XTEND© - A MICRO-SIMULATOR FOR USE AS A TRAINING AID IN TRIP PARAMETER ASSESSMENT

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ABSTRACT

The *XTEND*© package was developed in order to provide a user-friendly flexible training tool for the analysis of trip parameter effectiveness. The system is referred to as a micro-simulator, in that it allows the user to simulate accident situations on a micro-computer platform. A range of models allowing *XTEND*© to simulate a wide variety of accident scenarios is under development. The *XTEND*© modelling methodology is outlined, using the loss of reactivity control scenario (LORC) as an example, and sample results are provided. *XTEND*© is shown to be useful in trip analysis and sensitivity analysis. *XTEND*© has been utilized in a classroom training exercise at Darlington NGS, and this is detailed.

INTRODUCTION

A micro-simulator (*XTEND*© - Expert System for Training, Evaluation and Nuclear Development) is under development as a means of aiding the user's understanding of the assessment of trip parameter effectiveness following a postulated reactor accident. *XTEND*© is a menu-driven, user-friendly package which is designed to be visually oriented. The program incorporates station independent models, using plant specific input data to enable simulations to be performed for any CANDU reactor. The power of *XTEND*© lies in its ability to quickly help the user develop an intuitive concept of the manner in which postulated reactor accidents evolve, and the factors which influence the effectiveness of the relevant trip parameters. The highly visual presentation of specified plant parameters as the simulation is progressing enables the user to quickly gain an understanding of the order in which events occur, and the conditions which precipitate them. *XTEND*© is intended for use primarily by:

i) operations staff, to gain a better understanding of the effect that process parameters (*e.g.*, reactor inlet temperature) and trip-related parameters (*e.g.*, setpoints and time delays) have on trip parameter effectiveness, and

ii) analytical staff, as a scoping tool, to quickly see the overall trip assessment picture, prior to performing simulations with more detailed models.

To initiate an *XTEND©* session, the user selects the desired reactor for which the simulation will be performed from the "NGS" menu. All domestic CANDU stations are modelled. The user then selects the desired accident scenario (*e.g.*, LORC or loss of coolant accident (LOCA)) from the "SCENARIO" menu. Within an individual scenario, the user has full control over the initial conditions and the severity of the accident via easy-to-use dialogue windows. The user also has access to shutdown system (SDS) trip parameters, which can be either modified or reviewed. Once instructed to begin the simulation, *XTEND©* starts to calculate the evolution of plant variables as the accident situation progresses. Concurrently, the system displays the results of user-selected parameters graphically, and provides a chronology table that records the times at which important events take place. Prior to their placement in this summary table, the events are annunciated through the use of 'pop up' message windows. The simulation may be paused in mid-calculation, allowing the user to study the results obtained up to that point, or to change the parameters which are displayed graphically. Facility is provided to save the set of initial conditions for later retrieval, and to produce a printed copy of the screen display. A flowchart depicting *XTEND©* operation during a simulation is shown in Figure 1, and a representative initial conditions editor for an LORC event is shown in Figure 2.

INCORPORATION OF REACTOR MODELS

The structure of *XTEND©* is modular, facilitating the ease by which new models can be incorporated, and existing models may be updated. This ensures that flexibility is achieved in terms of both the range of situations that can be analyzed and the level of detail of the analysis. For example, the models that are physically based, although reasonably simple in nature, allow the system to generate data at, or faster than, real-time. Calculations with some of the simplifying assumptions removed can be invoked to meet the requirements of a more detailed simulation. At the core of the modelling routine is a mechanism to determine the times at which trip setpoints will be exceeded, or reactor regulating functions will be called upon.

XTEND© models are organized around the type of accident scenarios offered. The range of possible situations include:

- small break LOCA,
- large break LOCA,
- LORC,
- loss of power regulation (LOPR), and
- electrical failures.

Each of these categories is subdivided into subscenarios which further characterize the situation. For example, a small break LOCA can occur either inside or outside of the reactor core. The various *XTEND©* scenarios and subscenarios share common components where possible. For example, within the LORC and LOPR scenarios, the evolution of process parameters is driven by an imbalance in the power-to-coolant relative to that removed by the steam generators. The two scenarios develop the power excursion differently, but use a common set of routines to calculate the effect of the power transient on the heat transport system (HTS). Similarly, the in-core LOCA scenarios can be characterized by a combination of an effective reactivity insertion due to the dilution of soluble neutron poison in the moderator by the influx of coolant, and a mass loss in the HTS due to the break. (The in-core LOCA event is discussed in detail in Reference 1.) In this case, the point kinetics routine used in the LORC scenario and in reactor trip calculations is used to determine the resulting power transient. The set of LOCA scenarios share similar routines to calculate the effect of the mass loss on the HTS.

SDS TRIP CHECKING MECHANISM

XTEND© uses a model-independent mechanism to check for the occurrence of SDS trips. The program maintains a library of SDS data for each nuclear generating station (NGS). At each timestep within the main calculation loop, this mechanism is invoked, and if a trip has occurred since the last timestep, the simulation is paused to inform the user of the event. The trip is then recorded in the chronology table. This module is designed to be able to handle any CANDU SDS, and can be adapted to include reactor regulating system functions if necessary. Associated with each trip within the data structure used by the trip checking engine are the:

- nominal trip setpoint,
- instrumentation uncertainty,
- fixed delay,
- trip loop time constants, and
- conditioning signals.

The trip setpoint used in *XTEND©* (*i.e.*, the effective trip setpoint) is determined by adjusting the nominal trip setpoint in the conservative direction by an amount corresponding to the instrumentation uncertainty. For example, a heat transport high pressure (HTHP) trip with a nominal setpoint of 9410 kPa(a), and an instrumentation uncertainty of 210 kPa would have an effective setpoint of 9620 kPa(a), whereas a heat transport low pressure (HTLP) trip with a nominal setpoint of 6850 kPa(a), and an instrumentation uncertainty of 130 kPa would have an effective setpoint of 6720 kPa(a).

At each timestep in the simulation the calculated signal is compared with the effective setpoint. If the signal reaches the effective trip setpoint, then the fixed delay is added to the current time to give the time of trip, which is annunciated to the user, and subsequently entered into the chronology table.

XTEND© provides the user with the opportunity to modify the parameters associated with each trip using its SDS setpoint editors (Figure 3). Using these facilities, the user may change any of the aforementioned trip data used in the simulation. If the parameters are modified, then the changes can be saved to a data file for later use. In combination with the model initial conditions editor, the SDS editors can be used to examine the sensitivity, in terms of trip effectiveness, of changes in steady state conditions and SDS parameters.

The user is given the choice of either running the full simulation without crediting any reactor trips, or simulating shutdown when a certain number of trip signals have been received. Combinations of SDS1 and SDS2 trips may be set, or either system may be used independently. For example, the user may wish to credit a reactor trip after two trips have been recorded on SDS1 and two trips have been recorded on SDS2, *i.e.*, as in a licensing-type calculation. Alternatively, the user may wish to credit a reactor trip after on the first SDS1 signal, to determine the effectiveness of a specific trip parameter.

As *XTEND*© goes through the trip checking module at each timestep, it maintains a log of the number of trips recorded on each system. When the conditions for shutdown have been met, *XTEND*© annunciates to the user that the reactor has tripped, and records the time of this event in the chronology table. After initiating a reactor trip, *XTEND*© switches power calculation modes. It begins calculating negative reactivity insertion using a characteristic shutdown reactivity curve associated with each SDS at each station modelled. The calculated reactivity is fed to the point kinetics routines at each timestep after the initiation of shutdown. The power rundown then becomes the driving force for the evolution of other parameters in whatever scenario *XTEND*© is modelling.

CASE STUDY: LORC IN DARLINGTON / LORC IN PICKERING

Figure 4a shows the results of the simulation of a slow LORC in Darlington NGS, without credit taken for reactor trip. The retardation of the reactor outlet header pressurization that occurs at approximately 110 seconds, is the result of the opening of the liquid relief valves. This delays the HTHP trip to the extent that fuel centreline melting is predicted to occur first (although after the neutron overpower (NOP) trip), as shown in the reactor event chronology table, and thus the HTHP trip would not be considered to be effective for this event.

Figure 4b shows the results of the simulation of a slow LORC in Pickering NGS A, with reactor trip assumed to occur on the second trip signal. Fuel centreline melting is avoided entirely, and the NOP and heat transport high temperature trips are effective.

SENSITIVITY ANALYSIS

By using *XTEND*©'s Initial Conditions Editor (Figure 2), it is possible for the user to conduct a simple sensitivity analysis. For example, one may vary the value of a chosen input variable, such as inlet temperature or maximum channel power, to examine how deviations from nominal conditions in this parameter affect trip coverage. As the simulation is run under these conditions, the user will be able to quickly note various trends in the timing of the affected events (and, hence on the trip coverage) as a result of the perturbations in the selected parameter.

COMPARISON WITH SAFETY ANALYSIS RESULTS

Several LORC scenarios were parametrically analyzed using *XTEND©* for Pickering NGS A with initial reactor power set to 103 percent full power (FP), and with reactivity varied from 0.01 mk/s to 1 mk/s. The times of dryout and centreline melting, and the HTHP and NOP trips calculated by *XTEND©* are compared with the times reported in the Pickering NGS A Safety Report (Reference 2) in Figure 5. It can be seen that *XTEND©* gives reasonable predictions of these events over the range of ramps where Safety Report data is available.

CLASSROOM USE

At a recent seminar on design, operational and maintenance requirements of the shutdown system, offered to process engineers at Darlington NGS (Reference 3), *XTEND©* was used in two classroom exercises which dealt with trip parameter coverage and setpoint tolerances. The LORC scenario was used to illustrate, from a safety analysis point of view, how variations in accident conditions (in this case initial power and severity of the reactivity excursion) affect the performance of SDS trips. The HTHP and high log rate (HLR) trips were emphasized in the lesson. The participants were able to, in the span of approximately 30 minutes, determine the combinations of reactivity excursions and initial reactor power levels for which these trips would be considered to be effective. Once these results were established, the class varied the setpoints of the HTHP and HLR trips to examine how these changes affect the range of reactivity ramps over which the trips are effective. They were thus able to very quickly get an indication of the trip tolerances, and more importantly the factors which influence the tolerance. The exercise clearly demonstrated the ease with which new users can begin using *XTEND©*, and the speed with which a large number of simulations can be processed.

SUMMARY

XTEND© provides real-time simulation capability coupled with a user-friendly, active interface, which allows easy variation of model-specific input parameters, as well as SDS information. This allows a student in a training session to readily explore a large variety of situations in short order. At the same time, the use of the chronology table allows the user to develop a good sense of how variations in initial conditions alter the sequence of events. *XTEND©* has been shown to be extremely versatile in training applications including sensitivity analysis and trip setpoint tolerance analysis. The package has been designed in modular fashion, allowing for easy updates and additions to the library of stations, and the suite of accident scenarios.

REFERENCES

1. A.F. Oliva and L.J. Watt, "Assessment of Shutdown System Trip Parameter Effectiveness of CANDU Reactors Following In-Core Loss of Coolant Accidents", paper presented at 13th Annual Conference of the Canadian Society, St. John, New Brunswick, June 7-10, 1992.

2. Pickering NGS A Safety Report, Section 13.3.3, "Control Failures", Ontario Hydro, Design and Construction Division, April 1988.

3. Nuclear Safety Department Staff, "Darlington NGS Shutdown System Design, Operational and Maintenance Requirements", A seminar presented to the staff of the Darlington Technical Unit, May 25-28, 1992.

Figure 1
Flowchart of XTEND Operation During Accident Simulation

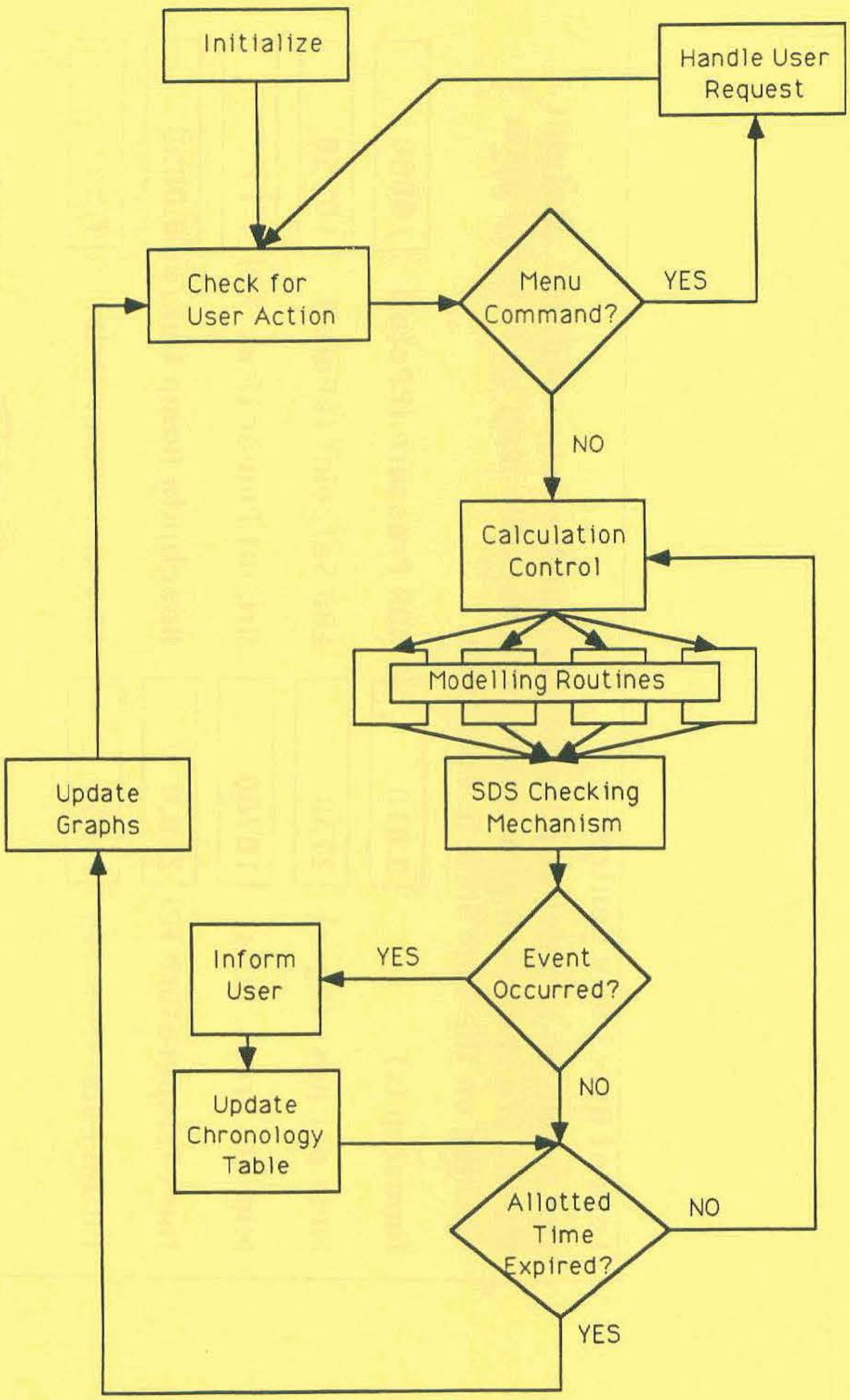
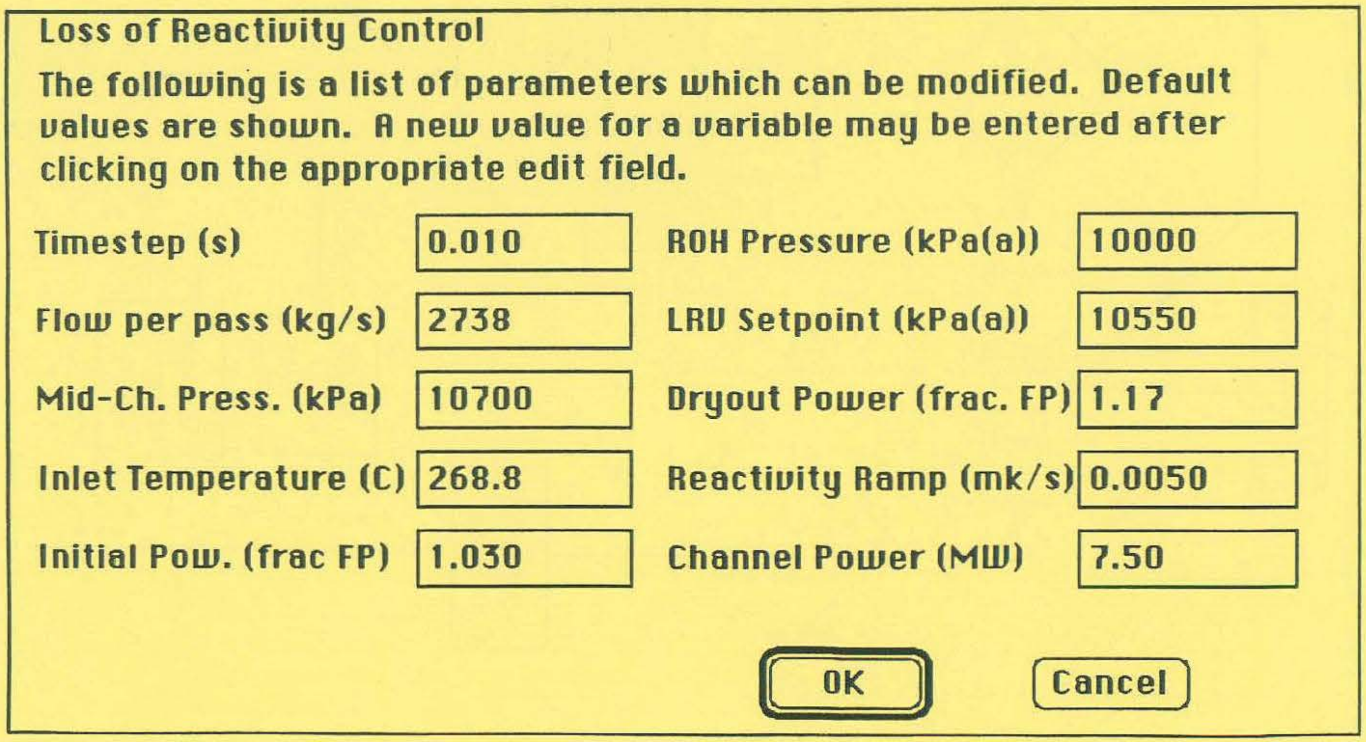


Figure 2
The XTEND Loss of Reactivity Control Initial Conditions Editor, with Darlington NGS default values shown.



Loss of Reactivity Control

The following is a list of parameters which can be modified. Default values are shown. A new value for a variable may be entered after clicking on the appropriate edit field.

Timestep (s)	0.010	ROH Pressure (kPa(a))	10000
Flow per pass (kg/s)	2738	LRV Setpoint (kPa(a))	10550
Mid-Ch. Press. (kPa)	10700	Dryout Power (frac. FP)	1.17
Inlet Temperature (C)	268.8	Reactivity Ramp (mk/s)	0.0050
Initial Pow. (frac FP)	1.030	Channel Power (MW)	7.50

OK Cancel

Figure 3
The XTEND Shutdown Systems Editor, displaying information for
Darlington NGS.

SDS1 Trip Setpoint Editor (Page One)

Parameter	Conditioning	Nom. Setpoint	Error	T. Const. (s)	Fixed Delay (s)
NOP (frac. FP)*		127.0	1.114	0.05	0.0
HLR (%/s)		10.00	0.21	0.500	0.0
HTHP(kPa(a)		10700	70	0.0	0.3
HTLP (kPa(a)	P >= 70% FP	8600	70	0.0	0.21
	P < 70% FP	7000	70	0.0	0.21
MHL (m)		9.340	0.006	0.0	0.0
MLL (m)		8.350	0.006	0.0	8.0
HTLF (kg/s)	P > 70% FP	20.50	0.64	0.0	0.3
	P <= 70% FP	13.00	0.41	0.0	0.3

* Error column refers to CPPF

OK   Cancel   Page Two

Figure 4a
Example of the XTEND Screen Display After Completion of a Loss of Reactivity Control Scenario for Darlington NGS.

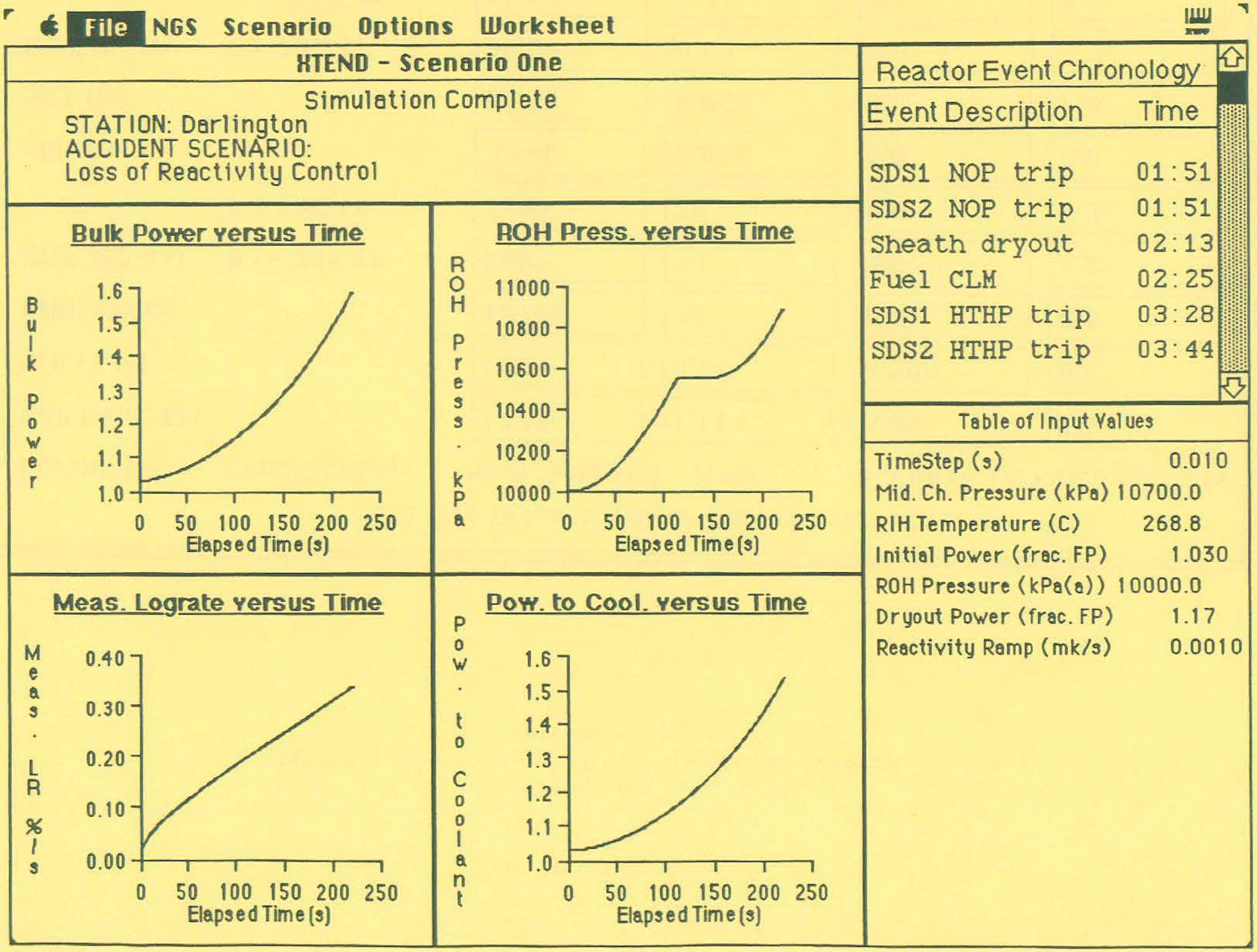


Figure 4b
Example of the XTEND Screen Display During a Loss of Reactivity Control Scenario for Pickering NGS A, with Shutdown Initiated after a Trip on HTHT.

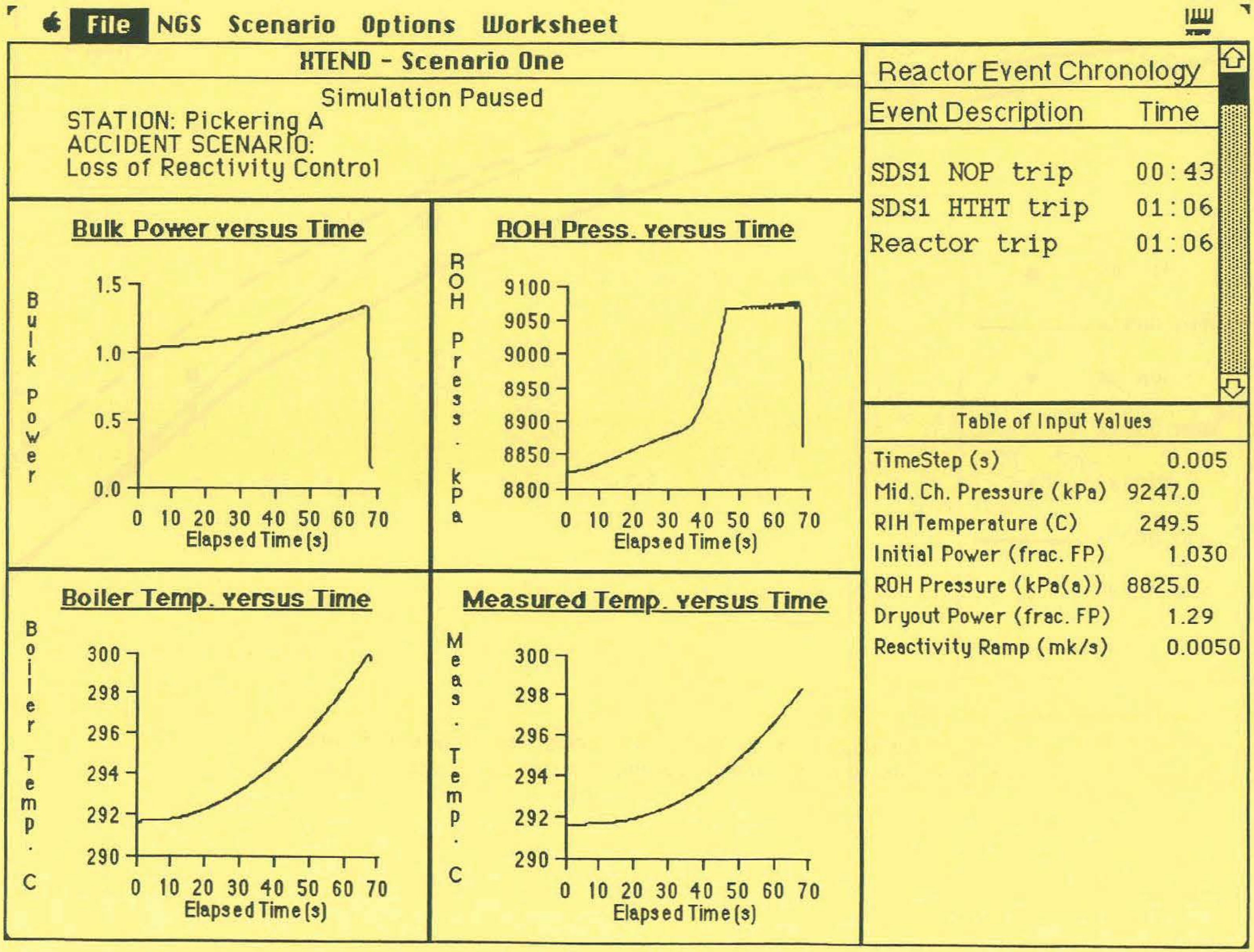


Figure 5
Comparison of XTEND and Safety Report Event Timing For Loss of Reactivity Control Scenarios From 103% FP (PNGSA)