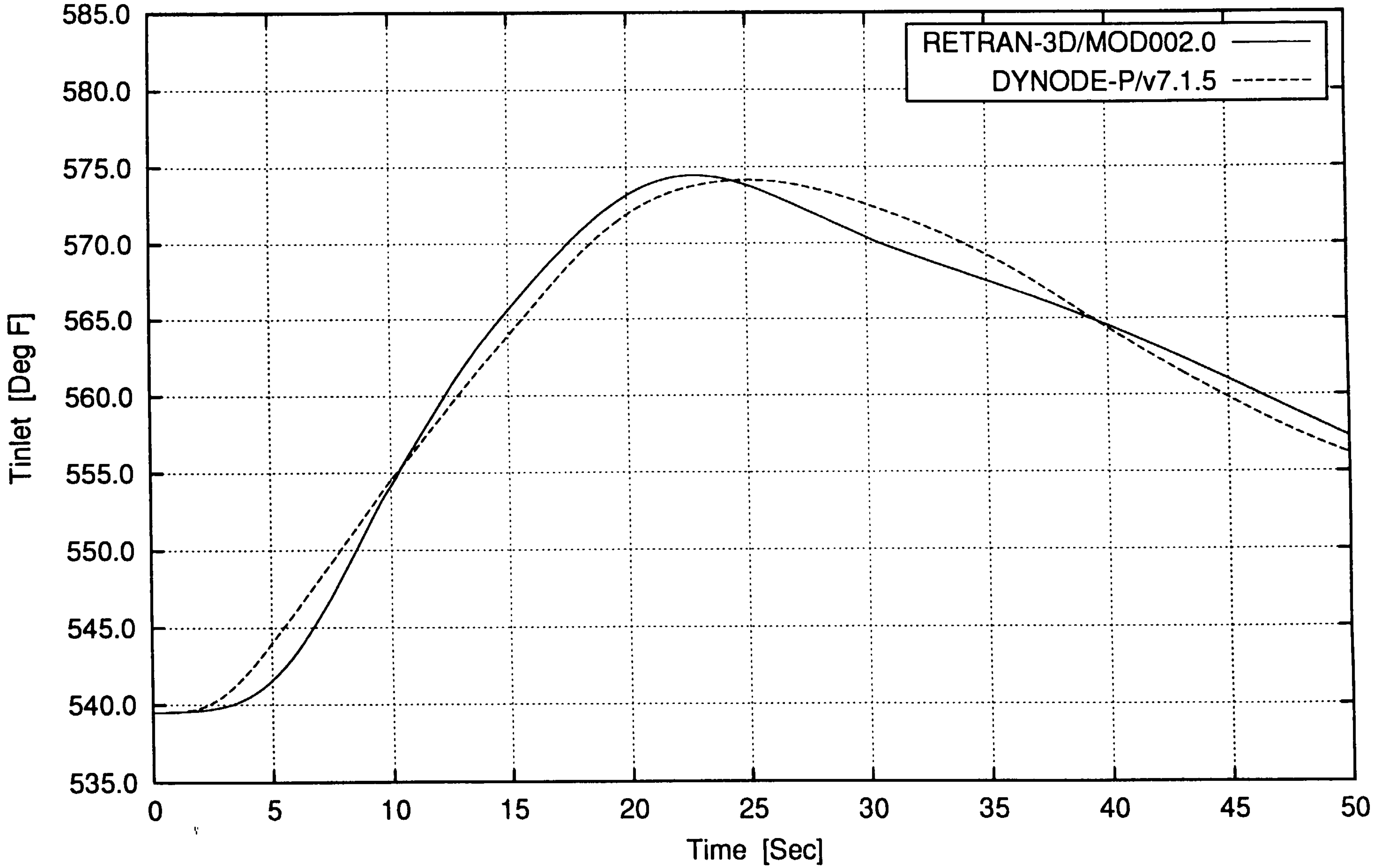
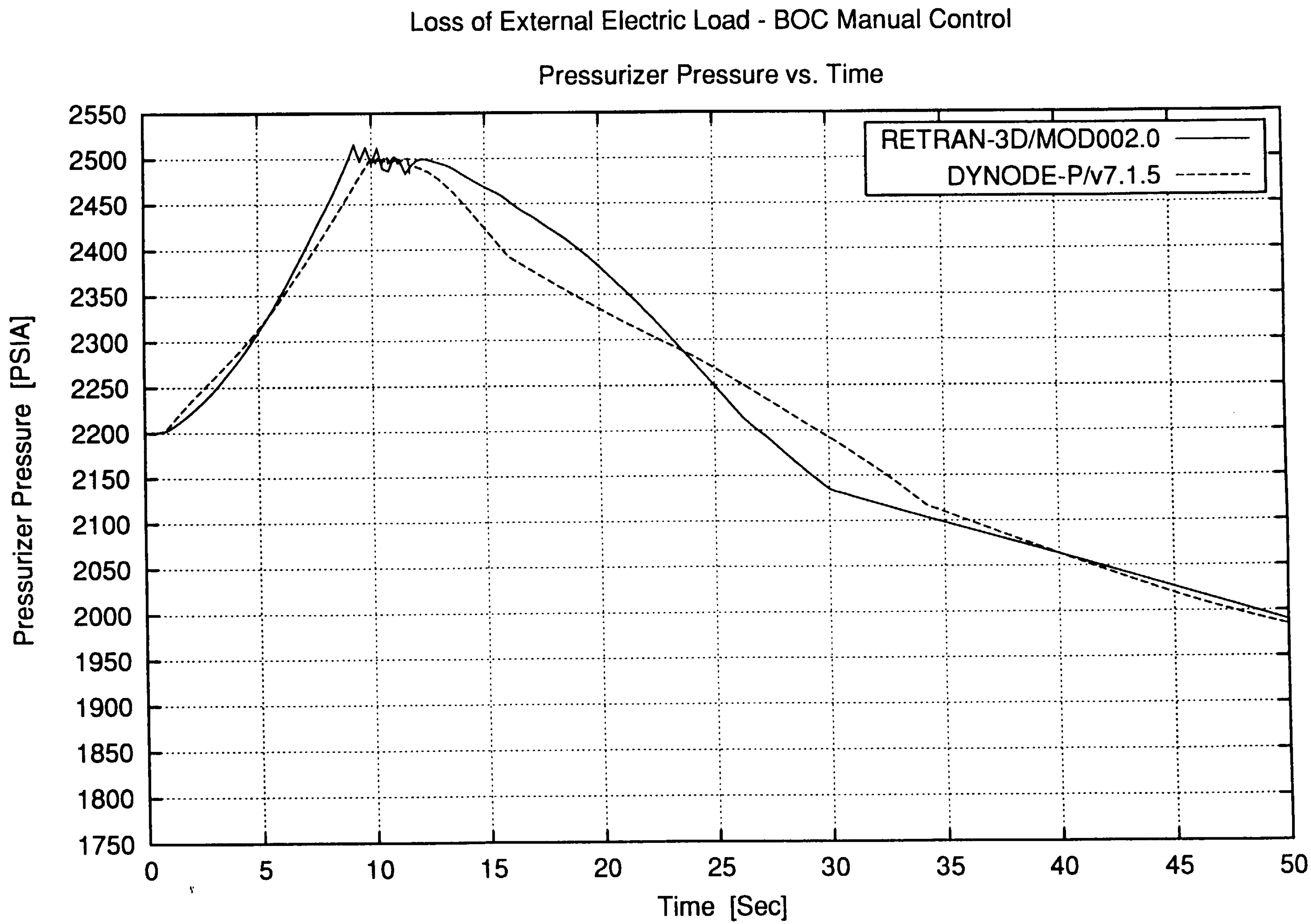


Figure 6-12



Loss of External Electric Load - BOC Manual Control
Pressurizer Pressure vs. Time
Pressurizer Pressure [PSIA]
2550
2500
2450
2400
2350
2300
2250
2200
2150
2100
2050
2000
1950
1900
1850
1800
1750
0
5
10
15
20
25
30
35
40
45
50
Time [Sec]
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5

Figure 6-13

Loss of External Electric Load - BOC Manual Control

Pressurizer Water Level vs. Time

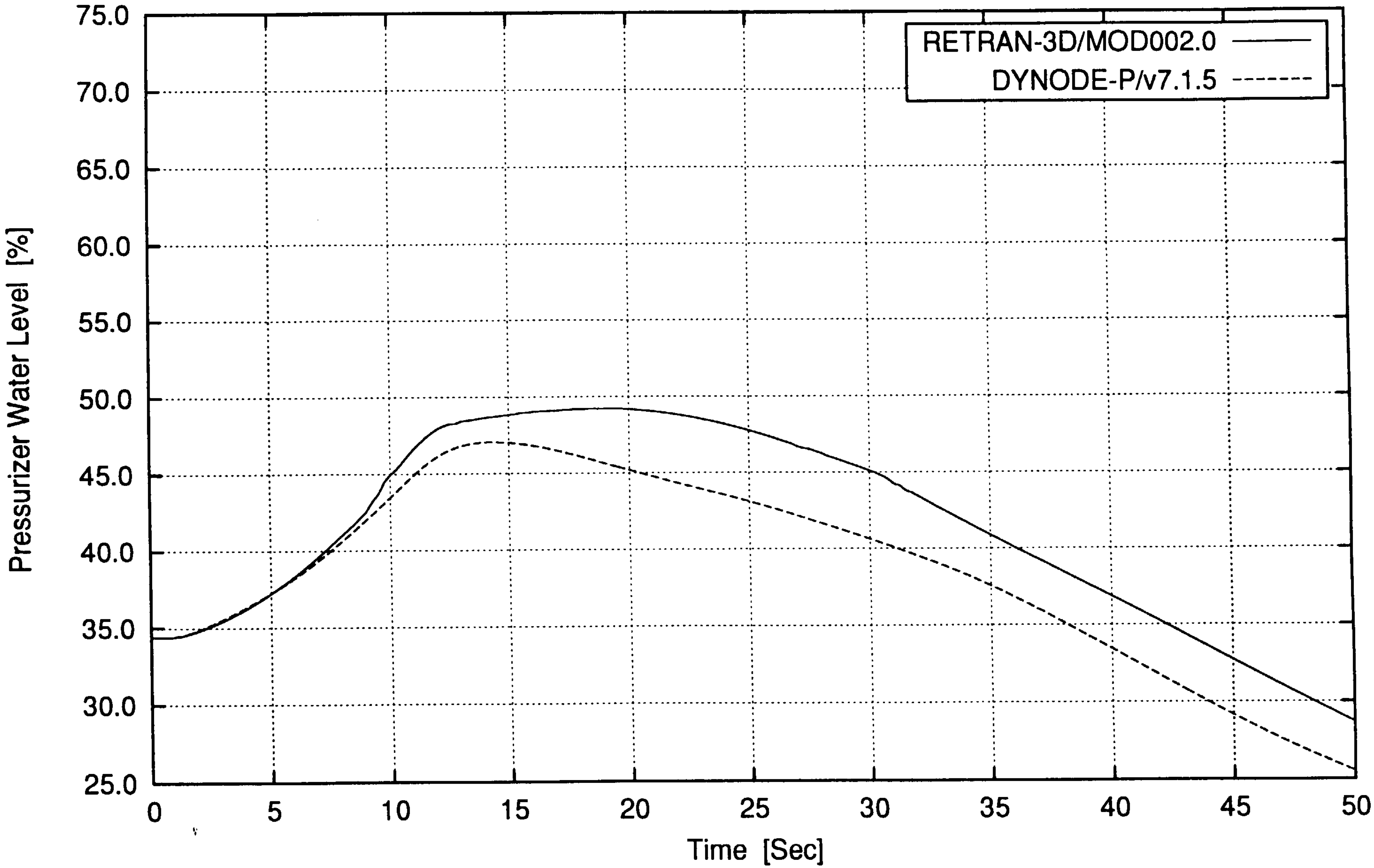
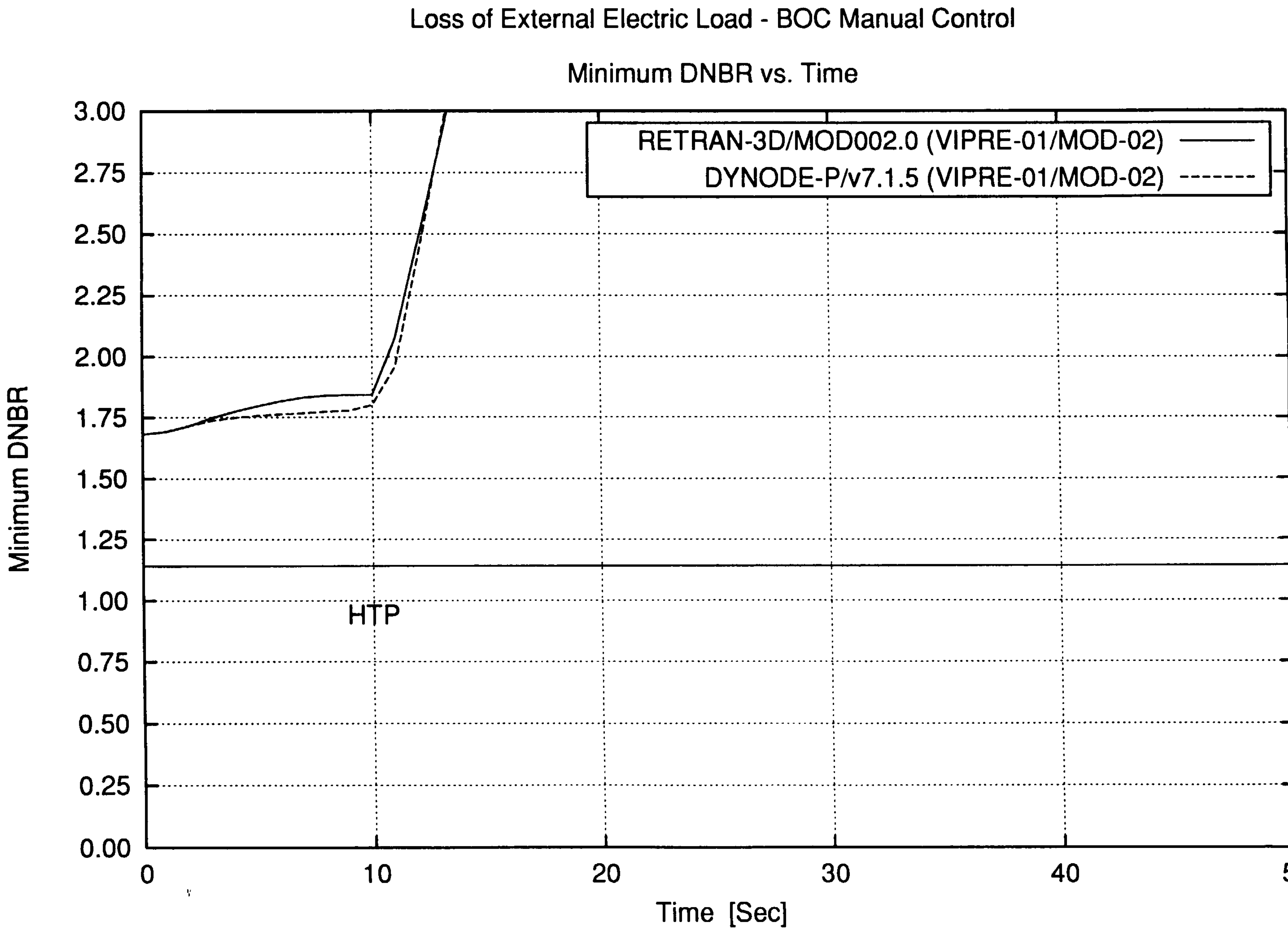


Figure 6-14



Loss of External Electric Load - BOC Manual Control
Minimum DNBR vs. Time
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Minimum DNBR
RETRAN-3D/MOD002.0 (VIPRE-01/MOD-02)
DYNODE-P/v7.1.5 (VIPRE-01/MOD-02)
HTP
0
10
20
30
40
50
Time [Sec]

Figure 6-15

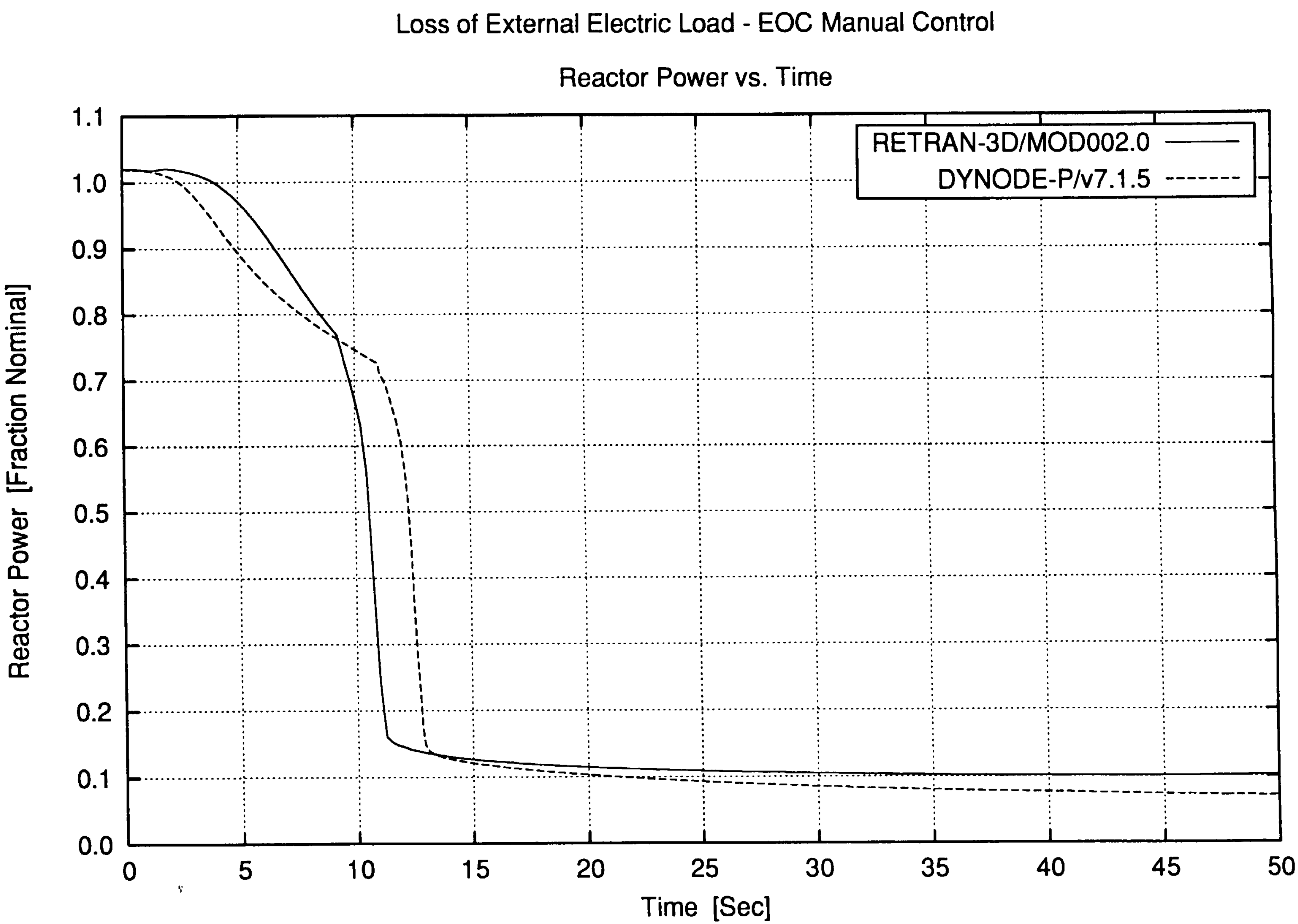
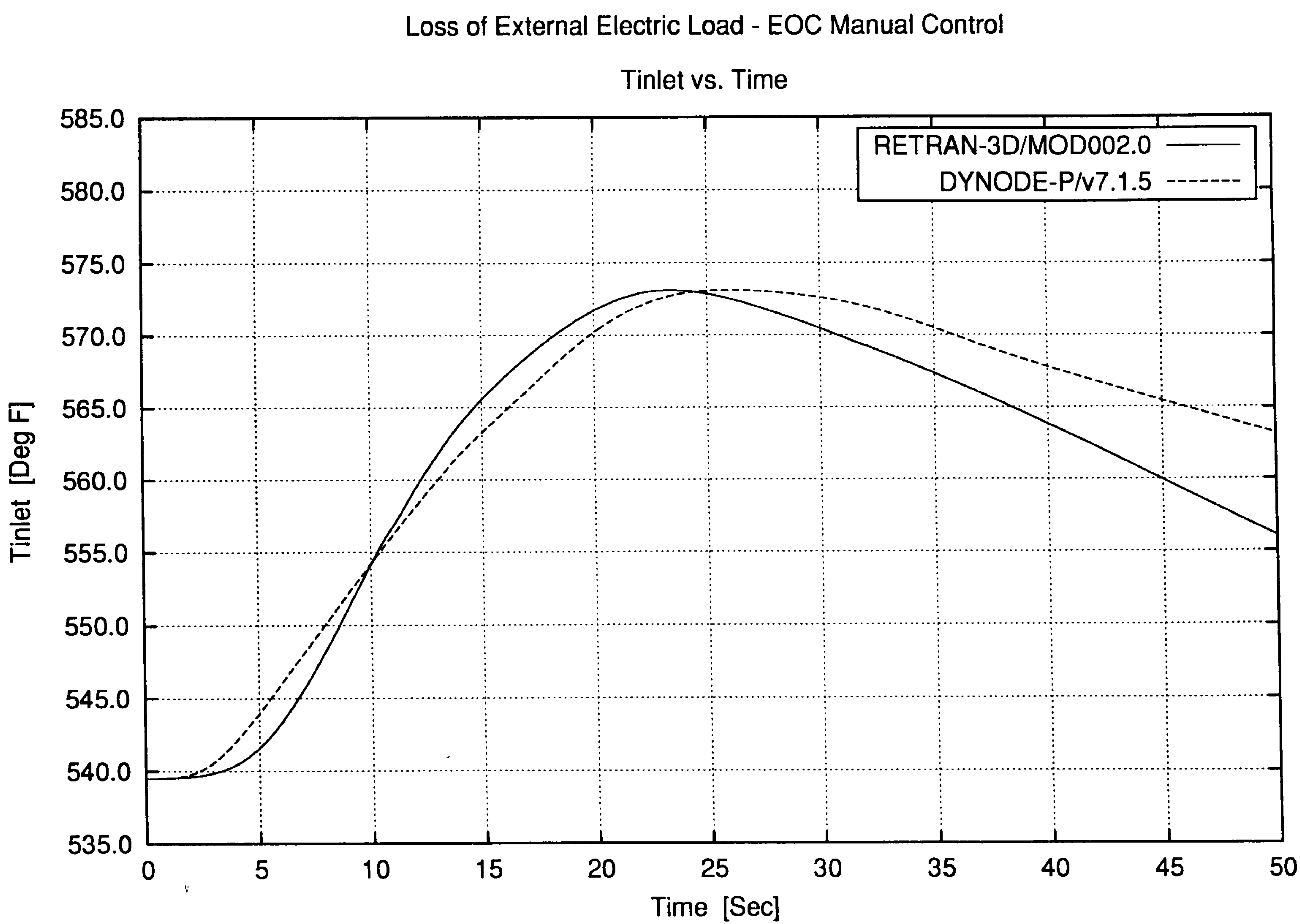

Loss of External Electric Load - EOC Manual Control
Reactor Power vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Reactor Power [Fraction Nominal]
Time [Sec]
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
45
50

Figure 6-16



Loss of External Electric Load - EOC Manual Control
Tinlet vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
585.0
580.0
575.0
570.0
565.0
560.0
555.0
550.0
545.0
540.0
535.0
Tinlet [Deg F]
0
5
10
15
20
25
30
35
40
45
50
Time [Sec]

Figure 6-17

Loss of External Electric Load - EOC Manual Control

Pressurizer Pressure vs. Time

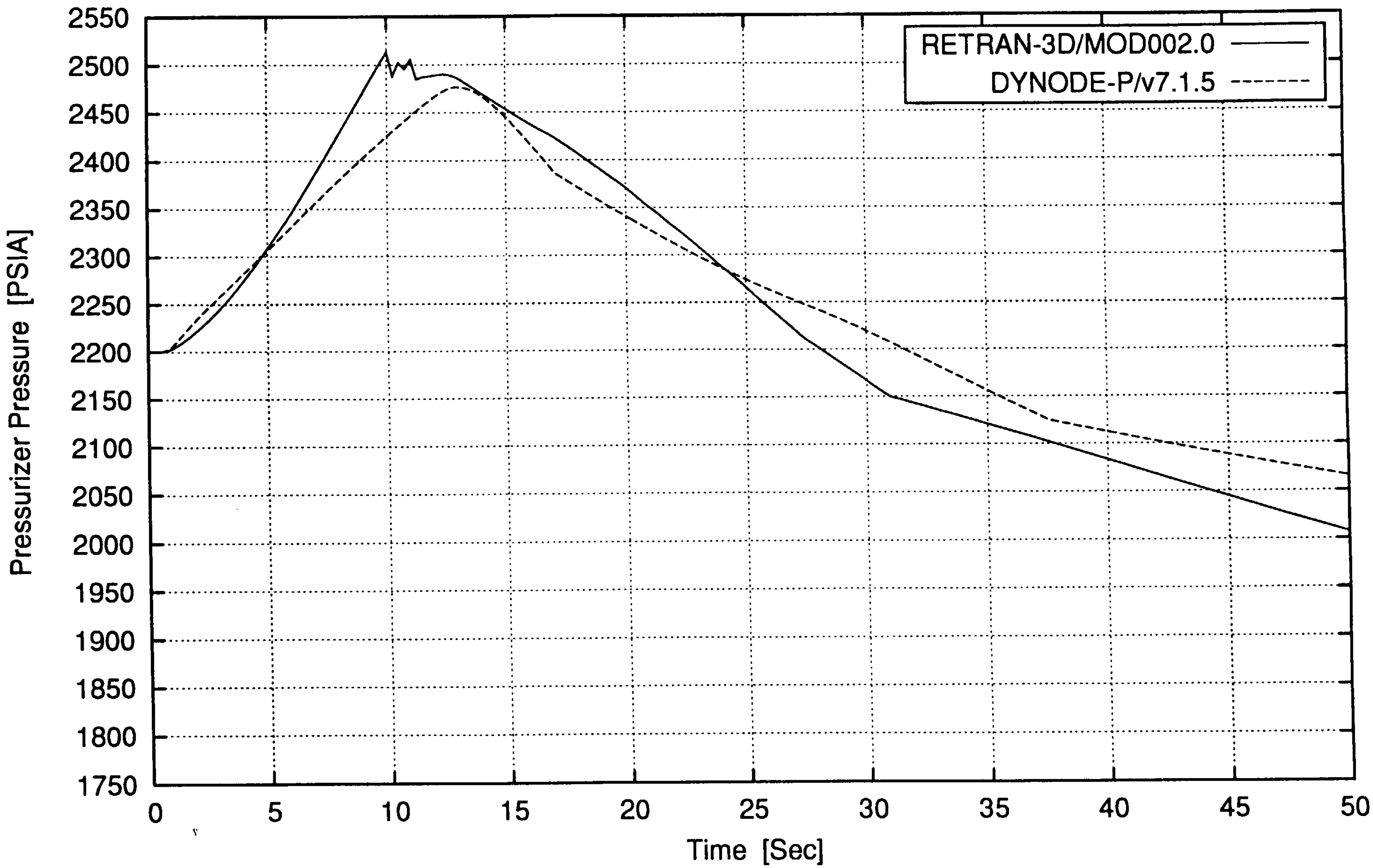


Figure 6-18

Loss of External Electric Load - EOC Manual Control

Pressurizer Water Level vs. Time

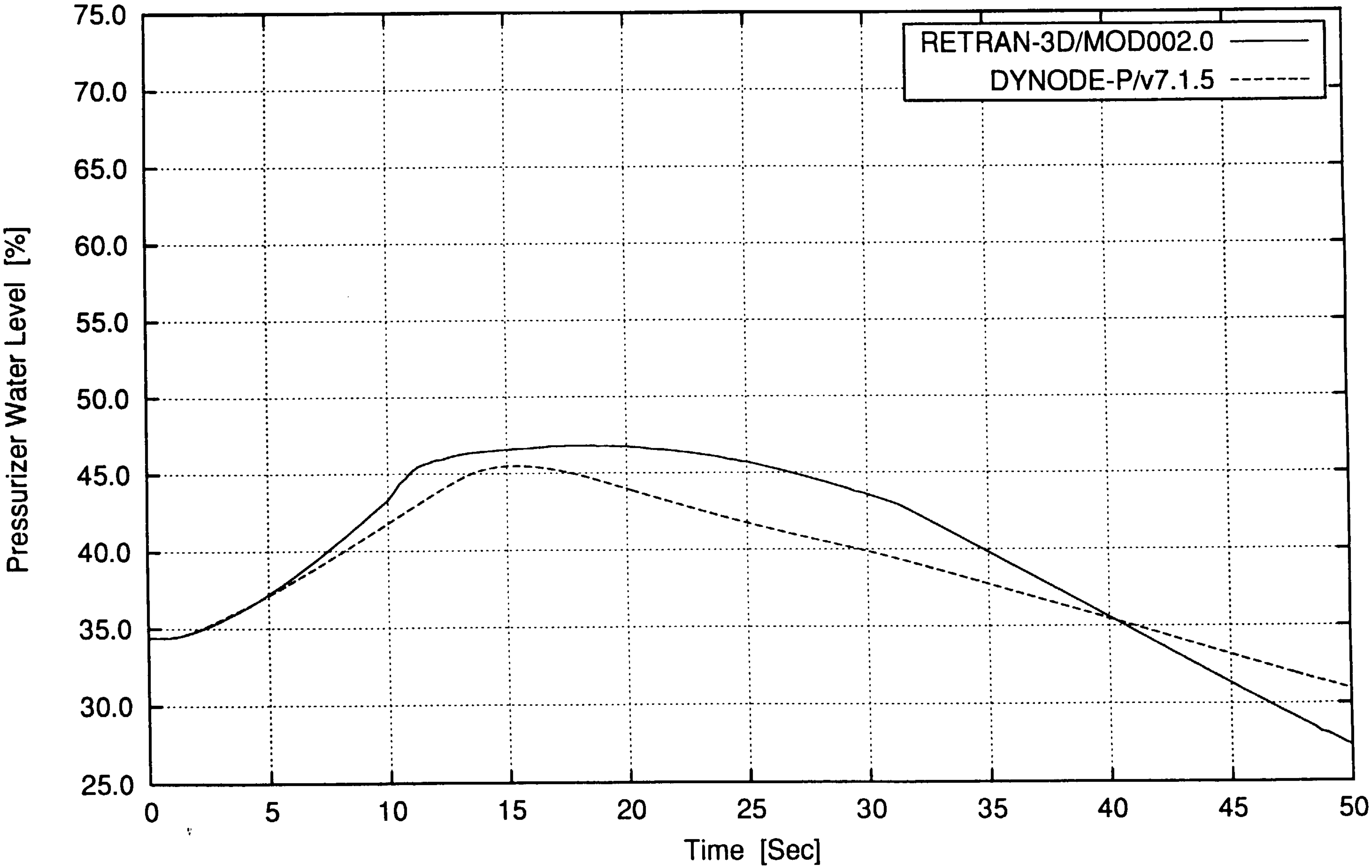
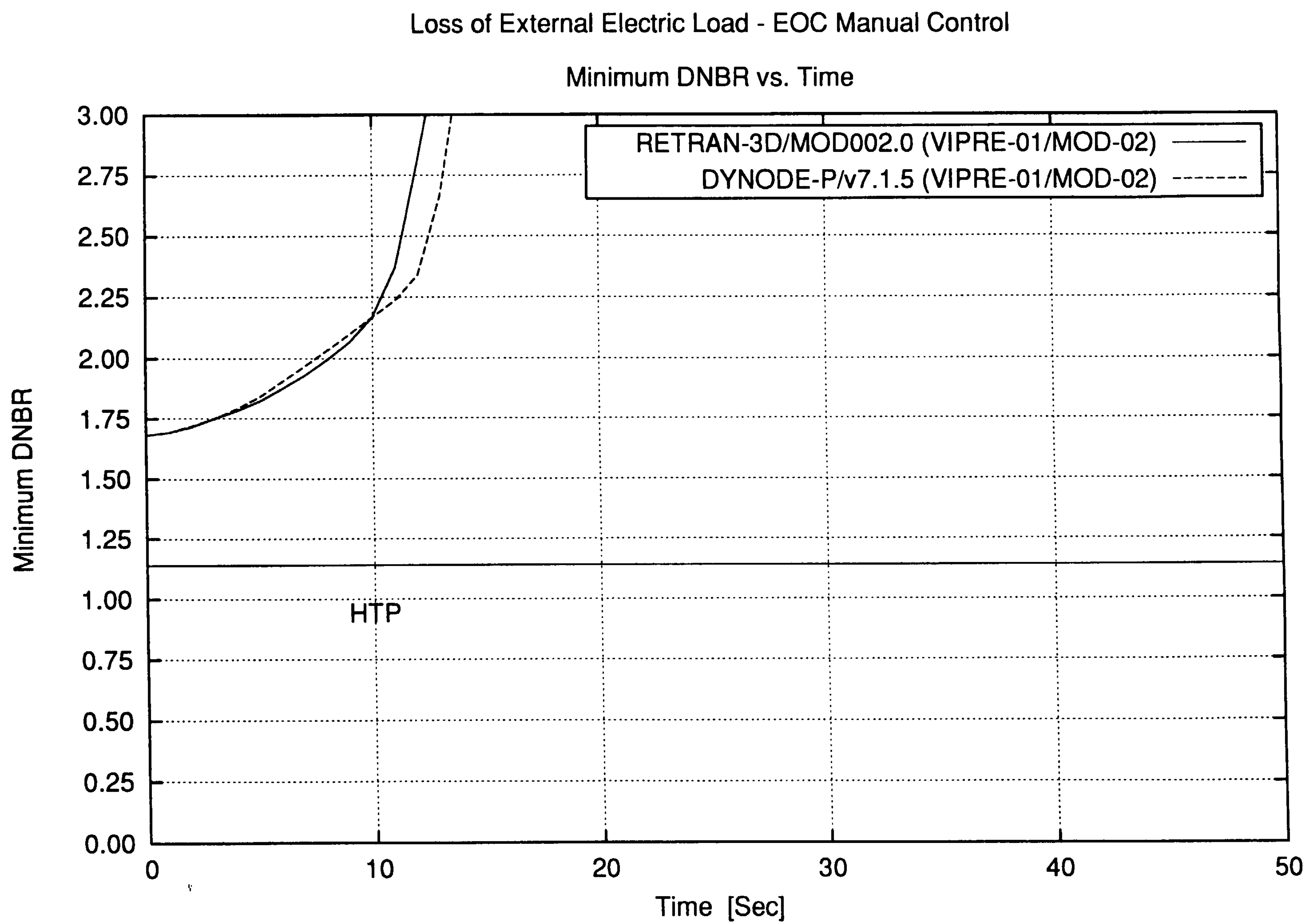


Figure 6-19



Loss of External Electric Load - EOC Manual Control
Minimum DNBR vs. Time
RETRAN-3D/MOD002.0 (VIPRE-01/MOD-02)
DYNODE-P/v7.1.5 (VIPRE-01/MOD-02)
Minimum DNBR
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
HTP
0
10
20
30
40
50
Time [Sec]

Figure 6-20

7. Loss of Feedwater

Figure 7-1 shows T_{ave} versus time. Both codes have an early reactor trip on low reactor coolant flow. The two codes are very close except that the increase due to steam generator B dryout is earlier in RETRAN due to differences in the steam generator model explained below under steam generator A wide range level.

Figure 7-2 shows pressurizer liquid volume versus time. The differences are due to differences in T_{ave}.

Figure 7-3 shows steam generator A wide range level versus time. The large perturbations in the RETRAN results are due to the effects of boundaries between vertical nodes. This problem was also observed in the early development of the replacement steam generator model and has been reduced significantly by adjustments to the nodalization. Another difference between the codes is that the level tends to by 5-10 feet higher after the onset of auxiliary feedwater. This difference is due to the fact that the initial water mass in the generators is larger in RETRAN than in DYNODE. The initial water mass is $7.65x10^4$ lbm in DYNODE and $8.33x10^4$ lbm in RETRAN, for a difference of 6800 lbm. The steam generator temperature at this time is about 560.5 °F. The density of saturated water at 560.5 °F is 45.3 lbm/ft^3. The area of the lower downcomer is equal to the volume over the height or 568.79 ft^3/38.8 ft = 14.7 ft^2. The height of this extra water is then 6800/(45.3 X 14.7) = 10 ft.

Figure 7-4 shows steam generator B wide range level versus time. The difference can be explained by the same reasoning used for the A generator discussed above.

Figure 7-5 shows the pressurizer pressure versus time. The earlier increase in RETRAN is due to the earlier dryout of steam generator B. The smaller variation in pressure from the safety valve setpoint in RETRAN is due to smaller time steps. The difference after the safety valve setpoint is reached (2800 to 3200 seconds) is due to a time step difference. RETRAN uses a more constant time step near the nominal of 0.1 second. When the safety valves open, they generally stay open for two time steps, or 0.2 seconds. DYNODE employs a variable time step scheme that apparently does not take safety valve opening into account. The time step size ranges from approximately 0.2 to 1 second. Since the valves must always be open for at least one time step, an unrealistically large time of opening is assumed, causing the pressure to drop about 25 Psi before the valves close. Reducing the time step size in DYNODE would alleviate this problem.

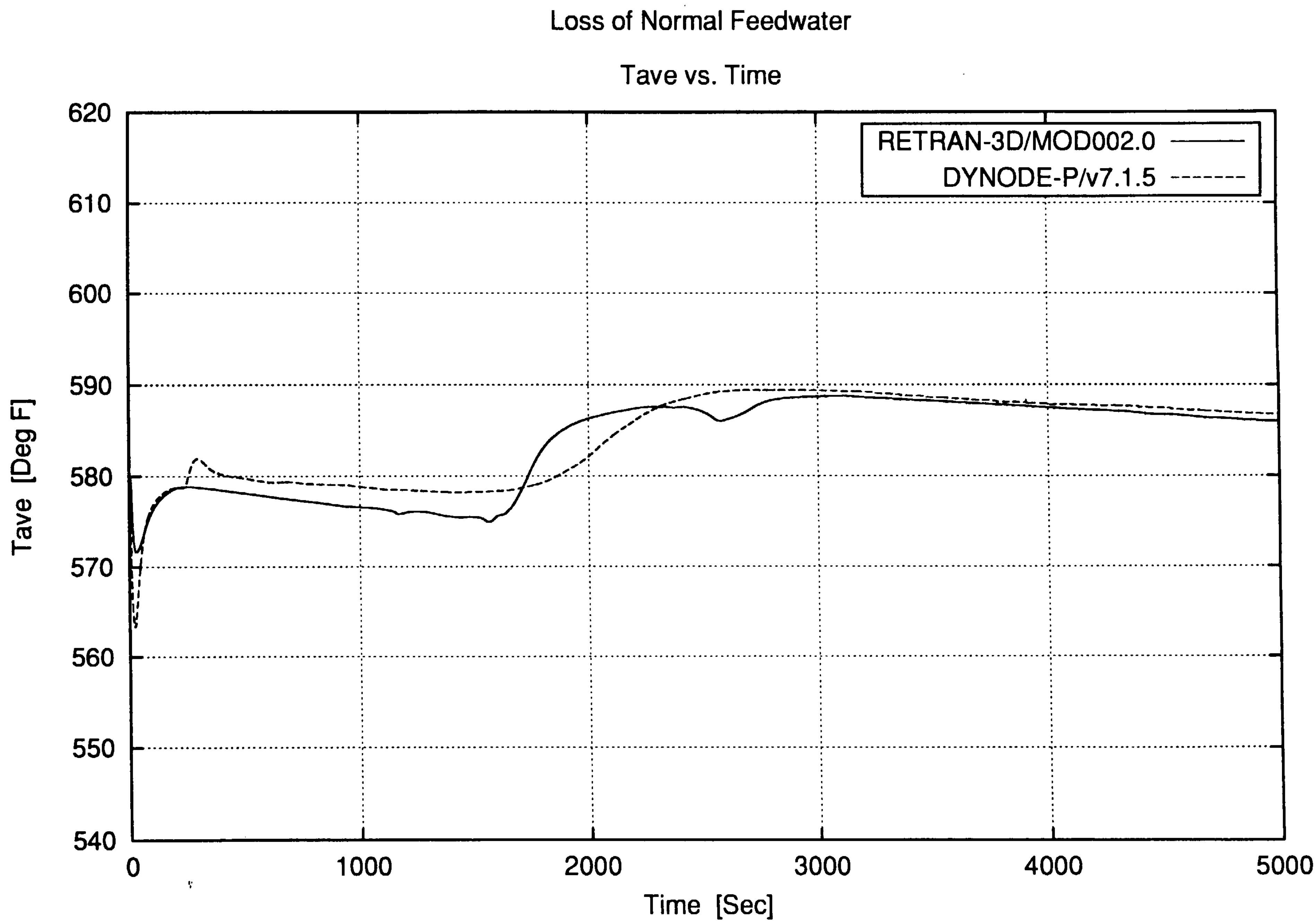

Loss of Normal Feedwater
Tave vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
Tave [Deg F]
620
610
600
590
580
570
560
550
540
0
1000
2000
3000
4000
5000
Time [Sec]

Figure 7-1

Loss of Normal Feedwater

Pressurizer Liquid Volume vs. Time

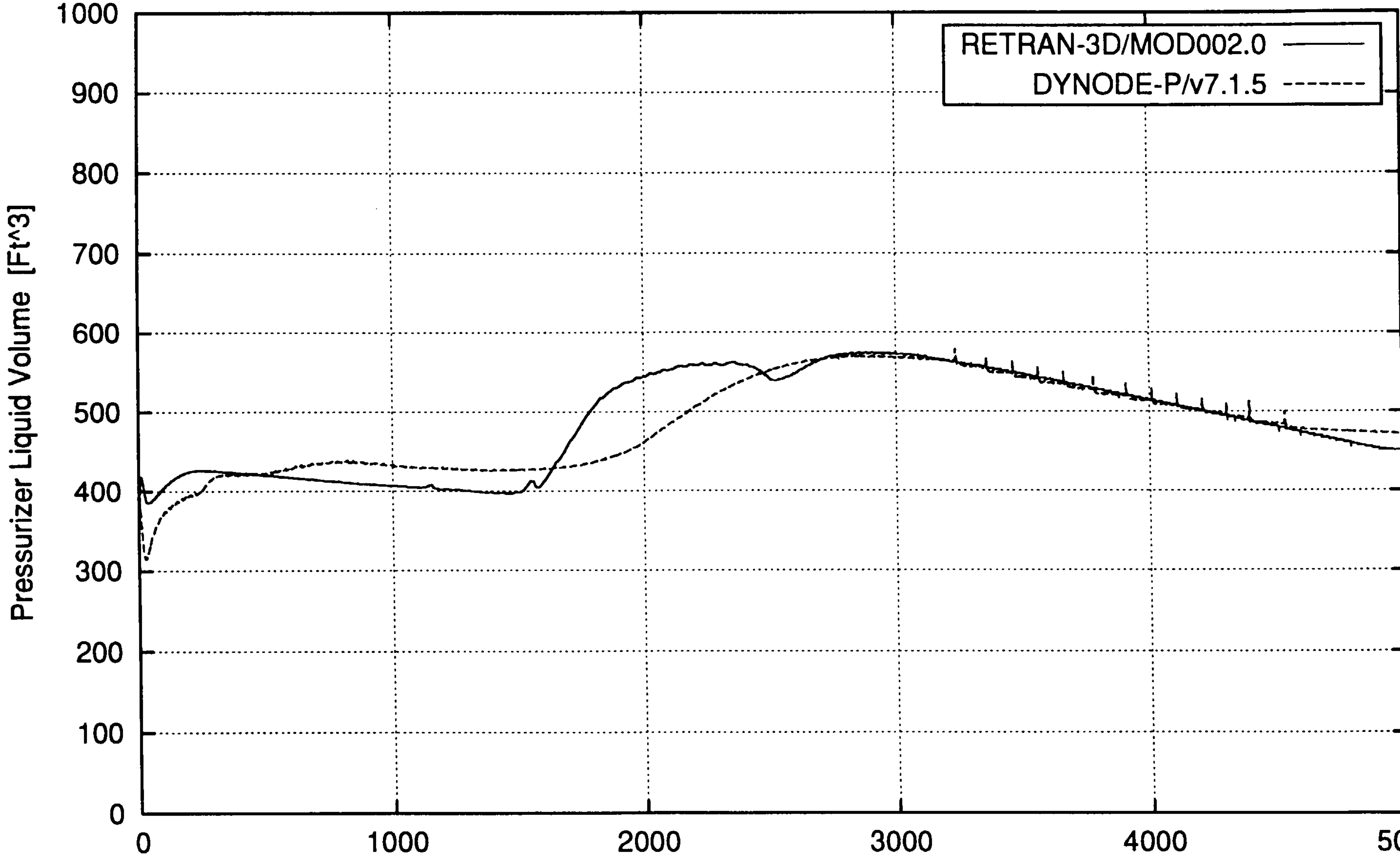
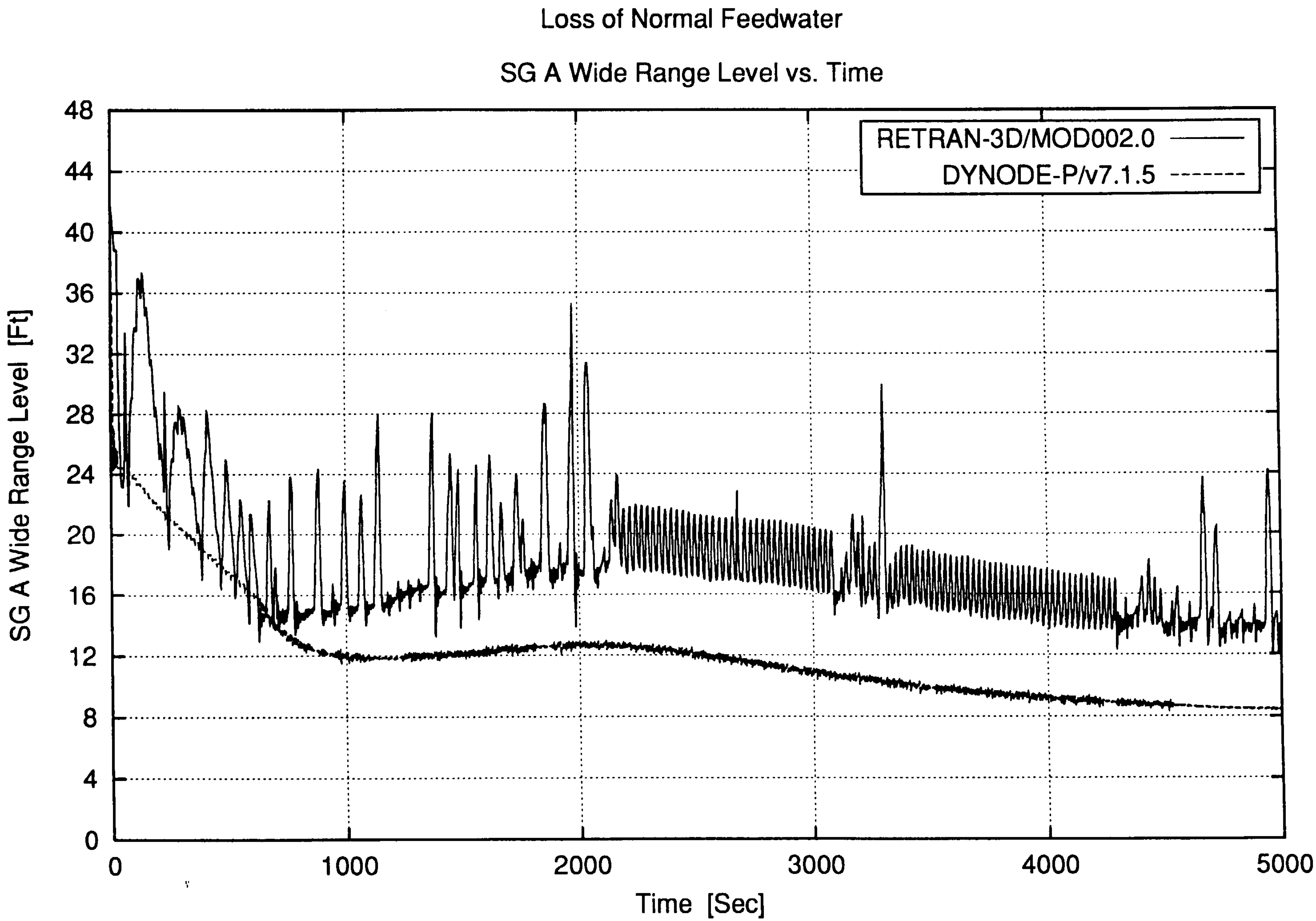


Figure 7-2



Loss of Normal Feedwater
SG A Wide Range Level vs. Time
RETRAN-3D/MOD002.0
DYNODE-P/v7.1.5
SG A Wide Range Level [Ft]
48
44
40
36
32
28
24
20
16
12
8
4
0
0
1000
2000
3000
4000
5000
Time [Sec]

Figure 7-3

Loss of Normal Feedwater

SG B Wide Range Level vs. Time

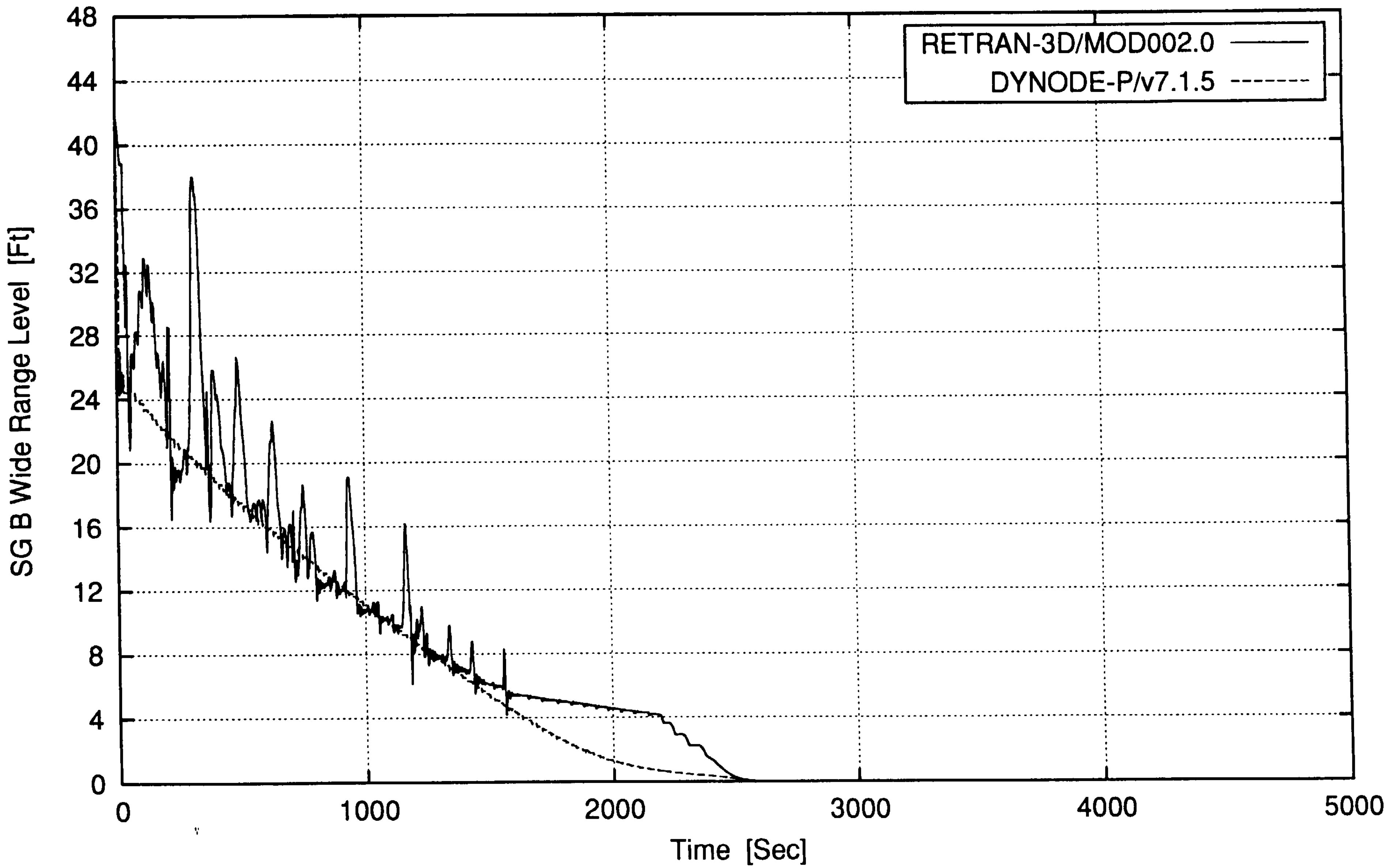


Figure 7-4

Loss of Normal Feedwater

Pressurizer Pressure vs. Time

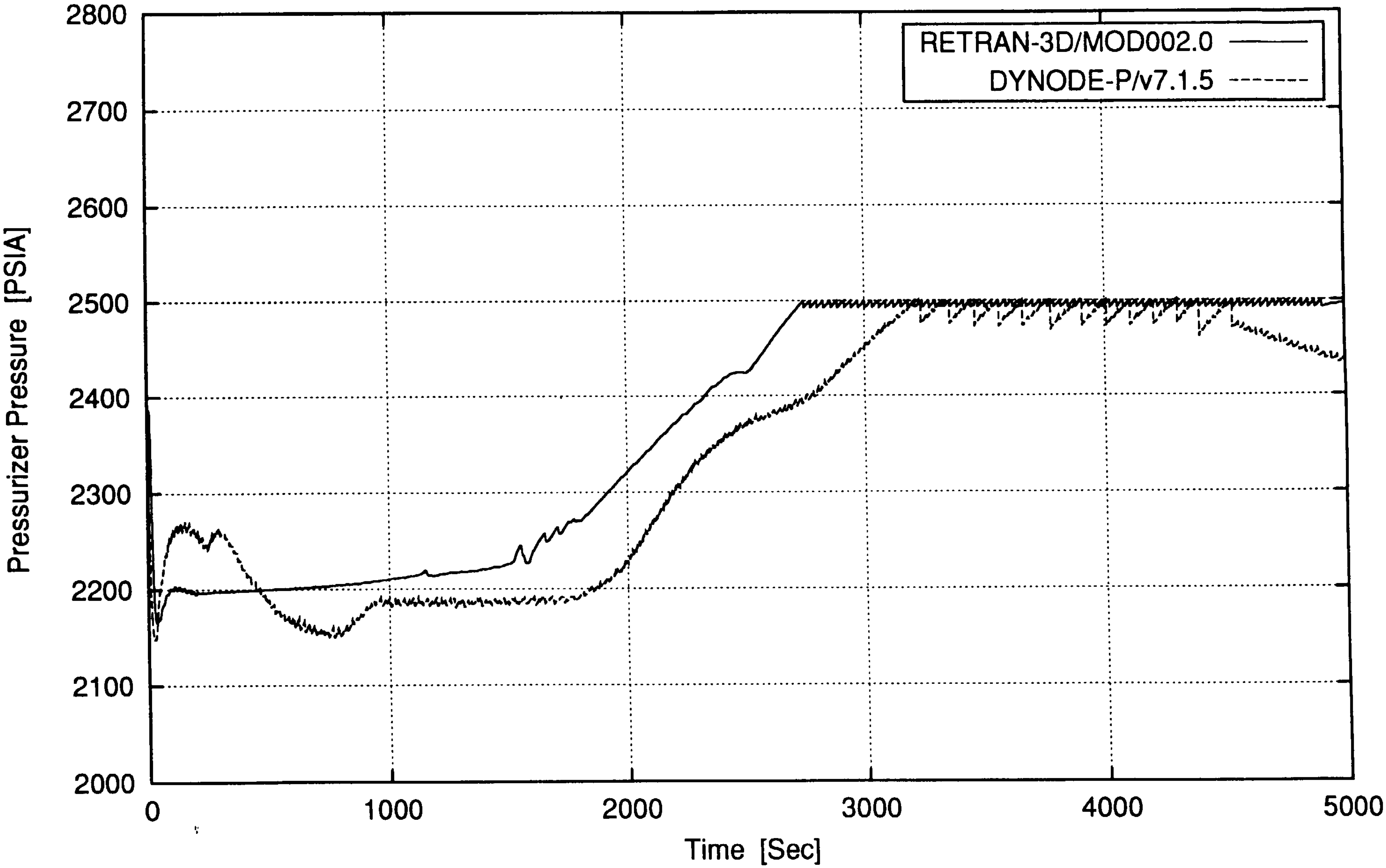


Figure 7-5

8. Summary of Results

In general, differences between the two codes are quite small. Table 8 shows the differences in USAR acceptance criteria values.

The following cases had results that are not within the review criteria for parameters that are USAR acceptance criteria:

In the Loss of Flow Underfrequency accident, the peak pressurizer pressure is 43 Psi higher in RETRAN. This is due to the higher heat flux for the later part of the transient as seen in figure 5-7. In the Loss of Load, the peak pressurizer pressure is higher in RETRAN by 14 to 78 Psi. As explained in Section III-6, this difference is due to the finer nodalization in the RETRAN steam generator.

In the Uncontrolled Rod Withdrawal Slow Rate Full Power accident, the peak steam generator pressure in RETRAN is higher than that of DYNODE by 101 Psi. In this case, the reactor trip is on overtemperature ΔT, which has a 6 second delay time. In RETRAN, the steam dump valves open immediately after the reactor and turbine trip, as would be the case in the actual plant. In DYNODE, the steam dump valves open immediately after the trip setpoint is reached, allowing the steam generators to begin to depressurize 6 seconds before the reactor trip. This difference accounts for the higher peak pressure in RETRAN. This effect may exist in other accidents, but is more pronounced in accidents that trip on reactor trips with long delay times.

In the Uncontrolled Rod Withdrawal Fast Rate Full Power, the peak steam generator pressure in RETRAN is higher than that of DYNODE by 43 Psi. Differences in the feedwater controller account for some of this difference. In RETRAN, the feedwater regulating valves are controlled by steam generator level and steam flow-feed flow mismatch, whereas DYNODE does not model any valve movement.

In the Feedwater Malfunction Regulating Valve Opening, the steam generator pressures are different by 49 Psi. As explained in Section III-3, the more detailed nodalization in RETRAN allows the temperature in the steam dome to be higher than that in the heat transfer area of the generator. Since the steam pressure is determined by the saturation temperature of the steam dome, a higher temperature in the steam dome result in a higher pressure in the steam generator. The 49 Psi difference in pressure corresponds to approximately a 6 °F difference in temperature.

In the Loss of Flow Two Pump Trip and the Loss of Flow Underfrequency Trip, the peak steam generator pressure in RETRAN is higher than that of DYNODE by 42 and 51 Psi, respectively. In both of these cases, the steam generator pressure is still increasing at 10 seconds, which is the end of problem time. In both of these accidents, the core flow decreases are slightly faster in RETRAN and the heat flux decreases are slightly slower in RETRAN, which cause the steam generator pressure to increase faster in RETRAN than in DYNODE. If the cases were run out far enough in time to reach their peak values, the peaks would likely be within 30 Psi. Future cases will be run until after the peak primary and secondary pressures are reached.

In the Locked Rotor, the peak clad temperature is higher in DYNODE than in RETRAN by 7°F. This difference, although greater than the review criteria on temperatures, is very small compared to the temperature variation in the accident (780°F) and well below the reportable value for a change in peak clad temperature (50°F). Since other transient values are close between the codes, the difference is deemed acceptable. The heat flux in RETRAN exhibits non-physical increases early in the transient due to heat transfer regime changes (see page III.5-1). The higher initial heat flux and slower decrease in heat flux cause the pressurizer and main steam system pressures to be 38 Psi higher in RETRAN than in DYNODE.

In each of these cases the difference is either due to a deficiency in DYNODE, a condition that will be corrected in the replacement steam generator analysis, or acceptably small.

Following is a summary of the RETRAN-DYNODE differences:

1. Feedwater flow is modeled in RETRAN as a constant flow rate multiplied by valve area, whereas DYNODE models the pump curve as a function of steam generator pressure with a constant valve area. As a result RETRAN does not model the effects of steam generator pressure on feedwater flow and DYNODE does not model the effects of steam generator level changes and flow mismatch. The difference, however, is fairly small. A future enhancement to the RETRAN model would be to model main feedwater as a pump curve, just as safety injection and auxiliary feedwater are modeled now.
2. The RETRAN steam generator model uses an unrealistic cross-sectional area for the steam generator separator, which results in level changes being too slow. This will be corrected in the replacement steam generator model.
3. The finer steam generator nodalization in RETRAN results in some differences between the codes. In the feedwater system malfunction, thermal stratification results in more secondary side cooling. In the loss of load, the early stages of the transient are affected by fact that the top of the riser heats up earlier than the bottom. The replacement steam generator model will have even finer steam generator nodalization, which will result in an even more realistic representation of the transient.
4. In RETRAN, the initial steam generator level is determined by the geometry and the initial mass is adjusted accordingly, resulting in differences from DYNODE. With better data for the replacement generators, the mass should be based on the data, and the level based on actual geometry, not just the area of the RETRAN volumes.
5. The core is modeled in RETRAN as three nodes, whereas DYNODE uses twelve nodes. This is only noticeable in the locked rotor accident. In this accident, non-physical power perturbations occur in RETRAN due to flow regime changes in individual nodes. These perturbations would be reduced if more nodes were added to the model, although the overall effect is small.
6. Large non-physical steam generator level oscillations occur in the RETRAN loss of feedwater transient. This will probably be corrected with the replacement steam generator model. If the oscillations appear in that model, more study will be necessary to determine their cause.

Table 8--Comparison of USAR Acceptance Criteria

Condition II and III Faults

Accident	MDNBR			Przr Press. (Psia)			SG Press. (Psia)		
	Dyn	Ret	Δ	Dyn	Ret	Δ	Dyn	Ret	Δ
Unc. Rod Withd. Fast, Full	1.547	1.541	-.006	2249	2244	-5	938	981	**43**
Unc. Rod Withd. Slow, Full	1.362	1.400	.038	2309	2311	2	946	1047	**101**
Unc. Rod Withd. Fast, Interm.	2.039	2.003	-.036	2314	2314	0	954	979	25
Unc. Rod Withd. Slow, Interm.	1.169	1.215	.046	2350	2326	-24	1182	1190	8
Boron Dilution at Full Power	1.347	1.393	.046	2321	2321	0	952	975	23
Fdwtr Malfunction BOC Man.	1.681	1.681	.000	2200	2204	4	751	752	1
Fdwtr Malfunction EOC Auto	1.647	1.660	.013	2200	2211	11	751	752	1
Fdwtr Malfunction Open Reg. V	1.681	1.657	-.024	2215	2202	-13	1062	1111	**49**
Exc. Load Incr. BOC Manual	1.681	1.681	.000	2200	2200	0	751	752	1
Exc. Load Incr. EOC Manual	1.478	1.486	.008	2200	2205	5	751	752	1
Exc. Load Incr. BOC Auto	1.430	1.407	-.023	2200	2207	7	751	752	1
Exc. Load Incr. EOC Auto	1.438	1.433	-.005	2200	2217	17	751	752	1
Loss of Flow--2 Pump Trip	1.314	1.289	-.025	2291	2287	-4	907	949	**42**
Loss of Flow--Underfrequency	1.248	1.219	-.029	2316	2359	**43**	878	929	**51**
Loss of Load BOC Auto	1.681	1.681	.000	2470	2503	**33**	1182	1173	-9
Loss of Load EOC Auto	1.681	1.681	.000	2377	2455	**78**	1198	1186	-12
Loss of Load BOC Manual	1.681	1.681	.000	2501	2515	14	1182	1173	-9
Loss of Load EOC Manual	1.681	1.681	.000	2477	2513	**36**	1181	1171	-10
Loss of Feedwater	1.681	1.681	.000	2501	2500	-1	1166	1157	-9

Condition IV Fault

Accident	Peak Clad Temp. (°F)			Limiting $F_{\Delta H}$*			Przr Pres. (Psia)			SG Press. (Psia)		
	Dyn	Ret	Δ	Dyn	Ret	Δ	Dyn	Ret	Δ	Dyn	Ret	Δ
Locked Rotor	1507	1500	**-7**	1.513	1.493	-.02	2365	2403	**38**	1044	1082	**38**

* Limiting $F_{\Delta H}$ is assumed to be directly proportional to DNBR. The change in $F_{\Delta H}$ corresponds to a .04 change in MDNBR, which is within the review criterion (0.14).

Results in bold are not within the review criteria (see Section II).

IV. Conclusions

RETRAN-3D results agree with DYNODE-P results to within established acceptance criteria. Differences between the two codes are small and can be explained. Therefore RETRAN-3D can be applied to KNPP design basis NON-LOCA transient events.

V. References

1. Letter from E. W. James (WPSC) to Document Control Desk (NRC) dated January 1979 transmitting Wisconsin Public Service Corporation (WPSC), Kewaunee Nuclear Power Plant (KNPP), topical report entitled "Reload Safety Evaluation Methods for Application to Kewaunee".

2. Letter from C. R. Steinhardt (WPSC) to Document Control Desk (NRC) dated 11-9-88 transmitting WPSC KNPP topical report WPSRSEM-NP-A Revision 2 entitled "Reload Safety Evaluation Methods for Application to Kewaunee".

3. Kewaunee Updated Safety Analysis Report, Revision 15, dated May 1999.

4. Letter from K. H. Weinhauer (WPSC) to Document Control Desk (NRC) dated 10-12-00 transmitting WPSC KNPP topical report WPSRSEM-NP Revision 3 entitled "Reload Safety Evaluation Methods for Application to Kewaunee".

5. DYNODE-P Plant Safety Analysis Case Setup Guide, 1998.

6. KNPP PSA 98 notebook, 1998.

Appendix A: Input Changes to Match DYNODE

The RETRAN cases in this report were run from Version 11.04 of the base case with changes to match DYNODE. These changes are discussed in this appendix.

Minor Edits

For the benchmark cases only, Control Block 54 is substituted for Control Block 13 for T_{ave} and Control Block 55 is substituted for Control Block 53 for ΔT.

Pressurizer Surge Line Changes

Calculation C11028 found a slight error in some pressurizer surge line parameters. These changes were made in the base case. Since the changes were not made to DYNODE, the old parameters are used for this benchmark.

```
055011 0 0     0.0     0.0  0.0    19.10    6.94        0.0 0.394   0.7083 619.06
082111 201 501  0  0  0.0        0.394  619.06  0.0  2.61      0.0  0  1  2  0
```

Line 055011 (Volume 501) – Pressurizer surge line

V = Volume = 19.10 ft^3 Old value from previous revision.
FLOWA = Flow area = 0.394 ft^2 Old value from previous revision.
DIAMV = Hydraulic diameter = 0.394 ft Old value from previous revision

Core Inlet and Exit Temperature

DYNODE uses instantaneous core ΔT and T_{ave} for output purposes and time-delayed loop ΔT and T_{ave} for control. In RETRAN, time-delayed loop ΔT and T_{ave} are used for both. It is therefore necessary to calculate instantaneous core ΔT and T_{ave} for a proper comparison to DYNODE.

```
*        CORE INLET AND EXIT TEMPERATURES
702059    59  TEMP,   5   1.0      606.602
702060    60  TEMP,   1   1.0      539.504
*       DELTA T
703054   -54  SUM,    59   60  1.0   1.0   -1.0  67.098
*       TAVG
703055   -55  SUM,    59   60  0.5   1.0    1.0  573.072
```

Line 702059 (Control Input 59) – Upper plenum temperature

IDC = 59	Control Input 59
CSYM = TEMP	This input is a temperature
IREG = 5	Volume 5 (Upper plenum)
GAIN = 1.0	Gain = 1
CIC = 606.602	Initially 606.602°F (from steady state initialization).

Line 702060 (Control Input 60) – Lower plenum temperature

IDC = 60	Control Input 60
CSYM = TEMP	This input is a temperature
IREG = 1	Volume 1 (Lower plenum)
GAIN = 1.0	Gain = 1
CIC = 539.504	Initially 539.504°F (from steady state initialization).

Line 703054 (Control Block 54) – Core ΔT

IDC = -54	Control Block 54
ITYPE = SUM	This block is a sum
INC1 = 59	Control Input 59 (Upper plenum temperature)
INC2 = 60	Control Input 60 (Lower plenum temperature)
CGAIN = 1.0	Gain = 1
CP1 = 1.0	1 X upper plenum temperature
CP2 = 1.0	-1 X lower plenum temperature
CIC = 67.098	Initial value = 606.602 – 539.504 = 67.098°F

Line 703055 (Control Block 55) – Core ΔT

IDC = -55	Control Block 55
ITYPE = SUM	This block is a sum
INC1 = 59	Control Input 59 (Upper plenum temperature)
INC2 = 60	Control Input 60 (Lower plenum temperature)
CGAIN = 1.0	Gain = 1
CP1 = 0.5	0.5 X upper plenum temperature
CP2 = 0.5	0.5 X lower plenum temperature
CIC = 67.098	Initial value = 0.5 X (606.602 + 539.504) = 573.053°F

These control blocks are edited as minor edits in the benchmark cases for ΔT and T_{ave}.

Changes to Pressurizer Level Controller

Pressurizer level control is modeled differently in RETRAN and DYNODE in the following three areas:

1. DYNODE does not take into account the fact that the reference level is linear with temperature up to 50%. In DYNODE, the maximum reference level is 34.4%, which corresponds to full power T_{ave}.
2. The integral portion of the level controller is not modeled in DYNODE.
3. Instead of modeling letdown, DYNODE subtracts the amount of flow corresponding to letdown flow from charging flow. If the controller calls for charging flow to be less than letdown flow, zero charging flow is assumed.

The following input lines force RETRAN to match these DYNODE assumptions. Instead of removing letdown, charging was adjusted so that it would never be less that letdown. This has the same net effect.

```
*           SET MAXIMUM PROGRAMED LEVEL TO 34.4%
703201 -201  SUM, -13  201  0.005154 1.0  -1.0  0.344  0.21  0.344
*       REMOVE INTRGRAL PORTION FROM CHARGING CONTROLLER
703204 -204  SUM, -202 -203 1.00000  1.0  0.0  0.0  -1.0  1.0
*       MAKE CHARGING NEVER LESS THAN LETDOWN
703205 -205  SUM, 202 -204  504.59 1.0  -4.0  252.2935780 252.293 504.59
*
```

Line 703201 (Control Block 201) Reference pressurizer level

CMAX = 0.344 Maximum reference level is 0.344

Line 703204 (Control Block 204) Pressurizer level controller signal

CP2 = 0.0 0.0 X Integral portion (This effectively zeros out the integral portion)

Line 703205 (Control Block205) Demand Charging Flow

CMIN = 252.293 Charging flow can never be less than letdown flow.

Changes to Pressurizer Pressure Controller

DYNODE does not model the integral portion of the controller. It also models the spray and relief valve setpoints as absolute setpoints rather than modeling them as relative to the reference pressurizer pressure. Since, in safety analysis, this setpoint is 2200 Psia as opposed to the normal setpoint of 2250 Psia, the RETRAN setpoints need to be adjusted by 50 Psi. Also, since all heaters are turned on when the pressurizer level is 10% above reference level, this feature must be adjusted for the change in level program discussed above. Finally, KAP 2486 found some differences between assumed values of power-operated relief valve opening and closing times and safety analysis. These changes were made to the base case, but since the old values were used in DYNODE, they are used for this benchmark.

```
*       CHANGE SPRAY, PORV SETPOINTS TO MATCH DYNODE
*       OLD PORV OPENING AND CLOSING TIMES
120700  3   0.0    0.0 10.0  1.0  1.0E6  1.0  * PORV A OPEN
120800  3   0.0    1.0  3.0  0.0  1.0E6  0.0  * PORV A CLOSE
121800  3   0.0    0.0 26.0  1.0  1.0E6  1.0  * PORV B OPEN
121900  3   0.0    1.0  5.0  0.0  1.0E6  0.0  * PORV B CLOSE
*       CONTROLLER CONSTANTS
702303  303  CONS,   0  -1.50   -1.50
043030   302   14 -303   0  150.0  0.0    "HIGH PRZR PRESS ERROR PORV SETPT"
043040  -302  -14 -303   0  130.0  0.0    "PORV CLOSES--HI PRZR ERROR RESET"
*       REMOVE INTEGRAL PORTION FROM PRZR PRESSURE CONTROLLER
703303 -303  SUM,   -301  -302  1.0    1.0   0.0   0.0
*           SET MAXIMUM HEATERS ON LEVEL TO 44.4%
703309 -309  SUM,   -13   307 0.006091 1.0 -1.0  0.444  0.31  0.444
```

*

Line 120700 (General Data Table 7) -- PORV A (PR-2A) open

TAREA(3) = 10.0	10 second opening time. From DYNODE

Line 120800 (General Data Table 8) -- PORV A (PR-2A) close

TAREA(3) = 3.0	3 second closing time. From KAP 2486

Line 121900 (General Data Table 19) -- PORV B (PR-2B) closed

TAREA(3) = 5.0	5 second closing time. From DYNODE.

Line 702303 (Control Input 303) – Zero intercept of spray flow versus pressure.

GAIN = –1.5	The normal equation is 0.02 X (pressure error – 0.5), resulting in the valve position being 0.0 (fully closed) at 25 Psia error and 1.0 (fully open) at 75 Psia error. This corresponds to 2275 and 2325 Psia if the reference pressure is 2250 Psia. Dynode uses these setpoints even though the programmed pressure is 2200 Psia. These setpoints can be reproduced with a reference pressure of 2250 Psia if the equation is changed to 0.02 X (pressure error – 1.5)
CIC = -1.5	Since this is a constant, the gain is equal to the initial value.

Line 043030 (Trip 303) Relief valve opening setpoint

SETPT = 150.0	This setpoint in increased to from 100.0 to 150.0 Psia above reference pressure because the programmed pressure is decreased by 50 Psi.

Line 043040 (Trip 304) Relief valve opening setpoint

SETPT = 130.0	This setpoint in increased to from 80.0 to 130.0 Psia above reference pressure because the reference is decreased by 50 Psi.

Line 703303 (Control Block 303) Pressurizer pressure controller signal

CP2 = 0.0	0.0 X Integral portion (This effectively zeros out the integral portion)
CIC = 0.0	Since there is no integral portion, the error is initially zero

Line 703309 (Control Block 309) Level at which all heaters must go on.

CMAX = 0.444	This level is 10% above the reference. The maximum reference level according to DYNODE is 34.4%

Changes to Steam Generator Level Controller

A new steam generator level controller was put into Version 11.04 of the input deck. Since a new level program will be in effect with steam generator replacement, the new program was used. Since the DYNODE cases used the old program, the old program has been reinstated for this study. If future RETRAN runs are made before steam generator replacement, this section needs to be added to the input deck. Also, KAP 2486 found some differences between assumed values of feedwater regulating valve opening times and safety analysis. These changes were made to the base case, but since the old values were used in DYNODE, they are used for this benchmark.

```
*       SWITCH TO OLD SG LEVEL CONTROLLER
*            CONSTANT 1.0
702409  409  CONS,    0   1.0     1.0
*     DETERMINE LEVEL ERROR IN SG A ( POSITIVE, UNDERFILLED)
703401 -401    SUM, -421   -40 1.0       1.0 -1.0  0.0
*     COMPUTE NEW VALVE AREA ( 8%/SEC OPENING, 5%/SEC CLOSING RATE )
703409 -409   SUM,    404 -408 1.0       1.0  1.0  0.88  0.0  1.0
703410 -410   VLM,   -409    0 1.0       0.08 0.05 0.88  0.0  1.0
*     DETERMINE LEVEL ERROR IN SG B ( POSITIVE, UNDERFILLED)
703411 -411    SUM, -421   -41 1.0       1.0 -1.0  0.0
*     COMPUTE NEW VALVE AREA ( 8%/SEC OPENING, 5%/SEC CLOSING RATE )
703419 -419   SUM,    408 -418 1.0       1.0  1.0  0.88  0.0  1.0
703420 -420   VLM,   -419    0 1.0       0.08 0.05 0.88  0.0  1.0
*              COMMON CONTROL BLOCKS FOR FEEDWATER CONTROLLER
*              COMPUTE REFERENCE LEVEL FROM LOAD
703421 -421    SUM,  409    20 1.0       0.33 0.55 0.44  0.33 0.44
```

Line 702409 (Control Input 409) – Constant for level calculation

GAIN = 1.0 Constant
CIC = 1.0 Initial value 1.0

Line 703401 (Control Block 401) – Level error in steam generator A

INC1 = -421 Control Block 421 (See below)

Line 703410 (Control Block 410) – Velocity limiter on A feedwater regulating valve

CP1 = 0.08 8 %/sec. Opening time limit from DYNODE.

Line 703411 (Control Block 411) – Level error in steam generator B

INC1 = -421 Control Block 421 (See below)

Line 703420 (Control Block 420) – Velocity limiter on A feedwater regulating valve

CP1 = 0.08 8 %/sec. Opening time limit from DYNODE.

Line 703421 (Control Block 421) – Reference level

IDC = -421	Control Block 421
ITYPE = SUM	This block is a sum
INC1 = 409	Control Input 409 (Constant 1.0)
INC2 = 20	Control Input 20 (Turbine load)
CGAIN = 1.0	Gain = 1
CP1 = 0.33	0.33 X 1
CP2 = 0.55	0.55 X Turbine Load
CIC = 0.44	Initial value = 0.44 (Maximum reference level)
CMIN = 0.33	Minimum reference level
CMAX = 0.44	Maximum reference level

The reference level at 0% load is 0.33 + .55 X 0.0 = 0.33
The reference level at 20% load is 0.33 + .55 X 0.2 = 0.44
The reference level above 20% load is the maximum reference level (0.44)
This is consistent with DYNODE and the PLS document.

Boron Dilution

```
*           PROBLEM DESCRIPTION CARD
*       NACC NGAP NUMRCS NSTK NTSH IVOID  NFIT  JFLG  NEQS  NSEP IG
010004   0    0     2     0    0     0     0     0     0     0  -1
*
020005 COUT,  50 COUT,  51 COUT,  52 COUT, -51 COUT,  20 COUT, -67
020006 DTOL,   0
*
*  PROBLEM END TIME
040010    1    1     0    0 100.0    0.0   "PROBLEM END TIME"
*
*       CHANGES FOR BORON DILUTION AT POWER
*
*        PRIMARY SYSTEM VOLUMES CAN CONTAIN BORON
*       NGSV NGSVCB RSVB
452001   1    0    0
*
*  INITIAL BORON CONCENTRATION
*       TPPMIN
454001  1600.0
*
*  BORON CONCENTATION & DENSITY IN CORE
702060    61   CONV,    2     1.0     1600.0
702061    62   CONV,    3     1.0     1600.0
702062    63   CONV,    4     1.0     1600.0
702063    64   AVED,    2   2.1222E-2  1.0
702064    65   AVED,    3   2.2216E-2  1.0
702065    66   AVED,    4   2.3448E-2  1.0
*
*  MULTIPLY CONCENTRATION BY NORMALIZED DENSITY
703060   -60  MUL    61    64   1.0     0.0    0.0          1600.0
703061   -61  MUL    62    65   1.0     0.0    0.0          1600.0
703062   -62  MUL    63    66   1.0     0.0    0.0          1600.0
*  TAKE WEIGHTED AVERAGE
703063   -63  SUM,  -60   -61   1.0 0.22346  0.55308    1242.464
703064   -64  SUM,  -63   -62   1.0  1.0     0.22346    1600.0
*  MULTIPLY BY BTC (-10 PCM/PPM)
703065   -65  SUM   -64   -63 -0.014164 1.0      0.0  -22.663
*  AVERAGE BORON CONCENTRATION FOR MINOR EDITS
703066   -66  SUM,  61    62   1.0     0.33333  0.33334  1066.672
703067   -67  SUM, -66    63   1.0     1.0      0.33333  1600.0
*  REACIVITY
141200   -65    1000
*
```

```
*   ADJUST MTC FOR BORON COMPONENT
*           DENWT   FTWT    ALPHTM     ALPHTW
140010    .22346  .22346  -2.312E-2  -8.428E-3
140020    .55308  .55308  -5.721E-2  -2.086E-2
140030    .22346  .22346  -2.312E-2  -8.428E-3
*
*             INCREASE CHARGING TO 120 GPM
703205 -205   SUM, 604   204   1.0   1.0E6 252.2935780 252.2935780
252.293 835.046
*             TRIP LETDOWN EARLY
042020    201     1     0    0  0.001   0.0     "LETDOWN TRIPPED"
```

Line 010004 (Problem description)

IGNTR = -1 Generalized transport model used for boron.

Lines 020005, 020006 (Minor Edits)

The following minor edit variable has been added:

COUT, -67 See calculation below. Reactor coolant system boron concentration

Line 040010 (Trip 1) -- Problem end time

SETPT = 100.0 100 seconds

Line 452001 (General Transport Volume 1) -- General Transport

NGSV = 1 Volume 1 is the lower plenum All connected volumes (the reactor coolant system) contain boric acid.
NGSVCB = 0 No sources are in any volume.
RSVB = 0 No concentration biases exist.

Line 454001 -- Initial Boron concentration

TPPMIN = 1600 ppm From Dynode

Line 702061 (Control Input 61) -- Boron concentration in lower core

IDC = 61 Control Input 61
CSYM = CONV This input is a concentration
IREG = 2 This is the lower core region
GAIN = 1.0 Gain = 1
CIC = 1600.0 Initial concentration = 1600 ppm.

Line 702062 (Control Input 62) -- Boron concentration in middle core

IDC = 62	Control Input 62
CSYM = CONV	This input is a concentration
IREG = 3	This is the middle core region
GAIN = 1.0	Gain = 1
CIC = 1600.0	Initial concentration = 1600 ppm.

Line 702063 (Control Input 63) -- Boron concentration in upper core

IDC = 63	Control Input 63
CSYM = CONV	This input is a concentration
IREG = 4	This is the upper core region
GAIN = 1.0	Gain = 1
CIC = 1600.0	Initial concentration = 1600 ppm.

Lines 702064 (Control Input 64) -- Normalized density in lower core

IDC = 64	Control Input 64
CSYM = AVED	This input is the average density
IREG = 2	This is the lower core region
GAIN = 2.1222×10^{-2}	Gain = 1/Density (47.1215 lbm/ft^3 from Steady State Initialization)
CIC = 1.0	Initial normalized concentration = 1

Lines 702065 (Control Input 65) -- Normalized density in middle core

IDC = 65	Control Input 65
CSYM = AVED	This input is the average density
IREG = 3	This is the middle core region
GAIN = 2.2216×10^{-2}	Gain = 1/Density (45.0132 lbm/ft^3 from Steady State Initialization)
CIC = 1.0	Initial normalized concentration = 1

Line 702066 (Control Input 66) -- Normalized density in upper core

IDC = 66	Control Input 66
CSYM = AVED	This input is the average density
IREG = 3	This is the upper core region
GAIN = 2.3448×10^{-2}	Gain = 1/Density (42.6477 lbm/ft^3 from Steady State Initialization)
CIC = 1.0	Initial normalized concentration = 1

Line 703060 (Control Block 60) -- Multiply concentration by normalized density in lower core.

IDC = -60	Control Block 60
ITYPE = MUL	This control block is a multiplier.

INC1 = 61	Control Input 61 (Boron concentration in lower core)
INC2 = 64	Control Input 64 (Normalized density in lower core)
CGAIN = 1.0	Gain = 1.0
CP1 = 0.0	Multipliers have no input gain
CP2 = 0.0	Multipliers have no input gain
CIC = 1600.0	Initial concentration x normalized density = 1600.0

Line 703061 (Control Block 61) -- Multiply concentration by normalized density in middle core.

IDC = -61	Control Block 61
ITYPE = MUL	This control block is a multiplier.
INC1 = 62	Control Input 62 (Boron concentration in middle core)
INC2 = 65	Control Input 65 (Normalized density in middle core)
CGAIN = 1.0	Gain = 1.0
CP1 = 0.0	Multipliers have no input gain
CP2 = 0.0	Multipliers have no input gain
CIC = 1600.0	Initial concentration x normalized density = 1600.0

Line 703062 (Control Block 62) -- Multiply concentration by normalized density in upper core.

IDC = -62	Control Block 62
ITYPE = MUL	This control block is a multiplier.
INC1 = 63	Control Input 63 (Boron concentration in upper core)
INC2 = 66	Control Input 66 (Normalized density in upper core)
CGAIN = 1.0	Gain = 1.0
CP1 = 0.0	Multipliers have no input gain
CP2 = 0.0	Multipliers have no input gain
CIC = 1600.0	Initial concentration x normalized density = 1600.0

Line 703063 (Control Block 63) – Flux weighted average of concentration times density.

IDC = -63	Control Block 63
ITYPE = SUM	This control block is a sum.
INC1 = -60	Concentration x normalized density in lower core
INC2 = -61	Concentration x normalized density in middle core
CGAIN = 1.0	Gain = 1.0
CP1 = 0.22346	Power in lower core
CP2 = 0.55308	Power in middle core
CIC = 1242.464	Initial value = (.22346 * 1600) + (.55308 * 1600)

Line 703064 (Control Block 64) – Flux weighted average of concentration times density.

IDC = -64	Control Block 64
ITYPE = SUM	This control block is a sum.

INC1 = -63	Concentration x normalized density in lower and middle core
INC2 = -62	Concentration x normalized density in upper core
CGAIN = 1.0	Gain = 1.0
CP1 = 1.0	Lower + middle are already weighted
CP2 = 0.22346	Power in upper core
CIC = 1600	Initial value = 1242.464 + (.22346 * 1600)

Line 703065 (Control Block 65) -- Boron reactivity

IDC = -65	Control Block 65
ITYPE = SUM	This control block is a sum.
INC1 = -64	Concentration x normalized density
INC2 = -63	Dummy value not used
CGAIN = -0.014164	-10 pcm/ppm / 706 pcm/$ (Safety Analysis Assumption)
CP1 = 1.0	Input gain = 1.0
CP2 = 0.0	Set at zero to zero out dummy value
CIC = -22.663	Initial value = 1600 X 0.014164

Line 703066 (Control Block 66) -- Average boron concentration for minor edits

IDC = -66	Control Block 66
ITYPE = SUM	This control block is a sum.
INC1 = 61	Concentration in lower core
INC2 = 62	Concentration in middle core
CGAIN = 1.0	Gain = 1.0
CP1 = 0.33333	Multiply by 1/3
CP2 = 0.33334	Multiply by 1/3
CIC = 1066.672	Initial value = (.33333 * 1600) + (.33334 * 1600)

Line 703067 (Control Block 67) -- Average boron concentration for minor edits

IDC = -67	Control Block 67
ITYPE = SUM	This control block is a sum.
INC1 = -66	Concentration in lower and middle core
INC2 = 63	Concentration in upper core
CGAIN = 1.0	Gain = 1.0
CP1 = 1.0	Lower + middle are already weighted
CP2 = 0.33333	Multiply by 1/3
CIC = 1600.0	Initial value = 1066.672 + (.33333 * 1600)

Line 141200 Scram table data

NSCR = -65	Control Block 65 controls reactivity
ITSCRM = 1000	Reactivity controlled by control system

Line 140010 (Core region 1) -- Reactivity coefficients

A negative MTC must be used to balance the effect of changing boron density with temperature, preserving a 0 MTC. Dynode uses AK = 2.02×10^{-4} lbm/Btu for enthalpy coefficient (from Dynode Calculational File 452-104-011). This needs to be converted to a temperature coefficient for Retran. Using a ratio of 1.3182 Btu/lbm°F, We get:

MTC = $2.02 \times 10^{-4} * 1.3182 = 2.6628 \times 10^{-4}$ /°F

ALPHTW for the top and bottom nodes is $\frac{2.6628 \times 10^{-4}\ °F^{-1} * 0.22346}{.00706\ \$^{-1}}$ = -8.428 x 10-3 \$/°F

ALPHTW for the middle node is $\frac{2.6628 \times 10^{-4}\ °F^{-1} * 0.55308}{.00706\ \$^{-1}}$ = -2.086 x 10-3 \$/°F

Line 703205 (Control Block 205) -- Charging flow

INC1 = 604	Time in seconds
INC2 = 204	Constant 1.0
CGAIN = 1.0	Gain = 1.0
CP1 = 1.0E6	Large value used so the output is initially normal charging and becomes the maximum almost immediately
CP2 = 252.2935780	Initial charging mass flux (same as base case)

CIC = 252.2935780	Initial charging mass flux
CMIN = 252.293	Minimum flux (same as base case)
CMAX = 835.046	Maximum flux, 18.204 lbm/sec (from DYNODE) /0.0218 ft^2 (Area of

Junction 802) = 835.046 lbm/ft^2-sec

Line 042020 (Trip 202) -- Letdown trip

IDSIG = 1	Trip is on time
IX1 = 0	Time has no region
SETPT = 0.001	Trip at 0.001 seconds (essentially, time 0).

Excessive Load Increase: BOC Auto Control

```
*  TIME STEPS
*        TRTG   TMIN   TRST   TMAJ   TDMP   NCHK   DELTM   TLAST   NSHAP
030010    0.0    0.1    0.0    5.0    0.0      0    0.1   1.E+6       0
*
*   PROBLEM END TIME
040010     1     1      0     0 150.0     0.0    "PROBLEM END TIME"
*
*        CHANGES FOR EXCESSIVE LOAD INCREASE BOC AUTO CONTROL
*
*             LOAD DEMAND AT TURBINE VALVE
121100    4
121101     0.0       1.0
121102     0.0001    1.2
121103    35.0       1.2
121104  1.0E+10      1.2
*
*             KEEP VALVE AREA CONSTANT
703611 -611  FNG,    604     11    1.0     0.0  0.0    1.0    0.0    1.2
*
*             SET INITIAL ROD POSITION TO 153 STEPS
703130 -130  INT, -129  0  1.0  0.0  0.0  153.0    0.0  228.0
```

Line 030010 -- Time Steps

TMIN = 0.1	One minor edit is printed for each standard time step
DELTM = 0.1	Maximum time step of 0.1 seconds prevents numerical problems.

Line 040010 (Trip 1) -- Problem end time

SETPT = 150.0 150 seconds

Lines 121100 through 121104 (General Data Table 11) -- Turbine load

TAREA(3) = 0.0001 Valve opens instantaneously.
TAREA(4) = TAREA(6) = TAREA(8) = 1.2 Final turbine load (Safety Analysis Assumption)

Line 703611 (Control Block 611) -- Turbine valve area

ITYPE = FNG This block is a function generator
INC1 = 604 The function is a function of time

INC2 = 11 Function generator number 11

CP1 = 0.0	Function generators have no input gains
CP2 = 0.0	Function generators have no input gains
CMAX = 1.2	Maximum area is now 1.2

Line 703130 (Control Block 130) -- Control rod position

CIC = 153.0	Initial rod position = 153 steps

Excessive Load Increase: BOC Manual Control

```
*  TIME STEPS
*       TRTG  TMIN  TRST  TMAJ  TDMP  NCHK  DELTM  TLAST  NSHAP
030010   0.0   1.0   0.0  25.0   0.0     0   1.0   1.E+6      0
*
*   PROBLEM END TIME
040010    1    1     0    0 240.0    0.0    "PROBLEM END TIME"
*
*       CHANGES FOR EXCESSIVE LOAD INCREASE BOC MANUAL CONTROL
*
*            LOAD DEMAND AT TURBINE VALVE
121100    4
121101     0.0      1.0
121102     0.0001   1.2
121103    35.0      1.2
121104  1.0E+10     1.2
*
*            KEEP VALVE AREA CONSTANT
703611 -611  FNG,   604    11   1.0   0.0  0.0   1.0   0.0   1.2
*
*          DISABLE ROD CONTROLLER
703130 -130  INT, -129  0  1.0  0.0  0.0  228.0  228.0  228.0
*          DISABLE PRESSURIZER CONTROL
*                SPRAYS
703304 -304   SUM,  303  -303   1.000   1.0  0.02  0.0  0.0 0.000
*                PORVS
043030   302   14 -303   0  5000.0 0.0    "HIGH PRZR PRESS ERROR
PORV SETPT"
043050   303   +4  500   0  5000.0 0.0    "HIGH PRZR PRESS PORV
SETPOINT"
*           DISABLE STEAM DUMP
703556 -556  MUL,  -550   509  0.0  0.0  0.0  0.0
703557 -557  MUL,  -551   509  0.0  0.0  0.0  0.0
703558 -558  MUL,  -552   510  0.0  0.0  0.0  0.0
703559 -559  MUL,  -553   510  0.0  0.0  0.0  0.0
*
```

Line 030010 -- Time steps

TMIN = 1.0	One minor edit is printed for each standard time step.
TMAJ = 25.0	One major edit for each 25 seconds prevents excess output.
DELTM = 1.0	One second maximum time step prevents excess output.

Line 040010 (Trip 1) -- Problem end time

SETPT = 240.0 240 seconds

Lines 121100 through 121104 (General Data Table 11) -- Turbine load

TAREA(3) = 0.0001 Valve opens at the first time step.
TAREA(4) = TAREA(6) = TAREA(8) = 1.2 Final turbine load (Safety Analysis Assumption)

Line 703611 (Control Block 611) -- Turbine valve area

ITYPE = FNG This block is a function generator
INC1 = 604 The function is a function of time
INC2 = 11 Function generator number 11
CP1 = 0.0 Function generators have no input gains
CP2 = 0.0 Function generators have no input gains
CMAX = 1.2 Maximum area is now 1.2

Line 703130 (Control Block 130) -- Control rod position

CMIN = 228.0 Minimum rod position = 228 steps. Rods disabled

Line 703304 (Control Block 304) -- Pressurizer spray control

CMAX = 0.0 Maximum spray flow = 0.0. Sprays disabled.

Line 043030 (Trip 303) -- PORV trip

SETPT = 5000.0 Trip setpoint = 5000 psi error. PORV disabled

Line 043050 (Trip 305) -- PORV trip

SETPT = 5000.0 Trip setpoint = 5000 psia. PORV disabled

Lines 703556 through 703559 (Control Blocks 556 through 559) -- Steam dump valve area

CGAIN = 0.0 Gain = 0.0 Steam dump valves disabled.

Excessive Load Increase: EOC Auto Control

Entire Physics Parameters section replaced by EOC physics parameters

```
*  TIME STEPS
*        TRTG   TMIN   TRST   TMAJ   TDMP   NCHK   DELTM   TLAST   NSHAP
030010   0.0    0.1    0.0    25.0   0.0       0   0.1     1.E+6       0
*
*   PROBLEM END TIME
040010    1     1      0     0 300.0    0.0    "PROBLEM END TIME"
*
*        CHANGES FOR EXCESSIVE LOAD INCREASE EOC AUTO CONTROL
*
*             LOAD DEMAND AT TURBINE VALVE
121100    4
121101     0.0      1.0
121102     0.0001   1.2
121103    35.0      1.2
121104  1.0E+10     1.2
*
*             KEEP VALVE AREA CONSTANT
703611 -611  FNG,    604    11   1.0    0.0  0.0   1.0   0.0   1.2
*
*             SET INITIAL ROD POSITION TO 153
703130 -130  INT, -129  0  1.0  0.0  0.0  153.0    0.0  228.0
*
```

Line 030010 -- Time Steps

TMIN = 0.1 One minor edit is printed for each standard time step.
TMAJ = 25.0 One major edit for each 25 seconds prevents excess output.
DELTM = 0.1 Maximum time step of 0.1 seconds prevents numerical problems.

Line 040010 (Trip 1) -- Problem end time

SETPT = 300.0 300 seconds

Lines 121100 through 121104 (General Data Table 11) -- Turbine load

TAREA(3) = 0.0001 Valve opens instantaneously.
TAREA(4) = TAREA(6) = TAREA(8) = 1.2 Final turbine load (Safety Analysis Assumption)

Line 703611 (Control Block 611) -- Turbine valve area

ITYPE = FNG This block is a function generator

INC1 = 604	The function is a function of time
INC2 = 11	Function generator number 11
CP1 = 0.0	Function generators have no input gains
CP2 = 0.0	Function generators have no input gains
CMAX = 1.2	Maximum area is now 1.2

Line 703130 (Control Block 130) -- Control rod position

CIC = 153.0	Initial rod position = 153 steps

Excessive Load Increase: EOC Manual Control

Entire Physics Parameters section replaced by EOC physics parameters

```
*  TIME STEPS
*       TRTG  TMIN  TRST  TMAJ  TDMP  NCHK  DELTM  TLAST  NSHAP
030010   0.0   0.1   0.0  25.0   0.0     0   0.1   1.E+6      0
*
*   PROBLEM END TIME
040010    1    1     0    0 240.0    0.0   "PROBLEM END TIME"
*
*       CHANGES FOR EXCESSIVE LOAD INCREASE BOC AUTO CONTROL
*
*            LOAD DEMAND AT TURBINE VALVE
121100    4
121101     0.0      1.0
121102     0.0001   1.2
121103    35.0      1.2
121104  1.0E+10     1.2
*
*            KEEP VALVE AREA CONSTANT
703611 -611  FNG,    604    11   1.0    0.0  0.0   1.0   0.0   1.2
*
*          DISABLE ROD CONTROLLER
703130 -130  INT, -129  0  1.0  0.0  0.0  228.0  228.0  228.0
*          DISABLE PRESSURIZER CONTROL
*                SPRAYS
703304 -304   SUM,  303  -303   1.000   1.0  0.02  0.0   0.0 0.000
*                PORVS
043030   302   14 -303   0  5000.0 0.0    "HIGH PRZR PRESS ERROR
PORV SETPT"
043050   303   +4  500   0  5000.0 0.0    "HIGH PRZR PRESS PORV
SETPOINT"
*           DISABLE STEAM DUMP
703556 -556  MUL,  -550   509  0.0  0.0  0.0  0.0
703557 -557  MUL,  -551   509  0.0  0.0  0.0  0.0
703558 -558  MUL,  -552   510  0.0  0.0  0.0  0.0
703559 -559  MUL,  -553   510  0.0  0.0  0.0  0.0
*
```

Line 030010 -- Time steps

TMIN = 0.1	One minor edit is printed for each standard time step.
TMAJ = 25.0	One major edit for each 25 seconds prevents excess output.
DELTM = 0.1	Maximum time step of 0.1 seconds prevents numerical problems.

Line 040010 (Trip 1) -- Problem end time

SETPT = 240.0 240 seconds

Lines 121100 through 121104 (General Data Table 11) -- Turbine load

TAREA(3) = 0.0001 Valve opens at the first tome step.
TAREA(6) = TAREA(6) = TAREA(8) = 1.2 Final turbine load (Safety Analysis Assumption)

Line 703611 (Control Block 611) -- Turbine valve area

ITYPE = FNG This block is a function generator
INC1 = 604 The function is a function of time
INC2 = 11 Function generator number 11
CP1 = 0.0 Function generators have no input gains
CP2 = 0.0 Function generators have no input gains
CMAX = 1.2 Maximum area is now 1.2

Line 703130 (Control Block 130) -- Control rod position

CMIN = 228.0 Minimum rod position = 228 steps. Rods disabled

Line 703304 (Control Block 304) -- Pressurizer spray control

CMAX = 0.0 Maximum spray flow = 0.0. Sprays disabled.

Line 043030 (Trip 303) -- PORV trip

SETPT = 5000.0 Trip setpoint = 5000 psi error. PORV disabled

Line 043050 (Trip 305) -- PORV trip

SETPT = 5000.0 Trip setpoint = 5000 psia. PORV disabled

Lines 703556 through 703559 (Control Blocks 556 through 559) -- Steam dump valve area

CGAIN = 0.0 Gain = 0.0 Steam dump valves disabled.

Feedwater Malfunction: BOC Manual Control

```
*  TIME STEPS
*       TRTG  TMIN  TRST  TMAJ  TDMP  NCHK  DELTM  TLAST  NSHAP
030010   0.0   1.0   0.0  25.0   0.0     0   1.0   1.E+6      0
*
*   PROBLEM END TIME
040010    1    1     0    0 300.0    0.0   "PROBLEM END TIME"
*
*        CHANGES FOR FEEDWATER MALFUNCTION BOC MANUAL CONTROL
*
*              FILL MASS FLUXES AND PROPERTIES
*              FEEDWATER LOOP A
130101  -16   3   0    0
*         TIME          FLUX              ENTH    PRESS
130102    0.0        827.2837954855   402.27   750.0
130103   20.0        827.2837954855   401.46   750.0
130104   50.00       827.2837954855   386.12   750.0
130105   75.00       827.2837954855   375.89   750.0
130106  100.00       827.2837954855   372.12   750.0
130107  130.00       827.2837954855   371.04   750.0
130108  150.00       827.2837954855   371.58   750.0
130109  190.00       827.2837954855   372.66   750.0
130110  200.00       827.2837954855   372.66   750.0
130111  225.00       827.2837954855   372.66   750.0
130112  240.00       827.2837954855   372.66   750.0
130113  275.00       827.2837954855   372.03   750.0
130114  300.00       827.2837954855   371.58   750.0
130115  375.00       827.2837954855   371.18   750.0
130116  400.00       827.2837954855   371.04   750.0
130117 1000.00       827.2837954855   371.04   750.0
*              FEEDWATER LOOP B
130201  -16   3   0    0
*         TIME          FLUX              ENTH    PRESS
130202    0.0        827.2837954855   402.27   750.0
130203   20.0        827.2837954855   401.46   750.0
130204   50.00       827.2837954855   386.12   750.0
130205   75.00       827.2837954855   375.89   750.0
130206  100.00       827.2837954855   372.12   750.0
130207  130.00       827.2837954855   371.04   750.0
130208  150.00       827.2837954855   371.58   750.0
130209  190.00       827.2837954855   372.66   750.0
130210  200.00       827.2837954855   372.66   750.0
130211  225.00       827.2837954855   372.66   750.0
```

```
130212  240.00        827.2837954855   372.66  750.0
130213  275.00        827.2837954855   372.03  750.0
130214  300.00        827.2837954855   371.58  750.0
130215  375.00        827.2837954855   371.18  750.0
130216  400.00        827.2837954855   371.04  750.0
130217 1000.00        827.2837954855   371.04  750.0
*
*           DISABLE ROD CONTROLLER
703130 -130  INT, -129  0  1.0  0.0  0.0  228.0  228.0  228.0
*           DISABLE PRESSURIZER CONTROL
*                 SPRAYS
703304 -304   SUM,  303  -303   1.000   1.0  0.02  0.0  0.0 0.000
*                 PORVS
043030   302   14 -303   0  5000.0 0.0    "HIGH PRZR PRESS ERROR
PORV SETPT"
043050   303   +4  500   0  5000.0 0.0    "HIGH PRZR PRESS PORV
SETPOINT"
*
*            DISABLE STEAM DUMP
703556 -556  MUL,  -550   509  0.0  0.0  0.0  0.0
703557 -557  MUL,  -551   509  0.0  0.0  0.0  0.0
703558 -558  MUL,  -552   510  0.0  0.0  0.0  0.0
703559 -559  MUL,  -553   510  0.0  0.0  0.0  0.0
*
```

Line 030010 -- Time steps

TMIN = 1.0	One minor edit is printed for each standard time step.
TMAJ = 25.0	One major edit for each 25 seconds prevents excess output.
DELTM = 1.0	One second maximum time step prevents excess output.

Line 040010 (Trip 1) -- Problem end time

SETPT = 300.0	300 seconds

Lines 130101 through 130117, 130201 through 1302117 (Fill Tables 1, 2) -- Feedwater flux to SGs A, B

NFILL = -16	16 points
FILTBL(1,2) = 20.0	Second Point (from Dynode Case Setup Guide)
FILENT(2) = 401.46	Second Enthalpy = 402.27 (initial enthalpy) - 0.8076 (Δ enthalpy from Dynode)
FILTBL(1,3) = 50	Third Point (Dynode)
FILENT(3) = 386.12	Third Enthalpy = 402.27 - 16.152 (Δ enthalpy from Dynode)

FILTBL(1,4) = 75 Fourth Point (Dynode)
FILENT(4) = 375.89 Fourth Enthalpy = 402.27 - 26.3816 (Δ enthalpy from Dynode)
FILTBL(1,5) = 100 Fifth Point (Dynode)
FILTBL(2,5) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(5) = 372.12 Fifth Enthalpy = 402.27 - 30.1504 (Δ enthalpy from Dynode)
FILPRS(5) = 750.0 Not used
FILTBL(1,6) = 130 Sixth Point (Dynode)
FILTBL(2,6) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(6) = 371.04 Sixth Enthalpy = 402.27 - 31.2272 (Δ enthalpy from Dynode)
FILPRS(6) = 750.0 Not used
FILTBL(1,7) = 150 Seventh Point (Dynode)
FILTBL(2,7) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(7) = 371.58 Seventh Enthalpy = 402.27 - 30.6888 (Δ enthalpy from Dynode)
FILPRS(7) = 750.0 Not used
FILTBL(1,8) = 190 Eighth Point (Dynode)
FILTBL(2,8) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(8) = 372.66 Eighth Enthalpy = 402.27 - 29.6120 (Δ enthalpy from Dynode)
FILPRS(8) = 750.0 Not used
FILTBL(1,9) = 200 Ninth Point (Dynode)
FILTBL(2,9) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(9) = 372.66 Ninth Enthalpy = 402.27 - 29.6120 (Δ enthalpy from Dynode)
FILPRS(9) = 750.0 Not used
FILTBL(1,10) = 225 Tenth Point (Dynode)
FILTBL(2,10) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(10) = 372.66 Tenth Enthalpy = 402.27 - 29.6120 (Δ enthalpy from Dynode)
FILPRS(10) = 750.0 Not used
FILTBL(1,11) = 240 Eleventh Point (Dynode)
FILTBL(2,11) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(11) = 372.66 Eleventh Enthalpy = 402.27 - 29.6120 (Δ enthalpy from Dynode)
FILPRS(11) = 750.0 Not used
FILTBL(1,12) = 275 Twelfth Point (Dynode)
FILTBL(2,12) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(12) = 372.03 Twelfth Enthalpy = 402.27 - 30.2400 (Δ enthalpy from Dynode)
FILPRS(12) = 750.0 Not used
FILTBL(1,13) = 300 Thirteenth Point (Dynode)
FILTBL(2,13) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(13) = 371.58 Thirteenth Enthalpy = 402.27 - 30.6888 (Δ enthalpy from Dynode)
FILPRS(13) = 750.0 Not used
FILTBL(1,14) = 375 Fourteenth Point (Dynode)
FILTBL(2,14) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(14) = 371.18 Fourteenth Enthalpy = 402.27 - 31.0926 (Δ enthalpy from Dynode)
FILPRS(14) = 750.0 Not used
FILTBL(1,15) = 400 Fifteenth Point (Dynode)
FILTBL(2,15) = 827.2837954855 Flux is constant. Flow controlled by valve.

FILENT(15) = 371.04 Fifteenth Enthalpy = 402.27 - 31.2272 (Δ enthalpy from Dynode)
FILPRS(15) = 750.0 Not used
FILTBL(1,16) = 1000 Sixteenth Point (Dynode)
FILTBL(2,16) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(16) = 371.04 Sixteenth Enthalpy = 402.27 - 31.2272 (Δ enthalpy from Dynode)
FILPRS(16) = 750.0 Not used

Line 703130 (Control Block 130) -- Control rod position

CMIN = 228.0 Minimum rod position = 228 steps. Rods disabled

Line 703304 (Control Block 304) -- Pressurizer spray control

CMAX = 0.0 Maximum spray flow = 0.0. Sprays disabled.

Line 043030 (Trip 303) -- PORV trip

SETPT = 5000.0 Trip setpoint = 5000 psi error. PORV disabled

Line 04305 (Trip 305) -- PORV trip

SETPT = 5000.0 Trip setpoint = 5000 psia. PORV disabled

Lines 703556 through 703559 (Control Blocks 556 through 559) -- Steam dump valve area

CGAIN = 0.0 Gain = 0.0 Steam dump valves disabled.

Feedwater Malfunction: EOC Auto Control

```
*  TIME STEPS
*       TRTG  TMIN  TRST  TMAJ  TDMP  NCHK  DELTM  TLAST  NSHAP
030010   0.0   1.0   0.0  25.0   0.0     0   1.0   1.E+6      0
*
*   PROBLEM END TIME
040010    1     1     0    0 200.0    0.0   "PROBLEM END TIME"
*
*        CHANGES FOR FEEDWATER MALFUNCTION EOC AUTO CONTROL
*
*              FILL MASS FLUXES AND PROPERTIES
*              FEEDWATER LOOP A
130101   -16   3   0    0
*         TIME            FLUX            ENTH    PRESS
130102     0.0        827.2837954855    402.27   750.0
130103    20.0        827.2837954855    401.46   750.0
130104    50.00       827.2837954855    386.12   750.0
130105    75.00       827.2837954855    375.89   750.0
130106   100.00       827.2837954855    372.12   750.0
130107   130.00       827.2837954855    371.04   750.0
130108   150.00       827.2837954855    371.58   750.0
130109   190.00       827.2837954855    372.66   750.0
130110   200.00       827.2837954855    372.66   750.0
130111   225.00       827.2837954855    372.66   750.0
130112   240.00       827.2837954855    372.66   750.0
130113   275.00       827.2837954855    372.03   750.0
130114   300.00       827.2837954855    371.58   750.0
130115   375.00       827.2837954855    371.18   750.0
130116   400.00       827.2837954855    371.04   750.0
130117  1000.00       827.2837954855    371.04   750.0
*              FEEDWATER LOOP B
130201   -16   3   0   0
*         TIME            FLUX            ENTH    PRESS
130202     0.0        827.2837954855    402.27   750.0
130203    20.0        827.2837954855    401.46   750.0
130204    50.00       827.2837954855    386.12   750.0
130205    75.00       827.2837954855    375.89   750.0
130206   100.00       827.2837954855    372.12   750.0
130207   130.00       827.2837954855    371.04   750.0
130208   150.00       827.2837954855    371.58   750.0
130209   190.00       827.2837954855    372.66   750.0
130210   200.00       827.2837954855    372.66   750.0
130211   225.00       827.2837954855    372.66   750.0
130212   240.00       827.2837954855    372.66   750.0
```

```
130213  275.00       827.2837954855   372.03  750.0
130214  300.00       827.2837954855   371.58  750.0
130215  375.00       827.2837954855   371.18  750.0
130216  400.00       827.2837954855   371.04  750.0
130217 1000.00       827.2837954855   371.04  750.0
*
*       RODS INITIALLY AT FULL POWER INSERTION LIMITS
703130 -130  INT, -129  0  1.0  0.0  0.0  153.0    0.0  228.0
*
```

Entire Physics Parameters section replaced by EOC physics parameters.

Line 030010 -- Time steps

TMIN = 1.0	One minor edit is printed for each standard time step.
TMAJ = 25.0	One major edit for each 25 seconds prevents excess output.
DELTM = 1.0	One second maximum time step prevents excess output.

Line 040010 (Trip 1) -- Problem end time

SETPT = 200.0 200 seconds

Lines 130101 through 130117, 130201 through 1302117 (Fill Tables 1, 2) -- Feedwater flux to SGs A, B

NFILL = -16 16 points

FILTBL(1,2) = 20.0	Second Point (from Dynode Case Setup Guide)
FILENT(2) = 401.46	Second Enthalpy = 402.27 (initial inthalpy) - 0.8076 (Δ enthalpy from Dynode)
FILTBL(1,3) = 50	Third Point (Dynode)
FILENT(3) = 386.12	Third Enthalpy = 402.27 - 16.152 (Δ enthalpy from Dynode)
FILTBL(1,4) = 75	Fourth Point (Dynode)
FILENT(4) = 375.89	Fourth Enthalpy = 402.27 - 26.3816 (Δ enthalpy from Dynode)
FILTBL(1,5) = 100	Fifth Point (Dynode)
FILTBL(2,5) = 827.2837954855	Flux is constant. Flow controlled by valve.
FILENT(5) = 372.12	Fifth Enthalpy = 402.27 - 30.1504 (Δ enthalpy from Dynode)
FILPRS(5) = 750.0	Not used
FILTBL(1,6) = 130	Sixth Point (Dynode)
FILTBL(2,6) = 827.2837954855	Flux is constant. Flow controlled by valve.
FILENT(6) = 371.04	Sixth Enthalpy = 402.27 - 31.2272 (Δ enthalpy from Dynode)
FILPRS(6) = 750.0	Not used
FILTBL(1,7) = 150	Seventh Point (Dynode)
FILTBL(2,7) = 827.2837954855	Flux is constant. Flow controlled by valve.

FILENT(7) = 371.58 Seventh Enthalpy = 402.27 - 30.6888 (Δ enthalpy from Dynode)
FILPRS(7) = 750.0 Not used
FILTBL(1,8) = 190 Eighth Point (Dynode)
FILTBL(2,8) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(8) = 372.66 Eighth Enthalpy = 402.27 - 29.6120 (Δ enthalpy from Dynode)
FILPRS(8) = 750.0 Not used
FILTBL(1,9) = 200 Ninth Point (Dynode)
FILTBL(2,9) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(9) = 372.66 Ninth Enthalpy = 402.27 - 29.6120 (Δ enthalpy from Dynode)
FILPRS(9) = 750.0 Not used
FILTBL(1,10) = 225 Tenth Point (Dynode)
FILTBL(2,10) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(10) = 372.66 Tenth Enthalpy = 402.27 - 29.6120 (Δ enthalpy from Dynode)
FILPRS(10) = 750.0 Not used
FILTBL(1,11) = 240 Eleventh Point (Dynode)
FILTBL(2,11) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(11) = 372.66 Eleventh Enthalpy = 402.27 - 29.6120 (Δ enthalpy from Dynode)
FILPRS(11) = 750.0 Not used
FILTBL(1,12) = 275 Twelfth Point (Dynode)
FILTBL(2,12) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(12) = 372.03 Twelfth Enthalpy = 402.27 - 30.2400 (Δ enthalpy from Dynode)
FILPRS(12) = 750.0 Not used
FILTBL(1,13) = 300 Thirteenth Point (Dynode)
FILTBL(2,13) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(13) = 371.58 Thirteenth Enthalpy = 402.27 - 30.6888 (Δ enthalpy from Dynode)
FILPRS(13) = 750.0 Not used
FILTBL(1,14) = 375 Fourteenth Point (Dynode)
FILTBL(2,14) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(14) = 371.18 Fourteenth Enthalpy = 402.27 - 31.0926 (Δ enthalpy from Dynode)
FILPRS(14) = 750.0 Not used
FILTBL(1,15) = 400 Fifteenth Point (Dynode)
FILTBL(2,15) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(15) = 371.04 Fifteenth Enthalpy = 402.27 - 31.2272 (Δ enthalpy from Dynode)
FILPRS(15) = 750.0 Not used
FILTBL(1,16) = 1000 Sixteenth Point (Dynode)
FILTBL(2,16) = 827.2837954855 Flux is constant. Flow controlled by valve.
FILENT(16) = 371.04 Sixteenth Enthalpy = 402.27 - 31.2272 (Δ enthalpy from Dynode)
FILPRS(16) = 750.0 Not used

Line 703130 (Control Block 130) -- Control rod position

CIC = 153.0 Initial rod position = 153 steps

Feedwater Malfunction: Opening of Regulating Valve

Entire Physics Parameters section replaced by EOC physics parameters.

```
*          PROBLEM DESCRIPTION AND OPTIONS CARD
*       TRTG   TMIN   TRST   TMAJ   TDMP   NCHK   DELTM   TLAST   NSHAP
030010   0.0    1.0    0.0    5.0    0.0      0    1.0    1.E+6       0
*
*  TIME STEPS
*        NMIN NMAJ NDMP NCHK DELTM TLAST
030010    1   10   1000   0   1.0   1.0E6
*
*   PROBLEM END TIME
040010    1    1      0    0 100.0    0.0   "PROBLEM END TIME"
*
*
*        CHANGES FOR FEEDWATER MALFUNCTION:  OPENING OF
REGULATING VALVE
*
*              FILL MASS FLUXES AND PROPERTIES
*              FEEDWATER LOOP A
*          TIME          FLUX          ENTH   PRESS
130103    1.0        1240.93          402.27  750.0
130104    1.0E6      1240.93          402.27  750.0
130105    2.0E6      1240.93          402.27  750.0
*              FEEDWATER LOOP B
*          TIME          FLUX          ENTH   PRESS
130203    1.0        1240.93          402.27  750.0
130204    1.0E6      1240.93          402.27  750.0
130205    2.0E6      1240.93          402.27  750.0
*
*       RODS INITIALLY AT FULL POWER INSERTION LIMITS
703130 -130  INT, -129  0  1.0  0.0  0.0  153.0    0.0  228.0
*
*            MAKE FW VALVE AREA CONSTANT
703410 -410   VLM, -409   0  1.0       0.08 0.05 0.88  0.88  0.88
703420 -420   VLM, -419   0  1.0       0.08 0.05 0.88  0.88  0.88
*
*            TURBINE TRIP LEADS TO REACTOR TRIP
049990  722   12   601   0  0.0   0.0 "TURBINE TRIP REACTOR TRIP"
*
```

Line 010001 -- Problem description

NTRP = 113 An additional trip is added.

Line 030010 -- Time steps

TMIN = 1.0	One minor edit is printed for each standard time step.
DELTM = 1.0	One second maximum time step prevents excess output.

Line 040010 (Trip 1) -- Problem end time

SETPT = 100.0	100 seconds

Lines 130103 through 130105 (Fill Table 1) -- Feedwater flux to SG A

FILTBL(1,2) = 1.0	Valve opens in 1 second (from DYNODE)
FILTBL (2,2) = 1240.93	150% of normal flow (From USAR) = 1.5 X 827.284 (normal flux from line 130102)
FILTBL (2,3) = 1240.93	150% of normal flow (From USAR) = 1.5 X 827.284 (normal flux from line 130102)
FILTBL (2,4) = 1240.93	150% of normal flow (From USAR) = 1.5 X 827.284 (normal flux from line 130102)

Lines 130203 through 130205 (Fill Table 2) -- Feedwater flux to SG B

FILTBL(1,2) = 1.0	Valve opens in 1 second (from DYNODE)
FILTBL (2,2) = 1240.93	150% of normal flow (From USAR) = 1.5 X 827.284 (normal flux from line 130202)
FILTBL (2,3) = 1240.93	150% of normal flow (From USAR) = 1.5 X 827.284 (normal flux from line 130202)
FILTBL (2,4) = 1240.93	150% of normal flow (From USAR) = 1.5 X 827.284 (normal flux from line 130202)

Line 703130 (Control Block 130) -- Control rod position

CIC = 153.0	Initial rod position = 153 steps

Line 703410, 703420 (Control Blocks 410, 420) -- Feedwater valve position

CMIN = 0.88	Minimum feedwater valve position = 88% open
CMAX = 0.88	Maximum feedwater valve position = 88% open. Valve position constant (flux used to vary flow)

Line 049990 (Trip 999) Turbine trip on reactor trip

This is a non-safety related trip that is only used here to match Dynode.

IDTRP = 722	Trip is a reactor trip
IDSIG = 12	Trip is an dependent trip
IX1 = 601	Trip is on trip 601 (turbine trip)
IX2 = 0	Time has no region
SETPT = 0.0	Dependent trips have no setpoint
DELAY =0.0	No delay

IDITL = "TURBINE TRIP REACTOR TRIP"

Locked Rotor

```
*  TIME STEPS
*       TRTG  TMIN   TRST  TMAJ  TDMP  NCHK  DELTM  TLAST  NSHAP
030010   0.0 0.0025  0.0   1.0   0.0     0 0.0025  1.E+6      0
*
*   PROBLEM END TIME
040010    1    1      0    0  10.0     0.0   "PROBLEM END TIME"
*
*           CHANGES FOR LOCKED ROTOR
*
*           LOCKED ROTOR CARD
095021     0.01   0.0   0.0
*
*           DISABLE ROD CONTROLLER
703130 -130  INT, -129  0  1.0  0.0  0.0  228.0  228.0  228.0
*           DISABLE PRESSURIZER CONTROL
*                 SPRAYS
703304 -304   SUM,  303  -303   1.000   1.0  0.02  0.0  0.0 0.000
*                 PORVS
043030   302   14 -303   0  5000.0 0.0    "HIGH PRZR PRESS ERROR
PORV SETPT"
043050   303   +4  500   0  5000.0 0.0    "HIGH PRZR PRESS PORV
SETPOINT"
*            DISABLE STEAM DUMP
703556 -556  MUL,  -550   509  0.0  0.0  0.0  0.0
703557 -557  MUL,  -551   509  0.0  0.0  0.0  0.0
703558 -558  MUL,  -552   510  0.0  0.0  0.0  0.0
703559 -559  MUL,  -553   510  0.0  0.0  0.0  0.0
*
* REACTIVITY COEFFICIENTS (DOPPLER = -2.32 PCM/DEGF)
*         DENWT  FTWT   ALPHTM    ALPHTW
140010   .22346 .22346 -5.363E-2  0.0
140020   .55308 .55308 -1.327E-1  0.0
140030   .22346 .22346 -5.363E-2  0.0
*
```

Line 030010 -- Time Steps

TMIN = 0.0025	One minor edit per standard time step.
NMAJ = 1.0	One major edit per second provides some resolution.
DELTM = 0.0025	Maximum time step of 0.0025 seconds prevents numerical problems.

Line 040010 (Trip 1) -- Problem end time

SETPT = 10.0 10 seconds

Line 095021 (Pump Stop Data Line 2) -- Locked rotor

CAVCON = 0.002	Locked rotor takes place at 0.002 seconds (the first time step).
FPUMP = 0.0	Maximum forward speed option not used.
SPUMP = 0.0	Maximum reverse speed option not used.

Line 703130 (Control Block 130) -- Control rod position

CMIN = 228.0 Minimum rod position = 228 steps. Rods disabled

Line 703304 (Control Block 304) -- Pressurizer spray control

CMAX = 0.0 Maximum spray flow = 0.0. Sprays disabled.

Line 043030 (Trip 303) -- PORV trip

SETPT = 5000.0 Trip setpoint = 5000 psi error. PORV disabled

Line 043050 (Trip 305) -- PORV trip

SETPT = 5000.0 Trip setpoint = 5000 psia. PORV disabled

Lines 703556 through 703559 (Control Blocks 556 through 559) -- Steam dump valve area

CGAIN = 0.0 Gain = 0.0 Steam dump valves disabled.

Line 140010 (Core Region 1) -- Reactivity coefficients

ALPHTM = Fuel Temperature Coefficient

FTWT = 0.22346 (from base case)
FTC = -2.32 pcm/°F (Safety Analysis Assumption)
Beta = 706 \$/pcm (Safety Analysis Assumption)
FT = Full power average fuel temperature = 1333.44°F (Steady State Initialization)

$$ALPHTM = \frac{2 * FTWT * FTC * FT^{1/2}}{\beta}$$

See base case documentation for derivation

$ALPHTM = -5.363 \times 10^{-2}$

Line 140020 (Core Region 2) -- Reactivity coefficients

ALPHTM = Fuel Temperature Coefficient

FTWT = 0.55308 (from base case)
FTC = -2.32 pcm/°F (Safety Analysis Assumption)
Beta = 706 $/pcm (Safety Analysis Assumption)

ALPHTM = 1.327×10^{-1} from above equation

Line 140030 (Core Region 3) -- Reactivity coefficients

Since the power in the top node is the same as that in the bottom node, all values on this line are the same as those on Line 140010.

Loss of Flow: 2/2 Pump Trip

```
*   TIME STEPS
*        TRTG  TMIN   TRST   TMAJ   TDMP   NCHK   DELTM   TLAST   NSHAP
030010    0.0 0.025   0.0    1.0    0.0      0   0.025   1.E+6       0
*
*   PROBLEM END TIME
040010     1     1     0    0  10.0     0.0    "PROBLEM END TIME"
*
*              CHANGES FOR 2/2 PUMP TRIP
*
*              TRIP BOTH RXCP'S ON TIME
040040      4    1   0     0  0.01  0.0 "REACTOR COOLANT PUMP TRIP"
*
*           DISABLE ROD CONTROLLER
703130 -130  INT, -129  0  1.0  0.0  0.0  228.0  228.0  228.0
*           DISABLE PRESSURIZER CONTROL
*                 SPRAYS
703304 -304   SUM,  303  -303   1.000   1.0  0.02  0.0  0.0 0.000
*                 PORVS
043030   302   14 -303   0  5000.0 0.0    "HIGH PRZR PRESS ERROR
PORV SETPT"
043050   303   +4  500   0  5000.0 0.0    "HIGH PRZR PRESS PORV
SETPOINT"
*            DISABLE STEAM DUMP
703556 -556  MUL,  -550   509  0.0  0.0  0.0  0.0
703557 -557  MUL,  -551   509  0.0  0.0  0.0  0.0
703558 -558  MUL,  -552   510  0.0  0.0  0.0  0.0
703559 -559  MUL,  -553   510  0.0  0.0  0.0  0.0
*
* REACTIVITY COEFFICIENTS (DOPPLER = -2.32 PCM/DEGF)
*          DENWT  FTWT   ALPHTM    ALPHTW
140010   .22346 .22346 -5.363E-2  0.0
140020   .55308 .55308 -1.327E-1  0.0
140030   .22346 .22346 -5.363E-2  0.0
*
```

Line 030010 -- Time Steps

TMIN = 0.025	One minor edit per standard time step.
NMAJ = 1.0	One major edit per second provides some resolution.
DELTM = 0.025	Maximum time step of 0.0025 seconds prevents numerical problems.

Line 040010 (Trip 1) -- Problem end time

SETPT = 10.0 10 seconds

Line 040040 (Trip 4) -- Reactor coolant pump trip

SETPT = 0.01 Pumps trip at 0.01 seconds
IDITL = "REACTOR COOLANT PUMP TRIP" Remove "(NEVER TRIPPED)"

Line 703130 (Control Block 130) -- Control rod position

CMIN = 228.0 Minimum rod position = 228 steps. Rods disabled

Line 703304 (Control Block 304) -- Pressurizer spray control

CMAX = 0.0 Maximum spray flow = 0.0. Sprays disabled.

Line 043030 (Trip 303) -- PORV trip

SETPT = 5000.0 Trip setpoint = 5000 psi error. PORV disabled

Line 043050 (Trip 305) -- PORV trip

SETPT = 5000.0 Trip setpoint = 5000 psia. PORV disabled

Lines 703556 through 703559 (Control Blocks 556 through 559) -- Steam dump valve area

CGAIN = 0.0 Gain = 0.0 Steam dump valves disabled.

Line 140010 (Core Region 1) -- Reactivity coefficients

ALPHTM = Fuel Temperature Coefficient

FTWT = 0.22346 (from base case)
FTC = -2.32 pcm/°F (Safety Analysis Assumption)
Beta = 706 $/pcm (Safety Analysis Assumption)
FT = Full power average fuel temperature = 1333.44°F (Steady State Initialization)

$$ALPHTM = \frac{2 * FTWT * FTC * FT}{\beta}$$

See base case documentation for derivation

ALPHTM = $-5.363\text{x}10^{-2}$

Line 140020 (Core Region 2) -- Reactivity coefficients

ALPHTM = Fuel Temperature Coefficient

FTWT = 0.55308 (from base case)
FTC = -2.32 pcm/°F (Safety Analysis Assumption)
Beta = 706 \$/pcm (Safety Analysis Assumption)
ALPHTM = 1.327×10^{-1} from above equation

Line 140030 (Core Region 3) -- Reactivity coefficients

Since the power in the top node is the same as that in the bottom node, all values on this line are the same as those on Line 140010.

Loss of Flow: Underfrequency Transient

```
*  TIME STEPS
*       TRTG  TMIN   TRST   TMAJ   TDMP   NCHK   DELTM   TLAST   NSHAP
030010    0.0 0.025   0.0    1.0    0.0      0   0.025   1.E+6       0
*
*   PROBLEM END TIME
040010     1     1     0    0   10.0     0.0    "PROBLEM END TIME"
*
*                CHANGES FOR UNDERFREQUENCY TRANSIENT
*
090011  1 -1000 0 0 -60 1189.0  1.00 89000.0 296.0 26482.0 80000.0
47.19 0.0
090021  1 -1000 0 0 -60 1189.0  1.00 89000.0 296.0 26482.0 80000.0
47.19 0.0
*
*             PUMP SPEED VS TIME
702061     61   TIMX,   0     -99.08     0.0
702062     62   CONS,   0    1189.00 1189.00
703060    -60   SUM,    61      62    1.0   1.0   1.0   1189.00    0.0
*
*           DISABLE ROD CONTROLLER
703130 -130  INT, -129  0  1.0  0.0  0.0  228.0  228.0  228.0
*           DISABLE PRESSURIZER CONTROL
*                 SPRAYS
703304 -304   SUM,  303  -303   1.000   1.0  0.02  0.0   0.0 0.000
*                 PORVS
043030   302   14 -303   0   5000.0 0.0    "HIGH PRZR PRESS ERROR
PORV SETPT"
043050   303   +4  500   0   5000.0 0.0    "HIGH PRZR PRESS PORV
SETPOINT"
*            DISABLE STEAM DUMP
703556 -556  MUL,  -550   509  0.0  0.0  0.0  0.0
703557 -557  MUL,  -551   509  0.0  0.0  0.0  0.0
703558 -558  MUL,  -552   510  0.0  0.0  0.0  0.0
703559 -559  MUL,  -553   510  0.0  0.0  0.0  0.0
*
* REACTIVITY COEFFICIENTS (DOPPLER = -2.32 PCM/DEGF)
*         DENWT  FTWT   ALPHTM    ALPHTW
140010   .22346 .22346 -5.363E-2  0.0
140020   .55308 .55308 -1.327E-1  0.0
140030   .22346 .22346 -5.363E-2  0.0
*
```

Line 040010 (Trip 1) -- Problem end time

TMIN = 0.025	One minor edit per standard time step.
NMAJ = 1.0	One major edit per second provides some resolution.
DELTM = 0.025	Maximum time step of 0.0025 seconds prevents numerical problems.

Line 090011 (Pump 1) -- Reactor coolant pump A description

ITPUMP = -1000	Pump speed controlled by a control block.
IMT = -60	Pump speed controlled by Control Block 60

Line 090021 (Pump 2) -- Reactor coolant pump B description

ITPUMP = -1000	Pump speed controlled by a control block.
IMT = -60	Pump speed controlled by Control Block 60

Line 702060 (Control Input 60) -- Slope of speed vs. time curve

IDC = 60	Control Input 60
CSYM = TIMX	Input is time.
IREG = 0	Time has no region.

Rated speed = POMGAR = 1189 RPM
Since 1189. RPM corresponds to 60 Hz nominal, there is a ratio of 1189./60 = 19.8167 RPM/Hz
Rate of frequency decay = -5.0 Hz/sec * 19.8167 RPM/Hz = -99.08 RPM/sec

GAIN = -99.08	-99.08 RPM/sec
CIC = 0.0	Initial frequency decay is 0 RPM

Line 702061 (Control Input 61) -- Initial speed

IDC = 61	Control Input 61
CSYM = CONS	Constant
IREG = 0	Constant has no region.
GAIN = 1189.0	1189 initial RPM
CIC = 1189.0	1189 initial RPM

Line 703060 (Control Block 60) -- Speed vs. Time

IDC -60	Control Block 60
ITYPE = SUM	Control Block is a sum.
INC1 = 60	First input is Control Input 60
INC2 = 61	Second input is Control Input 61
CGAIN = 1.0	Gain is 1.0
CP1 = 1.0	Input gain 1 is 1.0
CP2 = 1.0	Input gain 2 is 1.0
CIC = 1189.0	Initial speed is 1189 RPM

CMIN = 0.0 Speed cannot be less than 0.0

Line 703130 (Control Block 130) -- Control rod position

CMIN = 228.0 Minimum rod position = 228 steps. Rods disabled

Line 703304 (Control Block 304) -- Pressurizer spray control

CMAX = 0.0 Maximum spray flow = 0.0. Sprays disabled.

Line 043030 (Trip 303) -- PORV trip

SETPT = 5000.0 Trip setpoint = 5000 psi error. PORV disabled

Line 043050 (Trip 305) -- PORV trip

SETPT = 5000.0 Trip setpoint = 5000 psia. PORV disabled

Lines 703556 through 703559 (Control Blocks 556 through 559) -- Steam dump valve area

CGAIN = 0.0 Gain = 0.0 Steam dump valves disabled.

Line 140010 (Core Region 1) -- Reactivity coefficients

ALPHTM = Fuel Temperature Coefficient

FTWT = 0.22346 (from base case)
FTC = -2.32 pcm/°F (Safety Analysis Assumption)
Beta = 706 $/pcm (Safety Analysis Assumption)
FT = Full power average fuel temperature = 1333.44°F (Steady State Initialization)

$$ALPHTM = \frac{2 * FTWT * FTC * FT}{\beta}$$

See base case documentation for derivation

ALPHTM = -5.363×10^{-2}

Line 140020 (Core Region 2) -- Reactivity coefficients

ALPHTM = Fuel Temperature Coefficient

FTWT = 0.55308 (from base case)
FTC = -2.32 pcm/°F (Safety Analysis Assumption)

Beta = 706 \$/pcm (Safety Analysis Assumption)

ALPHTM = 1.327×10^{-1} from above equation
Line 140030 (Core Region 3) -- Reactivity coefficients

Since the power in the top node is the same as that in the bottom node, all values on this line are the same as those on Line 140010.

Loss of Load: BOC, Auto Control

```
*   PROBLEM END TIME
040010    1    1     0    0  50.0     0.0    "PROBLEM END TIME"
*
*         CHANGES FOR LOSS OF LOAD BOC AUTO CONTROL
*
*       TRIP TURBINE
046030   601    1     0    0  0.01    0.0     "TURBINE TRIP"
*
*       RODS INITIALLY AS FULL POWER INSERTION LIMITS
703130 -130   INT, -129  0  1.0  0.0  0.0  153.0    0.0  228.0
*
*             DISABLE STEAM DUMP
703556 -556  MUL,   -550   509  0.0  0.0  0.0  0.0
703557 -557  MUL,   -551   509  0.0  0.0  0.0  0.0
703558 -558  MUL,   -552   510  0.0  0.0  0.0  0.0
703559 -559  MUL,   -553   510  0.0  0.0  0.0  0.0
*
* REACTIVITY COEFFICIENTS (DOPPLER = -2.32 PCM/DEGF)
*          DENWT  FTWT   ALPHTM    ALPHTW
140010   .22346 .22346 -5.363E-2  0.0
140020   .55308 .55308 -1.327E-1  0.0
140030   .22346 .22346 -5.363E-2  0.0
*
```

Line 040010 (Trip 1) -- Problem end time

SETPT = 50.0 — 50 seconds

Line 046030 (Trip 603) -- Turbine trip

IDSIG = 1 — Trip is on elapsed time.
IX1 = 0 — Time has no region
SETPT = 0.01 — Trip is at 0.01 seconds
IDITL = "TURBINE TRIP" Trip is now a turbine trip on time, not on reactor trip.

Line 703130 (Control Block 130) -- Control rod position

CIC = 153.0 — Initial rod position = 153 steps

Lines 703556 through 703559 (Control Blocks 556 through 559) -- Steam dump valve area

CGAIN = 0.0 — Gain = 0.0 Steam dump valves disabled.

Line 140010 (Core Region 1) -- Reactivity coefficients

ALPHTM = Fuel Temperature Coefficient

FTWT = 0.22346 (from base case)
FTC = -2.32 pcm/°F (Safety Analysis Assumption)
Beta = 706 $/pcm (Safety Analysis Assumption)
FT = Full power average fuel temperature = 1333.44°F (Steady State Initialization)

$$ALPHTM = \frac{2 * FTWT * FTC * FT}{\beta}$$

See base case documentation for derivation

ALPHTM = -5.363×10^{-2}

Line 140020 (Core Region 2) -- Reactivity coefficients

ALPHTM = Fuel Temperature Coefficient

FTWT = 0.55308 (from base case)
FTC = -2.32 pcm/°F (Safety Analysis Assumption)
Beta = 706 $/pcm (Safety Analysis Assumption)

ALPHTM = 1.327×10^{-1} from above equation

Line 140030 (Core Region 3) -- Reactivity coefficients

Since the power in the top node is the same as that in the bottom node, all values on this line are the same as those on Line 140010.

Loss of Load: BOC, Manual Control

```
*   PROBLEM END TIME
040010    1    1     0    0  50.0     0.0    "PROBLEM END TIME"
*
*        CHANGES FOR LOSS OF LOAD BOC MANUAL CONTROL
*
*       TRIP TURBINE
046030   601    1     0    0  0.01    0.0    "TURBINE TRIP"
*
*           DISABLE ROD CONTROLLER
703123 -130  INT, -129  0  1.0  0.0  0.0  228.0  228.0  228.0
*           DISABLE PRESSURIZER CONTROL
*                 SPRAYS
703304 -304   SUM,  303  -303   1.000   1.0  0.02  0.0  0.0 0.000
*                 PORVS
043030   302   14 -303    0  5000.0 0.0    "HIGH PRZR PRESS ERROR
PORV SETPT"
043050   303   +4  500    0  5000.0 0.0    "HIGH PRZR PRESS PORV
SETPOINT"
*            DISABLE STEAM DUMP
703556 -556  MUL,  -550   509  0.0  0.0  0.0  0.0
703557 -557  MUL,  -551   509  0.0  0.0  0.0  0.0
703558 -558  MUL,  -552   510  0.0  0.0  0.0  0.0
703559 -559  MUL,  -553   510  0.0  0.0  0.0  0.0
*
* REACTIVITY COEFFICIENTS (DOPPLER = -2.32 PCM/DEGF)
*         DENWT  FTWT   ALPHTM   ALPHTW
140010   .22346 .22346 -5.363E-2  0.0
140020   .55308 .55308 -1.327E-1  0.0
140030   .22346 .22346 -5.363E-2  0.0
*
```

Line 040010 (Trip 1) -- Problem end time

SETPT = 50.0 50 seconds

Line 046030 (Trip 603) -- Turbine trip

IDSIG = 1	Trip is on elapsed time.
IX1 = 0	Time has no region
SETPT = 0.01	Trip is at 0.01 seconds
IDITL = "TURBINE TRIP"	Trip is now a turbine trip on time, not on reactor trip.

Line 703130 (Control Block 130) -- Control rod position

CMIN = 228.0 Minimum rod position = 228 steps. Rods disabled

Line 703304 (Control Block 304) -- Pressurizer spray control

CMAX = 0.0 Maximum spray flow = 0.0. Sprays disabled.

Line 043030 (Trip 303) -- PORV trip

SETPT = 5000.0 Trip setpoint = 5000 psi error. PORV disabled

Line 043050 (Trip 305) -- PORV trip

SETPT = 5000.0 Trip setpoint = 5000 psia. PORV disabled

Lines 703556 through 703559 (Control Blocks 556 through 559) -- Steam dump valve area

CGAIN = 0.0 Gain = 0.0 Steam dump valves disabled.

Line 140010 (Core Region 1) -- Reactivity coefficients

ALPHTM = Fuel Temperature Coefficient

FTWT = 0.22346 (from base case)
FTC = -2.32 pcm/°F (Safety Analysis Assumption)
Beta = 706 \$/pcm (Safety Analysis Assumption)
FT = Full power average fuel temperature = 1333.44°F (Steady State Initialization)

$$ALPHTM = \frac{2 * FTWT * FTC * FT^{1/2}}{\beta}$$

See base case documentation for derivation

$ALPHTM = -5.363 \times 10^{-2}$

Line 140020 (Core Region 2) -- Reactivity coefficients

ALPHTM = Fuel Temperature Coefficient

FTWT = 0.55308 (from base case)
FTC = -2.32 pcm/°F (Safety Analysis Assumption)
Beta = 706 \$/pcm (Safety Analysis Assumption)
ALPHTM = 1.327×10^{-1} from above equation

Line 140030 (Core Region 3) -- Reactivity coefficients

Since the power in the top node is the same as that in the bottom node, all values on this line are the same as those on Line 140010.

Loss of Load: EOC, Auto Control

Entire Physics Parameters section replaced by EOC physics parameters

```
*
*   PROBLEM END TIME
040010    1    1     0    0  50.0     0.0    "PROBLEM END TIME"
*
*
*               DISABLE HIGH PRESSURIZER PRESSURE TRIP
047340  722 4  500  0 10000.0 1.0 "HIGH PRZR PRESSURE REACTOR TRIP"
*
*         CHANGES FOR LOSS OF LOAD EOC AUTO CONTROL
*
*        TRIP TURBINE
046030   601    1    0    0  0.01   0.0    "TURBINE TRIP"
*
*        RODS INITIALLY AS FULL POWER INSERTION LIMITS
703130 -130  INT, -129  0  1.0  0.0  0.0  153.0    0.0  228.0
*
*            DISABLE STEAM DUMP
703556 -556  MUL,  -550   509  0.0  0.0  0.0  0.0
703557 -557  MUL,  -551   509  0.0  0.0  0.0  0.0
703558 -558  MUL,  -552   510  0.0  0.0  0.0  0.0
703559 -559  MUL,  -553   510  0.0  0.0  0.0  0.0
*
* REACTIVITY COEFFICIENTS (DOPPLER = -2.32 PCM/DEGF)
*          DENWT  FTWT   ALPHTM    ALPHTW
140010   .22346 .22346 -7.807E-2 -1.843E-2
140020   .55308 .55308 -1.932E-1 -4.561E-2
140030   .22346 .22346 -7.807E-2 -1.843E-2
*
```

Line 040010 (Trip 1) -- Problem end time

SETPT = 50.0 50 seconds

Line 047340 (Trip 734) – Reactor trip on high pressurizer pressure

SETPT = 10000.0 Set trip setpoint at 10,000 Psia, effectively disabling the trip.

Line 046030 (Trip 603) -- Turbine trip

IDSIG = 1 Trip is on elapsed time.
IX1 = 0 Time has no region

SETPT = 0.01 Trip is at 0.01 seconds
IDITL = "TURBINE TRIP" Trip is now a turbine trip on time, not on reactor trip.

Line 703130 (Control Block 130) -- Control rod position

CIC = 153.0 Initial rod position = 153 steps

Lines 703556 through 703559 (Control Blocks 556 through 559) -- Steam dump valve area

CGAIN = 0.0 Gain = 0.0 Steam dump valves disabled.

Line 140010 (Core Region 1) -- Reactivity coefficients

ALPHTM = Fuel Temperature Coefficient

FTWT = 0.22346 (from base case)
MTC = -40 pcm/°F (Safety Analysis Assumption)
FTC = -2.32 pcm/°F (Safety Analysis Assumption)
Beta = 485 $/pcm (Safety Analysis Assumption)
FT = Full power average fuel temperature = 1333.44°F (Steady State Initialization)

$$ALPHTM = \frac{2 * FTWT * FTC * FT^{1/2}}{\beta}$$

See base case documentation for derivation

$ALPHTM = -7.807 \times 10^{-2}$

Line 140020 (Core Region 2) -- Reactivity coefficients

ALPHTM = Fuel Temperature Coefficient

FTWT = 0.55308 (from base case)
FTC = -2.32 pcm/°F (Safety Analysis Assumption)
Beta = 485 $/pcm (Safety Analysis Assumption)

$ALPHTM = -1.932 \times 10^{-1}$ from above equation

Line 140030 (Core Region 3) -- Reactivity coefficients

Since the power in the top node is the same as that in the bottom node, all values on this line are the same as those on Line 140010.

Loss of Load: EOC, Manual Control

Entire Physics Parameters section replaced by EOC physics parameters

```
*
*   PROBLEM END TIME
040010    1    1     0    0   50.0     0.0    "PROBLEM END TIME"
*
*        CHANGES FOR LOSS OF LOAD EOC MANUAL CONTROL
*
*       TRIP TURBINE
046030   601    1     0    0   0.01    0.0    "TURBINE TRIP"
*
*           DISABLE ROD CONTROLLER
703130 -130  INT, -129  0  1.0  0.0  0.0  228.0  228.0  228.0
*           DISABLE PRESSURIZER CONTROL
*                 SPRAYS
703304 -304   SUM,  303  -303   1.000   1.0  0.02  0.0  0.0 0.000
*                 PORVS
043030   302   14 -303   0  5000.0 0.0    "HIGH PRZR PRESS ERROR
PORV SETPT"
043050   303   +4  500   0  5000.0 0.0    "HIGH PRZR PRESS PORV
SETPOINT"
*            DISABLE STEAM DUMP
703556 -556  MUL,  -550   509  0.0  0.0  0.0  0.0
703557 -557  MUL,  -551   509  0.0  0.0  0.0  0.0
703558 -558  MUL,  -552   510  0.0  0.0  0.0  0.0
703559 -559  MUL,  -553   510  0.0  0.0  0.0  0.0
*
* REACTIVITY COEFFICIENTS (DOPPLER = -2.32 PCM/DEGF)
*        DENWT  FTWT   ALPHTM    ALPHTW
140010   .22346 .22346 -7.807E-2 -1.843E-2
140020   .55308 .55308 -1.932E-1 -4.561E-2
140030   .22346 .22346 -7.807E-2 -1.843E-2
*
```

Line 040010 (Trip 1) -- Problem end time

SETPT = 50.0   50 seconds

Line 046030 (Trip 603) -- Turbine trip

IDSIG = 1	Trip is on elapsed time.
IX1 = 0	Time has no region
SETPT = 0.01	Trip is at 0.01 seconds

IDITL = "TURBINE TRIP"   Trip is now a turbine trip on time, not on reactor trip.

Line 703130 (Control Block 130) -- Control rod position

CMIN = 228.0   Minimum rod position = 228 steps. Rods disabled

Line 703304 (Control Block 304) -- Pressurizer spray control

CMAX = 0.0   Maximum spray flow = 0.0. Sprays disabled.

Line 043030 (Trip 303) -- PORV trip

SETPT = 5000.0   Trip setpoint = 5000 psi error. PORV disabled

Line 043050 (Trip 305) -- PORV trip

SETPT = 5000.0   Trip setpoint = 5000 psia. PORV disabled

Lines 703556 through 703559 (Control Blocks 556 through 559) -- Steam dump valve area

CGAIN = 0.0   Gain = 0.0 Steam dump valves disabled.

Line 140010 (Core Region 1) -- Reactivity coefficients

ALPHTM = Fuel Temperature Coefficient

FTWT = 0.22346 (from base case)
MTC = -40 pcm/°F (Safety Analysis Assumption)
FTC = -2.32 pcm/°F (Safety Analysis Assumption)
Beta = 485 $/pcm (Safety Analysis Assumption)
FT = Full power average fuel temperature = 1333.44°F (Steady State Initialization)

$$ALPHTM = \frac{2 * FTWT * FTC * FT^{1/2}}{\beta}$$

See base case documentation for derivation

$ALPHTM = -7.807x10^{-2}$

Line 140020 (Core Region 2) -- Reactivity coefficients

ALPHTM = Fuel Temperature Coefficient

FTWT = 0.55308 (from base case)

FTC = -2.32 pcm/°F (Safety Analysis Assumption)
Beta = 485 \$/pcm (Safety Analysis Assumption)

ALPHTM = -1.932×10^{-1} from above equation

Line 140030 (Core Region 3) -- Reactivity coefficients

Since the power in the top node is the same as that in the bottom node, all values on this line are the same as those on Line 140010.

Loss of Feedwater

```
*
*          PROBLEM DESCRIPTION AND OPTIONS CARD
*       LDMP  NEDI   NTC  NTRP  NVOL  NBUB  NTDV  NJUN NPMPC  NCKV
010001  -1    -32     1   112    50     5     0    85     2    28
*
*  TIME STEPS
*        TRTG  TMIN  TRST  TMAJ  TDMP  NCHK  DELTM  TLAST  NSHAP
030010   0.0   0.1   0.0 250.0   0.0     0   0.1    1.E+6      0
*
020005 COUT, 50 COUT, 51 COUT, 52 COUT,-51 COUT, 20 COUT,-66
020006 COUT,-67 DTOL,  0
*
*   PROBLEM END TIME
040010    1    1     0   0 5000.0   0.0   "PROBLEM END TIME"
*
*         CHANGES FOR LOSS OF FEEDWATER
*
*        DISABLE PROPORTIONAL HEATERS FOR DYNODE COMPARISON ONLY
703305 -305  SUM,  308  -303  1.0  0.5  -0.0333   0.0  0.0  0.0
*
*        TRIP TURBINE
046030   601    1    0   0  0.01   0.0    "TURBINE TRIP"
*        TRIP REACTOR COOLANT PUMPS
040040    4    1   0     0  0.01   0.0 "REACTOR COOLANT PUMP TRIP"
*         TRIP FEEDWATER
044030   402   1    0    0 0.01   0.0 "FEEDWATER TO SG A ISOLATED"
044060   403   1    0    0 0.01   0.0 "FEEDWATER TO SG B ISOLATED"
*
*         SET INITIAL S/G LEVEL TO 17%
053031 3 0 774.14 644.3 -1.0 3080.91 24.19 0.0 51.31 2.380 662.08
054031 4 0 774.14 644.3 -1.0 3080.91 24.19 0.0 51.31 2.380 662.08
060031     0.9929011 7.580414   3.336 0  0    0    * S/G A SEPARATOR
060041     0.9929011 7.580414   3.336 0  0    0    * S/G B SEPARATOR
*
*            DISABLE ROD CONTROLLER
703130 -130  INT, -129  0  1.0  0.0  0.0  228.0  228.0  228.0
*            DISABLE CHARGING AND LETDOWN
703205 -205  SUM, 202 -204  0.0 1.0  -4.0  0.0        0.0  504.59
703208 -208  SUM, 203  206  0.0         1.0   1.0      0.0
082081 208 209 -2  0 8872.2  5.24 611.81  0.0  0.55  0.0 0 1 2 0
082091 209 210  2  0 8872.2  4.12 617.854 0.0  0.0   0.0 1 1 2 0
230011  1   701  303   0.5000000 ** SG A
230021  2   702  403   0.5000000 ** SG B
```

```
230031
*          DISABLE PRESSURIZER CONTROL
*                SPRAYS
703304 -304   SUM,  303  -303   1.000   1.0  0.02  0.0  0.0 0.000
*                PORVS
043030   302   14 -303   0  500000.0 0.0  "HIGH PRZR PRESS ERROR
PORV SETPT"
043050   303   +4  500   0  500000.0 0.0  "HIGH PRZR PRESS PORV
SETPOINT"
*           DISABLE STEAM DUMP
121600  3   0.0   1.0   1.0  0.0  1E+6 0.0
703556 -556  MUL,  -550   509  0.0  0.0  0.0  0.0
703557 -557  MUL,  -551   509  0.0  0.0  0.0  0.0
703558 -558  MUL,  -552   510  0.0  0.0  0.0  0.0
703559 -559  MUL,  -553   510  0.0  0.0  0.0  0.0
*      DECREASE S/G SAFETY BLOWDOWN
048020 -801   -4   310  0  1123.0 0.0  "FIRST SG A SAFETY RESET"
048040 -802   -4   310  0  1140.0 0.0  "SECOND SG A SAFETY RESET"
048060 -803   -4   310  0  1156.0 0.0  "THIRD SG A SAFETY RESET"
048080 -804   -4   310  0  1167.0 0.0  "FOURTH SG A SAFETY RESET"
048100 -805   -4   310  0  1167.0 0.0  "FIFTH SG A SAFETY RESET"
048140 -807   -4   410  0  1123.0 0.0  "FIRST SG B SAFETY RESET"
048160 -808   -4   410  0  1140.0 0.0  "SECOND SG B SAFETY RESET"
048180 -809   -4   410  0  1156.0 0.0  "THIRD SG B SAFETY RESET"
048200 -810   -4   410  0  1167.0 0.0  "FOURTH SG B SAFETY RESET"
048220 -811   -4   410  0  1167.0 0.0  "FIFTH SG B SAFETY RESET"
*      AFW INITIATED TO S/G A AT 630 SECONDS
049080  905    1   0  0   630.0  0.0  "AUXILIARY FEEDWATER START"
049090  905    1   0  0   630.0  0.0  "AUXILIARY FEEDWATER START"
*      NO AFW FLOW TO S/G B
087041 704 400  0 28  0.0 0.0459 662.32 0.0 5.44 1.E30 1 -1  2  0
*                VALVE
110280 -906   17   0   0.0 0.0 0.0 0.0
*      NO AFW FLOW FROM PUMP B OR TURBINE DRIVEN PUMP
087071 0  704  5  0  0.0 0.0376 595.50  0.0  0.36 0.0  1 -1  3  0
049100 906  1  0  0  0.0  1E+6 "TD AFW PUMP START ON LO SG LEVEL"
*      DISABLE STEAM LINE PRESSURE TRIPS
047010 701  1  0  0  1.E+6  0.0   "SG A LOW PRESSURE SI SETPOINT"
047020 701  1  0  0  1.E+6  0.0   "SG B LOW PRESSURE SI SETPOINT"
*      DISABLE CROSSOVER
040020     2    1    0    0 1.E+6  0.0  "EQUALIZATION LINE OPENS"
*            MSIV CLOSING TIME SET TO 10 SECONDS
120500     3   0.0   1.0  10.0   0.0   1.0E6   0.0  * A
120600     3   0.0   1.0  10.0   0.0   1.0E6   0.0  * B
*
```

```
*               SEPARATOR LIQUID VOLUME
702061    61  LIQV, 303    1.0     377.7
702062    62  LIQV, 403    1.0     377.7
*               LOWER DOWNCOMER LIQUID VOLUME
702063    63  LIQV, 300    1.0     569.8
702064    64  LIQV, 400    1.0     569.8
*               LEVEL USING AREA OF LOWER VOLUME
703060   -60  SUM,   61    63 0.068215 1.0    1.0  64.6
703061   -61  SUM,   62    64 0.068215 1.0    1.0  64.6
*               CUT OFF AT 38.8 FEET
703062   -62  SUM,   61    63 0.068215 1.0    1.0  38.8    0.0    38.8
703063   -63  SUM,   62    64 0.068215 1.0    1.0  38.8    0.0    38.8
*               EXTRA LEVEL IN UPPER VOLUME
703064   -64  SUM, -60   -62 0.115100 1.0   -1.0   3.0    0.0
703065   -65  SUM, -61   -63 0.115100 1.0   -1.0   3.0    0.0
*               SUM OF BOTH LEVELS
703066   -66  SUM,   -62   -64   1.0     1.0    1.0  41.8
703067   -67  SUM,   -63   -65   1.0     1.0    1.0  41.8
```

Line 703305 (Control Block 305) – Proportional heater output (Dynode comparison only)

CMAX = 0.0 Maximum heater output = 0.0. Proportional heaters disabled.

Line 010001 -- Problem description

NEDI = -32 Two additional minor edits are added.
NCKV = 28 An additional valve is added

Line 030010 -- Time steps

TMIN = 0.1 One minor edit per standard time step.
NMAJ = 250.0 One major edit every 250 seconds prevents excess output.
DELTM = 0.1 Maximum time step of 0.1 seconds prevents numerical problems.

Lines 020005, 020006 (Minor Edits)

The following minor edit variables have been added:

COUT, -66 See calculations below. Steam generator A wide range level
COUT, -67 See calculations below. Steam generator A wide range level

Line 040010 (Trip 1) -- Problem end time

SETPT = 5000.0 5000 seconds

Line 046030 (Trip 603) -- Turbine trip

IDSIG = 1	Trip is on elapsed time.
IX1 = 0	Time has no region
SETPT = 0.01	Trip is at 0.01 seconds
IDITL = "TURBINE TRIP"	Trip is now a turbine trip on time, not on reactor trip.

Line 040040 (Trip 4) -- Reactor coolant pump trip

SETPT = 0.01 Pumps trip at 0.01 seconds
IDITL = "REACTOR COOLANT PUMP TRIP" Remove (never tripped)

Line 044030 (Trip 403) -- Feedwater trip to SG A

IDSIG = 1 Trip is on elapsed time.
IX1 = 0 Time has no region
SETPT = 0.01 Trip is at 0.01 seconds
IDITL = "FEEDWATER TO SG A ISOLATED" Trip is now a feedwater trip on time, not on T_{avg} with reactor trip.

Line 044060 (Trip 406) -- Feedwater trip to SG B

IDSIG = 1 Trip is on elapsed time.
IX1 = 0 Time has no region
SETPT = 0.01 Trip is at 0.01 seconds
IDITL = "FEEDWATER TO SG B ISOLATED" Trip is now a feedwater trip on time, not on T_{avg} with reactor trip.

Lines 053031, 054031 (Volumes 303, 403) -- Steam generator separators

HW = 774.14 Iterated upon until steam generator level was 0% NR span (Safety Analysis Assumption)

Lines 060031, 060041 (Bubble Rise Volumes 3, 4) -- Steam generator separators

ALPH = 0.9929011	From steady state initialization
VBUB = 7.580414	From steady state initialization
ZMIX = 3.336	Mixture level is (3.336 - .925) * .08333 = 20% NR. This value is not important and it achieved satisfactory results in steady state initialization. Lower values resulted in errors.

Line 703130 (Control Block 130) -- Control rod position

CMIN = 228.0 Minimum rod position = 228 steps. Rods disabled

Line 703205 (Control Block 205) -- Charging flow

CGAIN = 0.0	Gain = 0. Flow is always 0.0. Charging is disabled
CIC = 0.0	Initial charging flow is 0.0.

Line 703208 (Control Block 208) -- Letdown flow

CGAIN = 0.0	Gain = 0. Flow is always 0.0. Letdown is disabled
CIC = 0.0	Initial letdown flow is 0.0.

Lines 082081, 082091 (Junctions 208, 209) -- Inlet and exit of reactor coolant pump B

WP = 8872.2 Flow = 8872.2 lbm/sec (charging is not subtracted off)

Lines 230011, 230021 (Power removal systems 1, 2) -- Steam generators A, B

POWF = 0.5 Each steam generator removes 50% of the heat from the RCS

Line 230031 (Power removal system 3, Charging and letdown)

This line must be blank since there are now only two power removal systems.

Line 703304 (Control Block 304) -- Pressurizer spray control

CMAX = 0.0 Maximum spray flow = 0.0. Sprays disabled.

Line 043030 (Trip 303) -- PORV trip

SETPT = 500000.0 Trip setpoint = 500000 psi error. PORV disabled

Line 043050 (Trip 305) -- PORV trip

SETPT = 500000.0 Trip setpoint = 500000 psia. PORV disabled

Line 121600 (General Data Table 16) -- Steam Dump Drain

NAREA = 3	Three points
TAREA(1) = 0.0	0.0 seconds
TAREA(2) = 1.0	Initially open
TAREA(3) = 1.0	1.0 seconds
TAREA(4) = 0.0	Closed at 1 second
TAREA(5) = 1E6	1E6 seconds
TAREA(6) = 0.0	Stays closed

Lines 703556 through 703559 (Control Blocks 556 through 559) -- Steam dump valve area

CGAIN = 0.0 Gain = 0.0 Steam dump valves disabled.

048020, 048140 (Trips 802, 814) -- First SG A, B safety valve reset

30 psi blowdown (Safety Analysis Assumption)

SETPT = 1123.0 Reset = 1153 (setpoint from lines 048010, 048130) - 30

048040, 048160 (Trips 804, 816) -- Second SG A, B safety valve reset

SETPT = 1140.0 Reset = 1170 (setpoint from line 048030, 048150) - 30

048060, 048180 (Trips 806, 818) -- Third SG A, B safety valve reset

SETPT = 1156.0 Reset = 1186 (setpoint from line 048050, 048170) - 30

048080, 048200 (Trips 808, 820) -- Fourth SG A, B safety valve reset

SETPT = 1167.0 Reset = 1197 (setpoint from line 048070, 048190) - 30

048100, 048220 (Trips 810, 822) -- Fifth SG A, B safety valve reset

SETPT = 1167.0 Reset = 1197 (setpoint from line 048090, 048210) - 30

Lines 049080, 049090 (Trips 908, 909) -- Auxiliary feedwater start

IDTRP = 905 Trip to start MD AFW pump
IDSIG = 1 Trip is on time
IX1 = 0 Time has no region
SETPT = 630.0 630 seconds
DELAY = 0.0 No delay
IDITL = "AUXILIARY FEEDWATER START" Start AFW pumps on time

Line 087041 (Junction 704) -- Steam generator B inlet

IVALVE = 28 Valve number 28, which never opens. AFW can not flow into SG B.

Line 110280 (Valve 28) -- Valve to B steam generator

ITCV = -906 A closed valve to open on trip of ID = 906 (see below)
IACV = 17 General data table 17 is used for the opening

IACV2 = 0	Not used. Break never closes
PCV = 0.0	Not used
CV1 = 0.0	Not used
CV2 = 0.0	Not used
CV3 = 0.0	Not used

Line 087071 (Junction 707) -- AFW pump B discharge

IPUMP = 5	Fill table for disabled TDAFW pump. AFW pump B disabled.

Line 049100 (Trip 901) -- Turbine driven AFW pump start.

IDSIG = 1	Trip is on time.
IX1 = 0	Time has no region.
IX2 = 0	Time has no region.
SETPT = $1x10^6$	Never trips

Lines 047010, 047020 (Trips 701, 702) -- Steam line pressure trips

IDSIG = 1	Trip is on time.
IX1 = 0	Time has no region.
IX2 = 0	Time has no region.
SETPT = $1x10^6$	Never trips

Line 040020 (Trip 2) -- Trip to enable equalization line

SETPT = $1x10^6$	$1x10^6$ seconds. Never trips.

Lines 120500, 120600 (General data tables 5,6) -- Main steam isolation valves

TAREA(3) = 10.0	Ten second closing time (Safety Analysis Assumption)

Line 702061 (Control Input 61) -- Liquid level in A separator

IDC = 61	Control Input 61
CSYM = LIQV	This input is a liquid volume
IREG = 303	Volume 303 (Steam generator A separator)
GAIN = 1.0	Gain = 1
CIC = 377.7	Total volume is 3080.91 ft^3. (See Volume 303). Initial void fraction is .8774 (from steady state initialization). Liquid volume = 3080.91 X (1 - .8774) = 377.7 ft^3.

Line 702062 (Control Input 62) -- Liquid level in B separator

IDC = 62	Control Input 62
CSYM = LIQV	This input is a liquid volume
IREG = 403	Volume 403 (Steam generator B separator)
GAIN = 1.0	Gain = 1
CIC = 377.7	Total volume is 3080.91 ft^3. (See Volume 403). Initial void fraction is .8774 (from steady state initialization). Liquid volume = 3080.91 X (1 - .8774) = 377.7 ft^3.

Line 702063 (Control Input 63) -- Liquid level in A downcomer

IDC = 63	Control Input 63
CSYM = LIQV	This input is a liquid volume
IREG = 300	Volume 300 (Steam generator A downcomer)
GAIN = 1.0	Gain = 1
CIC = 569.8	Total volume is 569.8 ft^3. (See Volume 300). Initial void fraction is 0.0 so the entire volume is liquid.

Line 702064 (Control Input 64) -- Liquid level in B downcomer

IDC = 64	Control Input 64
CSYM = LIQV	This input is a liquid volume
IREG = 400	Volume 400 (Steam generator B downcomer)
GAIN = 1.0	Gain = 1
CIC = 569.8	Total volume is 569.8 ft^3. (See Volume 400). Initial void fraction is 0.0 so the entire volume is liquid.

Line 703060 (Control Block 60) -- SG A level using area of lower volume

IDC = -60	Control Block 60
ITYPE = SUM	This block is a sum
INC1 = 61	Control Input 61 (SG A separator liquid volume)
INC2 = 63	Control Input 63 (SG A downcomer liquid volume)
CGAIN = 0.068215	Gain = 1/Area of downcomer = height / volume for Volume 300 (see Volume 300) = 38.8 / 568.79 = .068215 ft^{-1}.
CP1 = 1.0	1 X separator liquid volume
CP2 = 1.0	1 X downcomer liquid volume
CIC = 64.6	Initial value = 0.068215 X (377.7 + 569.8) = 64.6 ft

Line 703061 (Control Block 61) -- SG B level using area of lower volume

IDC = -61	Control Block 61
ITYPE = SUM	This block is a sum
INC1 = 62	Control Input 62 (SG B separator liquid volume)
INC2 = 64	Control Input 64 (SG B downcomer liquid volume)

CGAIN = 0.068215	Gain = 1/Area of downcomer = height / volume for Volume 400 (see Volume 400) = 38.8 / 568.79 = .068215 ft^{-1}.
CP1 = 1.0	1 X separator liquid volume
CP2 = 1.0	1 X downcomer liquid volume
CIC = 64.6	Initial value = 0.068215 X (377.7 + 569.8) = 64.6 ft

Line 703062 (Control Block 62) -- SG A level using area of lower volume (cut off at top of volume)

IDC = -62	Control Block 62
ITYPE = SUM	This block is a sum
INC1 = 61	Control Input 61 (SG A separator liquid volume)
INC2 = 63	Control Input 63 (SG A downcomer liquid volume)
CGAIN = 0.068215	Gain = 1/Area of downcomer = height / volume for Volume 300 (see Volume 300) = 38.8 / 568.79 = .068215 ft^{-1}.
CP1 = 1.0	1 X seperator liquid volume
CP2 = 1.0	1 X downcomer liquid volume
CIC = 64.6	Initial value = 0.068215 X (377.7 + 569.8) = 64.6 ft
CMIN = 0.0	Minimum = 0.0
CMAX = 1.0	Maximum = 38.8 (This is the liquid volume in the downcomer assuming all liquid falls into the downcomer.)

Line 703063 (Control Block 63) -- SG B level using area of lower volume (cut off at top of volume)

IDC = -63	Control Block 63
ITYPE = SUM	This block is a sum
INC1 = 62	Control Input 62 (SG B separator liquid volume)
INC2 = 64	Control Input 64 (SG B downcomer liquid volume)
CGAIN = 0.068215	Gain = 1/Area of downcomer = height / volume for Volume 400 (see Volume 400) = 38.8 / 568.79 = .068215 ft^{-1}.
CP1 = 1.0	1 X separator liquid volume
CP2 = 1.0	1 X downcomer liquid volume
CIC = 64.6	Initial value = 0.068215 X (377.7 + 569.8) = 64.6 ft
CMIN = 0.0	Minimum = 0.0
CMAX = 1.0	Maximum = 38.8 (This is the liquid volume in the downcomer assuming all liquid falls into the downcomer.)

Line 703064 (Control Block 64) -- SG A level in separator

IDC = -64	Control Block 64
ITYPE = SUM	This block is a sum
INC1 = -60	Control Block 60 (SG A level based on downcomer area)
INC2 = -62	Control Block 62 (SG A downcomer level cut off at top)

CGAIN = 0.115100	Gain = Area of downcomer/Area of separator = Area of downcomer (see Control Block 60) X height / volume for Volume 303 (see Volume 303) = (24.19 / 3080.91 X .068215) = .115110. This gain provides a conversion from level based on downcomer area to level based on separator area.
CP1 = 1.0	1 X level based on downcomer area
CP2 = 1.0	1 X downcomer level cut off at top
CIC = 3.0	Initial value = 0.0115215 X (64.6 + 38.8) = 3.0 ft
CMIN = 0.0	Minimum = 0.0 (only the level actually in the riser is included)

Line 703065 (Control Block 65) -- SG B level in separator

IDC = -65	Control Block 65
ITYPE = SUM	This block is a sum
INC1 = -61	Control Block 61 (SG B level based on downcomer area)
INC2 = -63	Control Block 63 (SG B downcomer level cut off at top)
CGAIN = 0.115100	Gain = Area of downcomer/Area of seperator = Area of downcomer (see Control Block 60) X height / volume for Volume 403 (see Volume 403) = (24.19 / 3080.91 X .068215) = .115110. This gain provides a conversion from level based on downcomer area to level based on seperator area.
CP1 = 1.0	1 X level based on downcomer area
CP2 = 1.0	1 X downcomer level cut off at top
CIC = 3.0	Initial value = 0.0115215 X (64.6 + 38.8) = 3.0 ft
CMIN = 0.0	Minimum = 0.0 (only the level actually in the riser is included)

Line 703066 (Control Block 66) -- SG A wide range level

IDC = -66	Control Block 66
ITYPE = SUM	This block is a sum
INC1 = -62	Control Block 62 (SG A downcomer level cut off at top)
INC2 = -64	Control Block 64 (SG A separator level cut off at bottom)
CGAIN = 1.0	Gain = 1
CP1 = 1.0	1 X downcomer level cut off at top (if level is in separator, this is 38.8)
CP2 = 1.0	1 X separator level cut off at bottom (if level is in downcomer, this is 0.0)
CIC = 41.8	Initial value = 38.8 + 3.0 = 41.8 ft

Line 703067 (Control Block 67) -- SG B wide range level

IDC = -66	Control Block 66
ITYPE = SUM	This block is a sum
INC1 = -63	Control Block 63 (SG B downcomer level cut off at top)
INC2 = -65	Control Block 65 (SG B separator level cut off at bottom)
CGAIN = 1.0	Gain = 1
CP1 = 1.0	1 X downcomer level cut off at top (if level is in separator, this is 38.8)
CP2 = 1.0	1 X separator level cut off at bottom (if level is in downcomer, this is 0.0)

CIC = 41.8 Initial value = 38.8 + 3.0 = 41.8 ft

Uncontrolled Rod Withdrawal -- Fast Rate from Full Power

```
*   TIME STEPS
*        TRTG   TMIN   TRST   TMAJ   TDMP   NCHK   DELTM   TLAST   NSHAP
030010    0.0 0.001   0.0    5.0    0.0      0   0.001   1.E+6       0
*
*   PROBLEM END TIME
040010     1     1      0    0   20.0     0.0    "PROBLEM END TIME"
*
*   CHANGES FOR UNCONTROLLED ROD WITHDRAWAL  FAST RAMP FULL POWER
*
*                    GAIN REPRESENTS RATE OF ADDITION
702061     61   TIMX,     0      0.11613   0.0
*                    MULPIPLY BY COMPLIMENT OF REACTOR TRIP
702062     62   TRIP,  722      1.0        0.0
702063     63   CONS,     0      1.0        1.0
703060    -60   SUM,    63    62    1.0    1.0   -1.0    1.0
703061    -61   MUL,    61   -60    1.0    0.0    0.0    0.0
703062    -62   VLM,   -61     0    1.0  1E+50   0.0    0.0
141200    -62    1000
*
```

Line 030010 -- Time steps

TMIN = 0.001	One minor edit per standard time step.
DELTM = 0.001	Maximum time step of 0.001 seconds prevents numerical problems.

Line 040010 (Trip 1) -- Problem end time

SETPT = 20.0	20 seconds

Line 702061 (Control Input 61) -- Reactivity addition

IDC = 61	Control Input 61
CSYM = TIMX	Reactivity addition is proportional to time.
IREG = 0	Time has no region
GAIN = 0.11613	From Dynode
CIC = 0.0	Initially there is no reactivity addition

Line 702062 (Control Input 62) -- Reactivity addition

IDC = 62	Control Input 62
CSYM = TRIP	This input is a trip
IREG = 722	Reactor trip
GAIN = 1.0	Gain = 1 -- this input is 0 if reactor has not tripped and 1 if it has.

CIC = 0.0 Initially the reactor has not tripped.

Line 702063 (Control Input 63) -- Constant 1.0

IDC = 63	Control Input 63
CSYM = CONS	This input is a constant
IREG = 0	Constants have no region
GAIN = 1.0	Gain = 1 -- This input is always 1
CIC = 1.0	If it is always 1, it is initially 1

Line 703060 (Control Block 60) -- Compliment of reactor trip

IDC = -60	Control Block 60
ITYPE = SUM	This block is a sum
INC1 = 63	Constant 1.0
INC2 = 62	Reactor trip
CGAIN = 1.0	Gain = 1
CP1 = 1.0	1 X 1
CP2 = -1.0	-1 X Reactor trip
CIC = 1.0	This block is initially 1.0

This block is 1 before reactor trip and 0 afterwards.

Line 703061 (Control Block 61) -- Reactivity insertion times compliment of reactor trip

IDC = -61	Control Block 61
ITYPE = MUL	This block is a multiplier
INC1 = 61	Reactivity insertion
INC2 = -60	Compliment of reactor trip
CGAIN = 1.0	Gain = 1
CP1 = 0.0	Not used for multiplier
CP2 = 0.0	Not used for multiplier
CIC = 0.0	This block is initially 0.0

This block is reactivity insertion before reactor trip and 0 afterwards.

Line 703062 (Control Block 62) -- Reactivity insertion ending at reactor trip

IDC = -62	Control Block 62
ITYPE = VLM	This block is a velocity limiter
INC1 = -61	Reactivity insertion times compliment of reactor trip
INC2 = 0	Not used for velocity limiter
CGAIN = 1.0	Gain = 1
CP1 = $1x10^{50}$	A very large number -- effectively no upper limit

CP2 = 0.0	Lower limit 0. Value can not decrease
CIC = 0.0	This block is initially 0.0

This block is reactivity insertion before reactor trip. At the time of reactor trip it remains constant. This means that as of the reactor trip, the insertion stops.

Line 141200 (Scram Table 2) -- Control rod controller

NSCR = -62	Control Block 62 controls reactivity.
ITSCRM = 1000	Reactivity controlled by control system

Uncontrolled Rod Withdrawal -- Fast Rate from Intermediate Power

```
*  TIME STEPS
*       TRTG  TMIN   TRST   TMAJ   TDMP   NCHK   DELTM   TLAST   NSHAP
030010    0.0 0.025   0.0    5.0    0.0      0   0.025   1.E+6       0
*
*   PROBLEM END TIME
040010    1    1      0    0  20.0     0.0    "PROBLEM END TIME"
*
*   NORMALIZED INLET TEMPERATURE
702051   51  TEMP,    1 1.8379E-3   1.0
*   NORMALIZED CORE HEAT FLUX
702053   53  PHIR,    2 1.0          7.90188E4
702054   54  PHIR,    3 1.0          1.95577E5
702055   55  PHIR,    4 1.0          7.90188E4
703050  -50  SUM,    53    54  1.0  1.0    1.0      2.74596E5
703051  -51  SUM,   -50    55 2.82794E-6 1.0   1.0      1.0
*
*   HEAT FLUX (FRACTION NOMINAL)
702056   56  COUT   -51 0.62         0.62
*
*   AVERAGE DELTA T
703053  -53  SUM,    -9   -10  1.0    0.5  0.5    41.74
*
*   CHANGES FOR UNCONTROLLED ROD WITHDRAWAL  FAST RAMP
INTERMEDIATE POWER
*
*                 GAIN REPRESENTS RATE OF ADDITION
702061    61   TIMX,    0     0.11613   0.0
*                 MULPIPLY BY NEGATIVE OF REACTOR TRIP
702062    62   TRIP,  722      1.0         0.0
702063    63   CONS,    0      1.0         1.0
703060   -60   SUM,    63    62   1.0   1.0  -1.0   1.0
703061   -61   MUL,    61   -60   1.0   0.0   0.0   0.0
703062   -62   VLM,   -61     0   1.0  1E+50  0.0   0.0
141200   -62    1000
*
*       DISABLE SAFETY INJECTION TRIP ON LOW STEAM LINE PRESSURE
047010 701  1  0  0  1.E+6  0.0   "SG A LOW PRESSURE SI SETPOINT"
047020 701  1  0  0  1.E+6  0.0   "SG B LOW PRESSURE SI SETPOINT"
*  INLET TEMPERATURE
050011 0 0  0.0  539.69 0.0  493.97  8.400 0.0 1000.0 0.5  592.49
*
* REACTOR POWER
010005 1023.0
*
* STEAM FLOW
```

```
083001 300 301 0  0 2573.96 55.23 630.53 0.0 5.40 0.0    1 1  2  0
083011 301 302 0  0 2573.96 55.23 641.19 0.0 0.0  0.0    0 1  2  0
083021 302 303 0  0 2573.96 51.31 662.08 0.0 3.40 0.0    0 1  2  0
083031 303 310 0  0  584.99 1.40  686.27 0.0 -1.0 0.0    0 1  2  0
083101 310 311 0  5  584.99 4.30  687.49 0.0 1.10 1.E30 1 1  2  0
083111 311 600 0 26  584.99 4.30  687.49 0.0 0.0  0.0    1 1  2  0
083131 303 300 0  0 1988.97 7.77  662.08 0.0 -1.0 0.0    0 1  2  0
084001 400 401 0  0 2573.96 55.23 630.53 0.0 5.40 0.0    1 1  2  0
084011 401 402 0  0 2573.96 55.23 641.19 0.0 0.0  0.0    0 1  2  0
084021 402 403 0  0 2573.96 51.31 662.08 0.0 3.40 0.0    0 1  2  0
084031 403 410 0  0  584.99 1.40  686.27 0.0 -1.0 0.0    0 1  2  0
084101 410 411 0  6  584.99 4.30  687.49 0.0 1.10 1.E30 1 1  2  0
084111 411 600 0 26  584.99 4.30  687.49 0.0 0.0  0.0    1 1  2  0
084131 403 400 0  0 1988.97 7.77  662.08 0.0 -1.0 0.0    0 1  2  0
*
*  PRESSURIZER LEVEL
060051    0.8     4.3567    8.387    0    0    0    * PRESSURIZER
*              FEEDWATER FLOW
130101   -4   3    0     0
*         TIME           FLUX            ENTH    PRESS
130102    0.0         793.4796290630   402.27   750.0
130103    0.01        793.4796290630   402.27   750.0
130104    1.0E6       793.4796290630   402.27   750.0
130105    2.0E6       793.4796290630   402.27   750.0
*
130201   -4   3    0     0
*         TIME           FLUX            ENTH    PRESS
130202    0.0         793.4796290630   402.27   750.0
130203    0.01        793.4796290630   402.27   750.0
130204    1.0E6       793.4796290630   402.27   750.0
130205    2.0E6       793.4796290630   402.27   750.0
*
702404  404  AJNT, 701   0.71618 0.528
702408  408  AJNT, 702   0.71618 0.528
703409 -409   SUM,  404 -408 1.0       1.0  1.0  0.528 0.0  1.0
703410 -410   VLM, -409   0  1.0       0.08 0.05 0.528 0.0  1.0
703419 -419   SUM,  408 -418 1.0       1.0  1.0  0.528 0.0  1.0
703420 -420   VLM, -419    0 1.0       0.08 0.05 0.528 0.0  1.0
*
*   STEAM GENERATOR PRESSURE
053031 3 0 881.92 595.1 -1.0 3080.91 24.19 0.0 51.31 2.380 662.08
053111 0 0 851.92   0.0  0.0  1837.0  2.34 0.0  4.30 0.0   686.27
054031 4 0 881.92 595.1 -1.0 3080.91 24.19 0.0 51.31 2.380 662.08
054111 0 0 851.92   0.0  0.0   912.8  2.34 0.0  4.30 0.0   686.27
*     TREF
*      PERCENT LOAD BASED ON TURBINE VALVE FLOW
702020   20  WP**, 411 1.0257E-3   0.6
```

```
*         TREF
703020  -20   SUM,  20  21   1.0  26.0  1.0   562.6    547.0  573.0
*
* ROD CONTROLLER
702101  101  PNRM,   0   0.62    0.62
*
*.             HIGH FLUX TRIP
047490  722    2      0   0  1.903 0.5
*
* RELAX CONVERGENCE CRITERIA
230000     100  1.E-8  1.E-8
*
```

Line 030010 -- Time steps

TMIN = 0.025 One minor edit per standard time step.
DELTM = 0.025 Maximum time step of 0.025 seconds prevents numerical problems.

Line 040010 (Trip 1) -- Problem end time

SETPT = 20.0 20 seconds

Line 702051 (Control Input 51) -- Normalized inlet temperature

GAIN = 1.8379×10^{-3} 1/544.099 From 62% power initialization

Line 702053 (Control Input 53) – Heat flux in bottom of core

CIC = 7.90188×10^{4} From steady state initialization

Line 702054 (Control Input 54) – Heat flux in middle of core

CIC = 1.95577×10^{5} From steady state initialization

Line 702055 (Control Input 55) – Heat flux in top of core

CIC = 7.90188×10^{4} From steady state initialization

Line 703050 (Control Block 50) – Heat flux in bottom plus middle of core

CIC = 2.74596×10^{5} $7.90188 \times 10^{4} + 1.95577 \times 10^{5}$

Line 703051 (Control Block 51) -- Core heat flux (fraction nominal)

CGAIN = 2.82794×10^{-6} Based on 62% power initialization. (Heat flux for 3 core regions is 7.90188×10^{4}, 1.95577×10^{5}, 7.90188×10^{4}. Sum = 3.536146×10^{5} CGAIN = 1/sum)

Line 702056 (Control Input 56) -- Core heat flux (fraction nominal)

GAIN = 0.62	Initial power is 62% (Safety Analysis Assumption)
CIC = 0.62	Initial power is 62% (Safety Analysis Assumption)

Line 703053 (Control Block 53) -- Average ΔT

CIC = 41.74	Based on 62% power initialization.

Line 702061 (Control Input 61) -- Reactivity addition

IDC = 61	Control Input 61
CSYM = TIMX	Reactivity addition is proportional to time.
IREG = 0	Time has no region
GAIN = 0.11613	From Dynode
CIC = 0.0	Initially there is no reactivity addition

Line 702062 (Control Input 62) -- Reactivity addition

IDC = 62	Control Input 62
CSYM = TRIP	This input is a trip
IREG = 722	Reactor trip
GAIN = 1.0	Gain = 1 -- this input is 0 if reactor has not tripped and 1 if it has.
CIC = 0.0	Initially the reactor has not tripped.

Line 702063 (Control Input 63) -- Constant 1.0

IDC = 63	Control Input 63
CSYM = CONS	This input is a constant
IREG = 0	Constants have no region
GAIN = 1.0	Gain = 1 -- This input is always 1
CIC = 1.0	If it is always 1, it is initially 1

Line 703060 (Control Block 60) -- Compliment of reactor trip

IDC = -60	Control Block 60
ITYPE = SUM	This block is a sum
INC1 = 63	Constant 1.0
INC2 = 62	Reactor trip
CGAIN = 1.0	Gain = 1
CP1 = 1.0	1 X 1
CP2 = -1.0	-1 X Reactor trip
CIC = 1.0	This block is initially 1.0

This block is 1 before reactor trip and 0 afterwards.

Line 703061 (Control Block 61) -- Reactivity insertion times compliment of reactor trip

IDC = -61	Control Block 61
ITYPE = MUL	This block is a multiplier
INC1 = 61	Reactivity insertion
INC2 = -60	Compliment of reactor trip
CGAIN = 1.0	Gain = 1
CP1 = 1.0	1 X 1
CP2 = -1.0	-1 X Reactor trip
CP1 = 0.0	Not used for multiplier
CP2 = 0.0	Not used for multiplier
CIC = 0.0	This block is initially 0.0

This block is reactivity insertion before reactor trip and 0 afterwards.

Line 703062 (Control Block 62) -- Reactivity insertion ending at reactor trip

IDC = -62	Control Block 62
ITYPE = VLM	This block is a velocity limiter
INC1 = -61	Reactivity insertion times compliment of reactor trip
INC2 = 0	Not used for velocity limiter
CGAIN = 1.0	Gain = 1
CP1 = 1×10^{50}	A very large number -- effectively no upper limit
CP2 = 0.0	Lower limit 0. Value can not decrease
CIC = 0.0	This block is initially 0.0

This block is reactivity insertion before reactor trip. At the time of reactor trip it remains constant. This means that as of the reactor trip, the insertion stops.

Line 141200 (Scram Table 2) -- Control rod controller

NSCR = -62	Control Block -62 controls reactivity.
ITSCRM = 1000	Reactivity controlled by control system

Lines 047010, 047020 (Trips 701, 702) -- Steam line pressure trips

IDSIG = 1	Trip is on time.
IX1 = 0	Time has no region.
SETPT = 1×10^6	Never trips

Line 050011 (Volume 1) -- Lower head

HW = 539.69	Iterated upon to get 544.1°F
	Zero power Tinlet = 551°F From DYNODE
	Full power Tinlet = 539.5°F From base case

60% Tinlet = 551 - 0.6 x (551 - 539.5) = 544.1°F

Line 010005 -- Reactor power

POWER = 1023.0   62% x 1650 (Safety Analysis Assumption)

Lines 083001, 083011, 083021, 084001, 084011, 084021 (Junctions 300, 301, 302, 400, 401, 402) -- Steam generator risers

62% power steam flow = 584.99 lbm/sec (from Dynode 62% power case 2.105973x106 lb/hr / 3600 sec/hr)
Carryover = 4.4 (from WPD-PWEE 70-30 page 23 at 62%)
Riser flow = 4.4 x 584.99 = 2573.96

WP = 2573.96

Lines 083031, 083101, 083111, 084031, 084101, 084111 (Junctions 303, 310, 311, 403, 410, 411) -- Steam lines

WP = 584.99   See calculation above.

Lines 083131, 084131 (Junctions 313, 413) -- Steam generator carryover

WP = 1988.97   Carryover flow = 2573.96 - 584.99 = 1988.97

Line 060051 (Bubble Rise Volume 5) -- Pressurizer
ZMIX = 8.387   Tave = 564.962 Programmed level = (Tave - 516.539) x 0.006091 = .294944 Level in feet = (Level Fraction) * 22.46 ft + 1.763

Lines 130102, 130103, 130104, 130105, 130202, 130203, 130204, 130205 (Fill Tables 1, 2) -- Feedwater flow rate

FILTBL(2) = 793.4796290630   Feedwater flow = 584.99 lbm/sec (same as steam flow).
Area of junction = 1.3963 ft^2 See junctions 701, 702.
Initial fractional area = 0.528 (0.88 for 100% power; 0.88 * 0.6 for 60% power)
Initial flux = 584.99 / (.528 * 1.3963)

Lines 702404, 702408 (Control Inputs 404, 408) -- Normalized feedwater valve area

CIC = 0.528   0.88(100% fraction) * 0.6 (fraction of full power)

Lines 703409, 703410, 703419, 703420 (Control Blocks 409, 410, 419, 420) -- Feedwater flow area

CIC = 0.528   0.88(100% fraction) * 0.6 (fraction of full power)

Lines 053031, 054031 (Volumes 303, 403) -- Steam generator separators.

P = 881.92	Iterated to get pressure in Volume 410 of 853.785 Psia (from Dynode)
HW = 595.1	Iterated to get steam generator level = 44%

Lines 053111, 054111 (Volumes 311, 411) -- Steam lines downstream of MSIVs

P = 851.92	Iterated to get ΔP between Volumes 403 and 411 of 30 Psi. Same ΔP as base case.

Line 702020 (Control Input 20) Normalized Turbine Load

GAIN = 1.0257×10^{-3}	0.6 (initial load) / 584.99 (initial steam flow)
CIC = 0.6	Initial load

Line 703020 (Control Block 20) -- T-Reference

CIC = 562.6	547(No-load T_{ave}) + 0.6 (Initial load) x (573 (Full-load T_{ave}) – 547) Note that the actual Tave is 565°F. This results in controllers trying to cool down to 562.6. This is of no consequence, though, because control rod control is disabled and steam dumps do not arm until after the reactor trip.

Line 702101 (Control Input 101) -- Power for control rod controller

GAIN = 0.62	Initial power is 62% of full power
CIC = 0.62	Initial power is 62% of full power

Line 047490 (Trip 749) -- Overpower reactor trip

SETPT = 1.903	Initial power is 62%, trip is at 1.18. Corrected trip is at 1.18/.62 since the setpoint is a fraction of initial power.

Line 230000 -- Convergence Criteria

HEPSE = 1.0×10^{-8}	This must be increased from 1×10^{-10} for intermediate power initialization. The value used here is still more restrictive than the default (5×10^{-6}).

Uncontrolled Rod Withdrawal -- Slow Rate from Full Power

```
*   PROBLEM END TIME
040010    1    1     0   0  60.0     0.0    "PROBLEM END TIME"
*
*   CHANGES FOR UNCONTROLLED ROD WITHDRAWAL  SLOW RAMP FULL POWER
*
*                    GAIN REPRESENTS RATE OF ADDITION
702061    61   TIMX,    0      0.0042487 0.0
*                    MULPIPLY BY NEGATIVE OF REACTOR TRIP
702062    62   TRIP,  722      1.0        0.0
702063    63   CONS,    0      1.0        1.0
703060   -60   SUM,   63   62   1.0   1.0  -1.0   1.0
703061   -61   MUL,   61  -60   1.0   0.0   0.0   0.0
703062   -62   VLM,  -61    0   1.0  1E+50  0.0   0.0
141200   -62    1000
*
```

Line 040010 (Trip 1) -- Problem end time

SETPT = 60.0 60 seconds

Line 702061 (Control Input 61) -- Reactivity addition

IDC = 61	Control Input 61
CSYM = TIMX	Reactivity addition is proportional to time.
IREG = 0	Time has no region
GAIN = 0.0042487	From Dynode
CIC = 0.0	Initially there is no reactivity addition

Line 702062 (Control Input 62) -- Reactivity addition

IDC = 62	Control Input 62
CSYM = TRIP	This input is a trip
IREG = 722	Reactor trip
GAIN = 1.0	Gain = 1 -- this input is 0 if reactor has not tripped and 1 if it has.
CIC = 0.0	Initially the reactor has not tripped.

Line 702063 (Control Input 63) -- Constant 1.0

IDC = 63	Control Input 63
CSYM = CONS	This input is a constant
IREG = 0	Constants have no region
GAIN = 1.0	Gain = 1 -- This input is always 1
CIC = 1.0	If it is always 1, it is initially 1

Line 703060 (Control Block 60) -- Compliment of reactor trip

IDC = -60	Control Block 60
ITYPE = SUM	This block is a sum
INC1 = 63	Constant 1.0
INC2 = 62	Reactor trip
CGAIN = 1.0	Gain = 1
CP1 = 1.0	1 X 1
CP2 = -1.0	-1 X Reactor trip
CIC = 1.0	This block is initially 1.0

This block is 1 before reactor trip and 0 afterwards.

Line 703061 (Control Block 61) -- Reactivity insertion times compliment of reactor trip

IDC = -61	Control Block 61
ITYPE = MUL	This block is a multiplier
INC1 = 61	Reactivity insertion
INC2 = -60	Compliment of reactor trip
CGAIN = 1.0	Gain = 1
CP1 = 0.0	Not used for multiplier
CP2 = 0.0	Not used for multiplier
CIC = 0.0	This block is initially 0.0

This block is reactivity insertion before reactor trip and 0 afterwards.

Line 703062 (Control Block 62) -- Reactivity insertion ending at reactor trip

IDC = -62	Control Block 62
ITYPE = VLM	This block is a velocity limiter
INC1 = -61	Reactivity insertion times compliment of reactor trip
INC2 = 0	Not used for velocity limiter
CGAIN = 1.0	Gain = 1
CP1 = $1 x 10^{50}$	A very large number -- effectively no upper limit
CP2 = 0.0	Lower limit 0. Value can not decrease
CIC = 0.0	This block is initially 0.0

This block is reactivity insertion before reactor trip. At the time of reactor trip it remains constant. This means that as of the reactor trip, the insertion stops.

Line 141200 (Scram Table 2) -- Control rod controller

NSCR = -62	Control Block -62 controls reactivity.
ITSCRM = 1000	Reactivity controlled by control system

Uncontrolled Rod Withdrawal -- Slow Rate from Intermediate Power

```
*  TIME STEPS
*       TRTG   TMIN   TRST   TMAJ   TDMP   NCHK   DELTM   TLAST   NSHAP
030010   0.0    0.1    0.0   25.0    0.0      0     0.1   1.E+6       0
*
*   PROBLEM END TIME
040010     1     1      0    0 250.0    0.0    "PROBLEM END TIME"
*
*   NORMALIZED INLET TEMPERATURE
702051   51  TEMP,    1 1.8379E-3   1.0
*   NORMALIZED CORE HEAT FLUX
702053   53  PHIR,    2 1.0          7.90188E4
702054   54  PHIR,    3 1.0          1.95577E5
702055   55  PHIR,    4 1.0          7.90188E4
703050  -50  SUM,    53    54  1.0  1.0   1.0      2.74596E5
703051  -51  SUM,   -50    55 2.82794E-6 1.0   1.0      1.0
*
*   HEAT FLUX (FRACTION NOMINAL)
702056   56  COUT   -51 0.62         0.62
*   PRESSURIZER LEVEL (PCT)
702058   58  COUT   -30 100.0        29.49
*   AVERAGE DELTA T
703053  -53  SUM,    -9   -10  1.0    0.5  0.5    41.74
*
*   CHANGES FOR UNCONTROLLED ROD WITHDRAWAL  SLOW RAMP
INTERMEDIATE POWER
*
*                GAIN REPRESENTS RATE OF ADDITION
702061    61   TIMX,     0      0.0021243 0.0
*                MULPIPLY BY NEGATIVE OF REACTOR TRIP
702062    62   TRIP,  722      1.0        0.0
702063    63   CONS,     0      1.0        1.0
703060   -60   SUM,    63    62    1.0    1.0  -1.0    1.0
703061   -61   MUL,    61   -60    1.0    0.0   0.0    0.0
703062   -62   VLM,   -61     0    1.0  1E+50   0.0    0.0
141200   -62    1000
*
*        DISABLE SAFETY INJECTION TRIP ON LOW STEAM LINE PRESSURE
047010 701  1  0  0  1.E+6  0.0   "SG A LOW PRESSURE SI SETPOINT"
047020 701  1  0  0  1.E+6  0.0   "SG B LOW PRESSURE SI SETPOINT"
*  INLET TEMPERATURE
050011 0 0  0.0  539.69 0.0  493.97  8.400 0.0 1000.0 0.5  592.49
*
* REACTOR POWER
```

```
010005 1023.0
*
* STEAM FLOW
083001 300 301 0  0 2573.96 55.23 630.53 0.0 5.40 0.0    1 1  2  0
083011 301 302 0  0 2573.96 55.23 641.19 0.0 0.0  0.0    0 1  2  0
083021 302 303 0  0 2573.96 51.31 662.08 0.0 3.40 0.0    0 1  2  0
083031 303 310 0  0  584.99 1.40  686.27 0.0 -1.0 0.0    0 1  2  0
083101 310 311 0  5  584.99 4.30  687.49 0.0 1.10 1.E30  1 1  2  0
083111 311 600 0 26  584.99 4.30  687.49 0.0 0.0  0.0    1 1  2  0
083131 303 300 0  0 1988.97 7.77  662.08 0.0 -1.0 0.0    0 1  2  0
084001 400 401 0  0 2573.96 55.23 630.53 0.0 5.40 0.0    1 1  2  0
084011 401 402 0  0 2573.96 55.23 641.19 0.0 0.0  0.0    0 1  2  0
084021 402 403 0  0 2573.96 51.31 662.08 0.0 3.40 0.0    0 1  2  0
084031 403 410 0  0  584.99 1.40  686.27 0.0 -1.0 0.0    0 1  2  0
084101 410 411 0  6  584.99 4.30  687.49 0.0 1.10 1.E30  1 1  2  0
084111 411 600 0 26  584.99 4.30  687.49 0.0 0.0  0.0    1 1  2  0
084131 403 400 0  0 1988.97 7.77  662.08 0.0 -1.0 0.0    0 1  2  0
*
*  PRESSURIZER LEVEL
060051    0.8     4.3567    8.387    0    0    0    * PRESSURIZER
*               FEEDWATER FLOW
130101    -4   3    0     0
*         TIME            FLUX            ENTH    PRESS
130102    0.0          793.4796290630   402.27   750.0
130103    0.01         793.4796290630   402.27   750.0
130104    1.0E6        793.4796290630   402.27   750.0
130105    2.0E6        793.4796290630   402.27   750.0
*
130201    -4   3    0     0
*         TIME            FLUX            ENTH    PRESS
130202    0.0          793.4796290630   402.27   750.0
130203    0.01         793.4796290630   402.27   750.0
130204    1.0E6        793.4796290630   402.27   750.0
130205    2.0E6        793.4796290630   402.27   750.0
*
702404  404  AJNT, 701   0.71618 0.528
702408  408  AJNT, 702   0.71618 0.528
703409 -409   SUM,  404 -408 1.0       1.0  1.0  0.528 0.0  1.0
703410 -410   VLM, -409   0  1.0       0.08 0.05 0.528 0.0  1.0
703419 -419   SUM,  408 -418 1.0       1.0  1.0  0.528 0.0  1.0
703420 -420   VLM, -419    0 1.0       0.08 0.05 0.528 0.0  1.0
*
*    STEAM GENERATOR PRESSURE
053031 3 0 881.92 595.1 -1.0 3080.91 24.19 0.0 51.31 2.380 662.08
053111 0 0 851.92   0.0  0.0  1837.0  2.34 0.0  4.30 0.0   686.27
```

```
054031 4 0 881.92 595.1 -1.0 3080.91 24.19 0.0 51.31 2.380 662.08
054111 0 0 851.92   0.0  0.0   912.8  2.34 0.0  4.30 0.0   686.27
*       TREF
*        PERCENT LOAD BASED ON TURBINE VALVE FLOW
702020   20  WP**, 411 1.0257E-3   0.6
*        TREF
703020  -20   SUM,  20  21   1.0  26.0  1.0   562.6    547.0  573.0
*
* ROD CONTROLLER
702101  101  PNRM,   0   0.62    0.62
*
*              HIGH FLUX TRIP
047490  722    2      0    0  1.903 0.5
*
* RELAX CONVERGENCE CRITERIA
230000     100  1.E-8  1.E-8
*
```

Line 030010 -- Time steps

TMIN = 0.1	One minor edit per standard time step.
NMAJ = 25.0	One major edit every 125 seconds prevents excess output.
DELTM = 0.1	Maximum time step of 0.1 seconds prevents numerical problems.

Line 040010 (Trip 1) -- Problem end time

SETPT = 250.0 250 seconds

Line 702051 (Control Input 51) -- Normalized inlet temperature

GAIN = 1.8379×10^{-3} 1/544.099 From 62% power initialization

Line 702053 (Control Input 53) – Heat flux in bottom of core

CIC = 7.90188×10^{4} From steady state initialization

Line 702054 (Control Input 54) – Heat flux in middle of core

CIC = 1.95577×10^{5} From steady state initialization

Line 702055 (Control Input 55) – Heat flux in top of core

CIC = 7.90188×10^{4} From steady state initialization

Line 703050 (Control Block 50) – Heat flux in bottom plus middle of core

CIC = 2.74596×10^5 $7.90188 \times 10^4 + 1.95577 \times 10^5$

Line 703051 (Control Block 51) -- Core heat flux (fraction nominal)

CGAIN = 2.82794×10^{-6}	Based on 62% power initialization. (Heat flux for 3 core regions is 7.90188×10^4, 1.95577×10^5, 7.90188×10^4. Sum = 3.536146×10^5 CGAIN = 1/sum)

Line 702056 (Control Input 56) -- Core heat flux (fraction nominal)

GAIN = 0.62	Initial power is 62% (Safety Analysis Assumption)
CIC = 0.62	Initial power is 62% (Safety Analysis Assumption)

Line 702058 (Control Input 58) -- Pressurizer level

CIC = 29.49	Level fraction .2949 from 62% power initialization.

Line 703053 (Control Block 53) -- Average ΔT

CIC = 41.74	Based on 62% power initialization.

Line 702061 (Control Input 61) -- Reactivity addition

IDC = 61	Control Input 61
CSYM = TIMX	Reactivity addition is proportional to time.
IREG = 0	Time has no region
GAIN = 0.0021243	From Dynode
CIC = 0.0	Initially there is no reactivity addition

Line 702062 (Control Input 62) -- Reactivity addition

IDC = 62	Control Input 62
CSYM = TRIP	This input is a trip
IREG = 722	Reactor trip
GAIN = 1.0	Gain = 1 -- this input is 0 if reactor has not tripped and 1 if it has.
CIC = 0.0	Initially the reactor has not tripped.

Line 702063 (Control Input 63) -- Constant 1.0

IDC = 63	Control Input 63
CSYM = CONS	This input is a constant
IREG = 0	Constants have no region
GAIN = 1.0	Gain = 1 -- This input is always 1
CIC = 1.0	If it is always 1, it is initially 1

Line 703060 (Control Block 60) -- Compliment of reactor trip

IDC = -60	Control Block 60
ITYPE = SUM	This block is a sum
INC1 = 63	Constant 1.0
INC2 = 62	Reactor trip
CGAIN = 1.0	Gain = 1
CP1 = 1.0	1 X 1
CP2 = -1.0	-1 X Reactor trip
CIC = 1.0	This block is initially 1.0

This block is 1 before reactor trip and 0 afterwards.

Line 703061 (Control Block 61) -- Reactivity insertion times compliment of reactor trip

IDC = -61	Control Block 61
ITYPE = MUL	This block is a multiplier
INC1 = 61	Reactivity insertion
INC2 = -60	Compliment of reactor trip
CGAIN = 1.0	Gain = 1
CP1 = 1.0	1 X 1
CP2 = -1.0	-1 X Reactor trip
CP1 = 0.0	Not used for multiplier
CP2 = 0.0	Not used for multiplier
CIC = 0.0	This block is initially 0.0

This block is reactivity insertion before reactor trip and 0 afterwards.

Line 703062 (Control Block 62) -- Reactivity insertion ending at reactor trip

IDC = -62	Control Block 62
ITYPE = VLM	This block is a velocity limiter
INC1 = -61	Reactivity insertion times compliment of reactor trip
INC2 = 0	Not used for velocity limiter
CGAIN = 1.0	Gain = 1
CP1 = $1x10^{50}$	A very large number -- effectively no upper limit
CP2 = 0.0	Lower limit 0. Value can not decrease
CIC = 0.0	This block is initially 0.0

This block is reactivity insertion before reactor trip. At the time of reactor trip it remains constant. This means that as of the reactor trip, the insertion stops.

Line 141200 (Scram Table 2) -- Control rod controller

NSCR = -62	Control Block -62 controls reactivity.
ITSCRM = 1000	Reactivity controlled by control system

Lines 047010, 047020 (Trips 701, 702) -- Steam line pressure trips

IDSIG = 1	Trip is on time.
IX1 = 0	Time has no region.
SETPT = $1x10^6$	Never trips

Line 050011 (Volume 1) -- Lower head

HW = 539.69 Iterated upon to get 544.1°F
Zero power Tinlet = 551°F From DYNODE
Full power Tinlet = 539.5°F From base case
60% Tinlet = 551 - 0.6 x (551 - 539.5) = 544.1°F

Line 010005 -- Reactor power

POWER = 1023.0 62% x 1650 (Safety Analysis Assumption)

Lines 083001, 083011, 083021, 084001, 084011, 084021 (Junctions 300, 301, 302, 400, 401, 402) -- Steam generator risers

62% power steam flow = 584.99 lbm/sec (from Dynode 62% power case 2.105973x106 lb/hr / 3600 sec/hr)
Carryover = 4.4 (from WPD-PWEE 70-30 page 23 at 62%)
Riser flow = 4.4 x 584.99 = 2573.96

WP = 2573.96

Lines 083031, 083101, 083111, 084031, 084101, 084111 (Junctions 303, 310, 311, 403, 410, 411) -- Steam lines

WP = 584.99 See calculation above.

Lines 083131, 084131 (Junctions 313, 413) -- Steam generator carryover

WP = 1988.97 Carryover flow = 2573.96 - 584.99 = 1988.97

Line 060051 (Bubble Rise Volume 5) -- Pressurizer
ZMIX = 8.387 Tave = 564.962 Programmed level = (Tave - 516.539) x 0.006091 = .294944 Level in feet = (Level Fraction) * 22.46 ft + 1.763

Lines 130102, 130103, 130104, 130105, 130202, 130203, 130204, 130205 (Fill Tables 1, 2) -- Feedwater flow rate

FILTBL(2) = 793.4796290630 — Feedwater flow = 584.99 lbm/sec (same as steam flow). Area of junction = 1.3963 ft^2 See junctions 701, 702. Initial fractional area = 0.528 (0.88 for 100% power; 0.88 * 0.6 for 60% power) Initial flux = 584.99 / (.528 * 1.3963)

Lines 702404, 702408 (Control Inputs 404, 408) -- Normalized feedwater valve area

CIC = 0.528 — 0.88(100% fraction) * 0.6 (fraction of full power)

Lines 703409, 703410, 703419, 703420 (Control Blocks 409, 410, 419, 420) -- Feedwater flow area

CIC = 0.528 — 0.88(100% fraction) * 0.6 (fraction of full power)

Lines 053031, 054031 (Volumes 303, 403) -- Steam generator separators.

P = 881.92 — Iterated to get pressure in Volume 410 of 853.785 Psia (from Dynode)
HW = 595.1 — Iterated to get steam generator level = 44%

Lines 053111, 054111 (Volumes 311, 411) -- Steam lines downstream of MSIVs

P = 851.92 — Iterated to get ΔP between Volumes 403 and 411 of 30 Psi. Same ΔP as base case.

Line 702020 (Control Input 20) Normalized Turbine Load

GAIN = 1.0257×10^{-3} — 0.6 (initial load) / 584.99 (initial steam flow)
CIC = 0.6 — Initial load

Line 703020 (Control Block 20) -- T-Reference

CIC = 562.6 — 547(No-load T_{ave}) + 0.6 (Initial load) x (573 (Full-load T_{ave}) – 547) Note that the actual Tave is 565°F. This results in controllers trying to cool down to 562.6. This is of no consequence, though, because control rod control is disabled and steam dumps do not arm until after the reactor trip.

Line 702101 (Control Input 101) -- Power for control rod controller

GAIN = 0.62 Initial power is 62% of full power
CIC = 0.62 Initial power is 62% of full power

Line 047490 (Trip 749) -- Overpower reactor trip
SETPT = 1.903 Initial power is 62%, trip is at 1.18. Corrected trip is at 1.18/.62 since the setpoint is a fraction of initial power

Line 230000 -- Convergence Criteria

HEPSE = 1.0×10^{-8} This must be increased from 1×10^{-10} for intermediate power initialization. The value used here is still more restrictive than the default (5×10^{-6}).