DYNAMIC BENCHMARKING OF SIMULATION CODES

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ABSTRACT

Computer simulation of nuclear power plant response can be a full-scope control room simulator, an engineering simulator to represent the general behavior of the plant under normal and abnormal conditions, or the modeling of the plant response to conditions that would eventually lead to core damage. In any of these, the underlying foundation for their use in analyzing situations, training of vendor/utility personnel, etc. is how well they represent what has been known from industrial experience, large integral experiments and separate effects tests. Typically, simulation codes are benchmarked with some of these; the level of agreement necessary being dependent upon the ultimate use of the simulation tool. However, these analytical models are computer codes, and as a result, the capabilities are continually enhanced, errors are corrected, new situations are imposed on the code that are outside of the original design basis, etc. Consequently, there is a continual need to assure that the benchmarks with important transients are preserved as the computer code evolves. Retention of this benchmarking capability is essential to develop trust in the computer code.

Given the evolving world of computer codes, how is this retention of benchmarking capabilities accomplished? For the MAAP4 codes this capability is accomplished through a "dynamic benchmarking" feature embedded in the source code. In particular, a set of dynamic benchmarks are included in the source code and these are exercised every time the archive codes are upgraded and distributed to the MAAP users. Three different types of dynamic benchmarks are used:

- plant transients,
- large integral experiments, and
- separate effects tests.

Each of these is performed in a different manner. The first is accomplished by developing a parameter file for the plant modeled and an input deck to describe the sequence; i.e. the entire MAAP4 code is exercised. The pertinent plant data is included in the source code and the computer output includes a plot of the MAAP calculation and the plant data.

For the large integral experiments, a major part, but not all of the MAAP code is needed. These use an experiment specific benchmark routine that includes all of the information and boundary conditions for performing the calculation, as well as the information of which parts of MAAP are unnecessary and can be "bypassed".

Lastly, the separate effects tests only require a few MAAP routines. These are exercised through their own specific benchmark routine that includes the experiment specific information and boundary conditions. This benchmark routine calls the appropriate MAAP routines from the source code, performs the calculations, including integration where necessary and provide the comparison between the MAAP calculation and the experimental observations.

I. INTRODUCTION

Integral reactor safety computer codes include representations of numerous phenomena, each of which should be benchmarked with available experiments and plant experience. Previously, this has generally been performed at various stages in the code or module development, but not necessarily repeated for new versions/revisions. This means that the benchmark fidelity is potentially eroded as additional capabilities are added, errors corrected, etc. Therefore, it is increasingly important that the benchmarking for complex analytical tools be integrated into the code so the benchmarks are continually updated. Through this process, developers and users can continually examine the benchmarks to assure code capabilities are maintained. In particular, each officially released, archived version should be tested against the experimental database formed by major experiments and industrial experience. For these exercises to be repeated on a regular basis, it is necessary to integrate the information, including the experimental observations, directly into the integral code software. MAAP4 accomplishes this by creating three types of benchmarks (plant experience, integral experiments and separate effects tests) supported by the necessary documentation in the User's Manual with experimental specific benchmark routines integrated directly into the code.

II. THE MAAP4 APPROACH TO DYNAMIC BENCHMARKING

In MAAP4, the dynamic benchmarking capability is integrated into the source code. This includes the three types mentioned above with the plant experience exercises using the entire code and the other two being controlled through the executive subroutine BENCH. These are accomplished as follows:

- Plant Experience: A plant parameter file (plant geometry), is used with an input deck to represent operator actions and specific plant responses (such as scram) when the particular timing is known. With this, MAAP4 is exercised for the particular sequence and compared with the plant data. This "sequence definition" (input deck) and the transient plant data becomes part of the MAAP4 software and is incorporated into the test matrix to be examined for all versions/revisions.

- Integral Experiments Benchmarking: Tests like CORA and HDR exercise a significant part, but not all, of the MAAP code. The executive subroutine BENCH organizes the benchmarking activities and calls subroutine BENCH1 which contains the pertinent CORA and HDR experimental information. Figure 1 illustrates this organization of the benchmark specific routines. For example, the HDR benchmarks include a parameter file for the containment, the test injection history and the transient data for comparison with MAAP. Furthermore, some aspects of MAAP are not required, i.e. primary system (HDR). In this case, the unnecessary MAAP routines are bypassed and the remainder are used. Through this organization, those routines used for plant evaluations are tested directly as opposed to using a similar stand alone code that may not be current with the complete code. This benchmark is also included in the testing matrix.

- Separate Effects Tests: These exercises involve only limited parts of MAAP. Subroutine BENCH calls benchmark specific routines which in turn call the appropriate MAAP routines (Fig. 1). Here again the MAAP routines are tested directly, but the testing is more limited than the entire MAAP code. These benchmarking activities are also included in the source code.

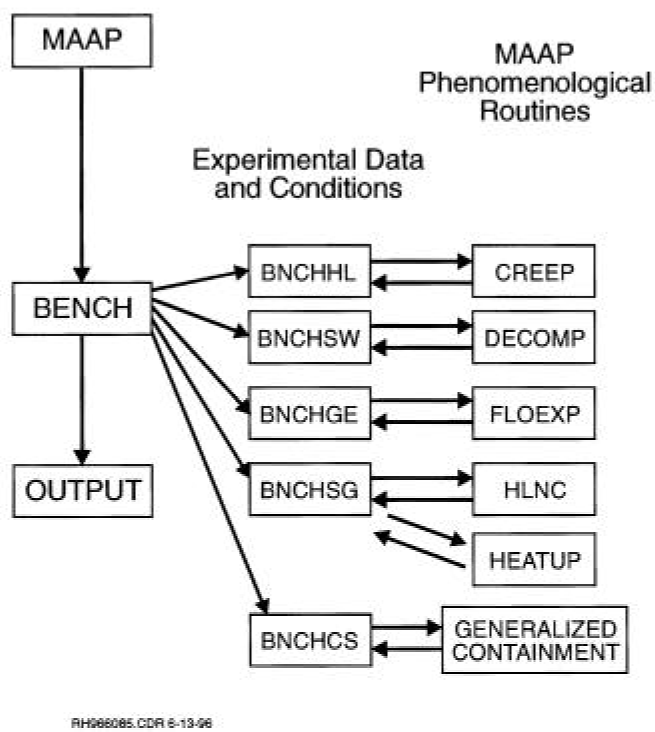

Figure 1, Strategy for incorporating separate effects tests in the MAAP4 code.

Such dynamic benchmarks should be performed using the uncertainty boundaries for the various model parameters. Typically, large integral computer codes that characterize the plant and containment response contain numerous individual models, some are influential and some are of minor importance. However, each model parameter should have a characterization of "optimistic" and "pessimistic" values for the individual parameters and these benchmarking exercises can be used to help determine these values. Furthermore, a technical basis should be developed and documented for these boundaries, i.e. what experiments or experiences have been used (benchmarked) to develop these boundaries. Of course, such evaluations should be current with the available experimental observations. "Optimistic" parameters represent uncertainty bounds for physical processes that would (a) slow the accident progression, (b) increase the rate of recovery of the damaged core and/or decrease the consequence of an accident. "Pessimistic" boundaries are those that would (a) increase the rate of the accident progression, (b) slow the recovery rate of a damaged core and/or increase the consequences of an accident. It is realized that some processes may be difficult to characterize in this light, thus some may need to be evaluated two different ways. However, these are typically processes not dominant in the accident progression.

III. RESULTS FOR THE PLANT TRANSIENT BENCHMARKS

Table 1 lists the plant transients currently used as MAAP4 dynamic benchmarks. These include PWR and BWR designs as well as short transients, such as the Peach Bottom turbine trip tests and others which evolve over an extended interval, e.g. the Brown's Ferry fire and the TMI-2 core damage accident. Since the TMI-2 benchmark has been recently published (Paik et al., 1995), we will focus on others to illustrate the MAAP4 approach.

Table 1 Plant Experience Benchmarks
• TMI-2 accident (PWR).
• Oyster Creek loss-of-feedwater (BWR).
• Crystal River loss-of-feedwater and stuck open PORV (PWR).
• Peach Bottom turbine trip tests (BWR).
• Tokai-2 turbine trip (BWR).
• Davis-Besse loss-of-feedwater (PWR).
• Brown's Ferry fire (BWR).

The Oyster Creek loss-of-feedwater event is an interesting example since this transient invokes the use of the two isolation condensers in this design. Hence, this provides a means of assessing both the RCS and the isolation condenser models in MAAP4. In this transient, feedwater was lost to the RPV and the operators initiated RPV heat removal using the A and B isolation condensers. The MAAP4 benchmark is performed using an Oyster Creek parameter file and the input deck (describing the operator actions) given in Table 2. Actions such as activating the isolation condenser are straightforward in MAAP. Figure 2 shows the RPV pressure (2a) and water level (2b) during this transient and that the actions were effective, as well as the MAAP4 results corresponding with the measured response. This agreement is seen for those conditions in which the isolation condensers are not active, when a single unit is activated and when both A and B units are in service. As discussed previously, such benchmark analyses are performed with the "optimistic" and "pessimistic" bounds of the uncertainty parameters used for the physical models in MAAP, but these typically characterize the behavior after the core is uncovered. Since there is little difference between the two boundaries for these analyses, only best estimate values were used.

Table 2
Oyster Creek Loss-of-Feedwater Event

```
START TIME IS 0. SEC

END TIME IS 1910. SEC

INITIATORS
  REACTOR MAN SCRAMMED
END

IF TIM > 2.
  TURBINE STOP VALVE CLOSED
END

IF TIM > 13.
  FEEDWATER MAN OFF
  AJET = 0.05*AJET
END

IF TIME > 43.
  MSIVS LOCKED CLOSED
END

IF TIM > 76.                  ! ISOLATION CONDENSER B STARTED
  AGO(3) = 0.041
END

IF TIM > 250.                 ! B ISOLATION CONDENSER TURNED OFF
  AGO(3) = 0.0
END

IF TIM > 450.                 ! BOTH ISOLATION CONDENSERS TURNED ON
  AGO(3) = 0.041
  AGO(2) = 0.041
END

IF TIM > 528.                 ! B ISOLATION CONDENSER TURNED OFF
  AGO(3) = 0.0
END

IF TIM > 1212.                ! A ISOLATION CONDENSER TURNED OFF
  AGO(2) = 0.0
END

IF T IM > 1512.               ! ISOLATION CONDENSERS STARTED
  AGO(3) = 0.041
  AGO(2) = 0.041
END

IF TIM > 1620.                ! ISOLATION CONDENSERS TURNED OFF
```

Table 2
Oyster Creek Loss-of-Feedwater Event

```
  AGO(3) = 0.0
  AGO(2) = 0.0
END

IF TIM > 1746.                 ! ISOLATION CONDENSERS STARTED
  AGO(3) = 0.041
  AGO(2) = 0.041
END
```

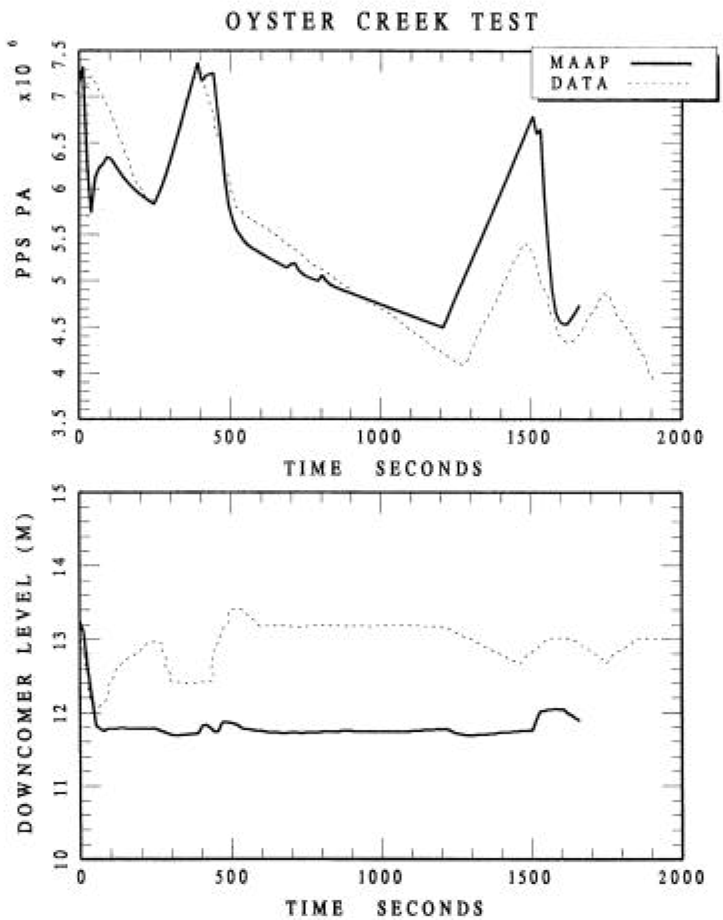

Figure 2, Transient pressure and downcomer water level for the Oyster Creek loss-of-feedwater event.

The Crystal River transient resulted from an instrument and control system electrical malfunction (Brown et al., 1981) causing the Integrated Control System (ICS) to stop feedwater to the steam generators. Eventually the reactor core was cooled by using high pressure injection, but the pressurizer Power Operator Relief Valve (PORV) opened prematurely and remained open. To assure that the core was adequately cooled, the operators continued to inject water to the RCS. The core was cooled down and stabilized as a result of this injection.

The Crystal River dynamic benchmark is performed using a modified (to represent Crystal River specific values) TMI parameter file with the operator actions characterized for the MAAP input deck as shown in Table 3. As with the Oyster Creek input deck, the representations needed for the operator actions are straightforward and easily characterized by the MAAP4 input. Both the parameter changes to the TMI parameter file and the operator action characterizations are a permanent part of the MAAP4 source code. Figure 3a compares the MAAP4.0.2 calculated RCS pressure with the plant data, the depressurization resulting from the LOCA and injection and the subsequent repressurization because the pressurizer was filled with water. Figure 3b compares the measured hot leg temperature with the MAAP calculation for several of the temperatures including the core average temperature (TWCR) and the water temperature entering steam generators (TSGBHP). As shown, there is general agreement between the pressure and temperature responses for this dynamic transient.

Table 3
Crystal River Unit 3 Incident

```
START TIME IS 0. SEC
END TIME IS 800. SEC
PRINT INTERVAL IS 20.SEC

INITIATORS
END

IF TIM GE 10.
  UNBKN LOOP TURBINE DRIVEN AFW:  NOT MAN ON
  BKN LOOP TURBINE DRIVEN AFW:  NOT MAN ON
  MOTOR-DRIVEN AUX FEED WATER FORCED OFF
  PZR HTRS FORCED OFF
  ISTUCK(1)=1
  HPI FORCED OFF
  LPI FORCED OFF
END

IF TIM GE 15.
  WFWMX = 1.D0
END

IF TIM GE 34.
  KEEP MAIN FEED ON AT SCRAM
  MANUAL SCRAM
  S/G MSIV:  FORCED CLOSED
END

IF TIM GE 220.
  UNBKN S/G PORV OPENED MANUALLY
  HPI SWITCH NO FORCED OFF
  HPI SWITCH:  MAN ON
  MCP SWITCH OFF OR HI-VIBR TRIP
  WFWMX = 6.7D5              !NSAC/15
  TFW = 400.                 !NSAC/15
```

Table 3 **Crystal River Unit 3 Incident**
ZWCTLU = 0.01 ZWCTLB = 30. END IF TIM GE 450. ISTUCK(1)=0 END IF TIM GE 510. UNBKN S/G PORV AUTOMATIC OPEN/CLOSE MAIN FEED OFF AT SCRAM UNBKN LOOP TURBINE DRIVEN AFW: MAN ON BKN LOOP TURBINE DRIVEN AFW: MAN ON MOTOR-DRIVEN AUX FEED WATER SWITCH: AUTO WFWMX = 0. END

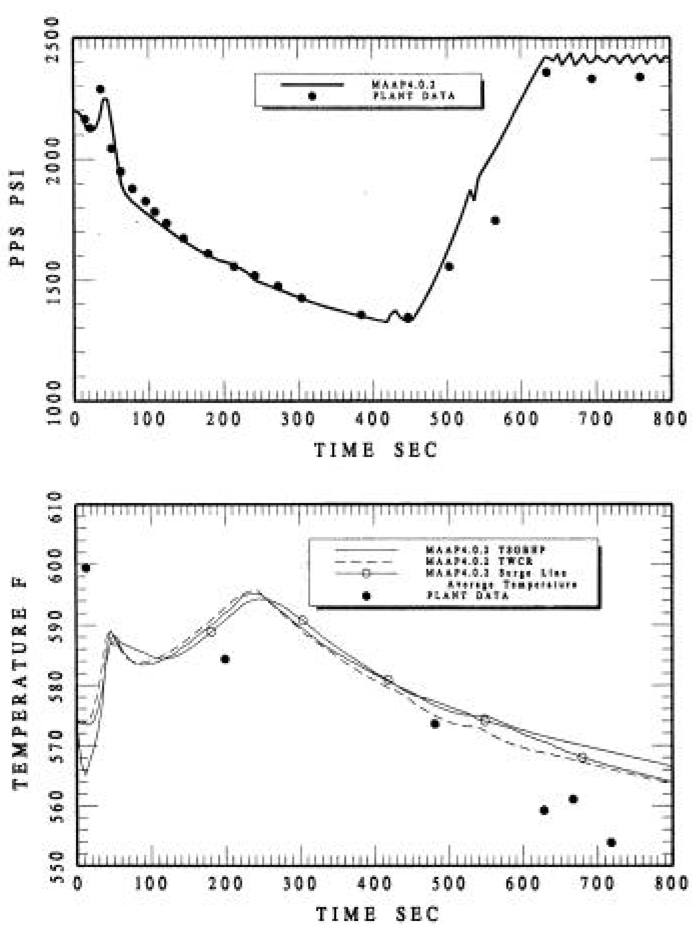

Figure 3, RCS pressure and hot leg temperature response for the Crystal River loss-of-feedwater event.

Another plant benchmark is the Davis-Besse loss-of-feedwater event (NRC, 1985). In response to this event, the control room operators used a startup feedwater pump to restore secondary side cooling. For the MAAP4 benchmark, the TMI-2 parameter file is modified to represent the pertinent differences for the Davis-Besse design. Table 4 lists the operator actions detailed in the report describing the event. As with the TMI-2 benchmark, the steam generator levels and pressure are input as boundary conditions. The subsequent RCS response is determined by the MAAP4 models. Given this approach, the resulting RCS pressure, temperature and pressurizer level are illustrated in Fig. 4. As with the previous benchmark activities, this illustrates that the MAAP code represents the general behavior of the reactor coolant system and is in agreement with the measured values. Like the other dynamic benchmarks, the modifications to the TMI parameter file and the list of pertinent operator actions in Table 3 becomes a permanent part of the MAAP4 archived code such that this comparison can be repeated with subsequent code versions.

Table 4
Davis-Besse Loss-of-Feedwater Event

```
INITIATORS
  DONT SCRAM WHEN CHARGING PUMP ON
  PS MAKEUP ON
END

IF TIM GE 1.5 S                     !1:35:01
  QCR0 = 8.42E09                    !POWER RUNBACK INITIATED
END                                 !AVG POWER BETWEEN 1 AND 3 SECS

IF TIM GE 3. S                      !AVG POWER BETWEEN 3 AND 5 SECS
  QCR0 = 8.3E09
END

IF TIM GE 5. S                      !AVG POWER BETWEEN 5 AND 10 SECS
  QCR0 = 8.05E09
  WFWMX = 2.83E06
END

IF TIM GE 10. S                     !AVG POWER BETWEEN 10 AND 15 SECS
  QCR0 = 7.69E09
END

IF TIM GE 15. S                     !AVG POWER BETWEEN 15 AND 21 SECS
  QCR0 = 7.304E09
END

IF TIM GE 21. S                     !AVG POWER BETWEEN 21 AND 30 SECS
  QCR0 = 6.77E09
  PZR SPRAYS AUTOMATIC ON/OFF
  PZR SPR MAN ON
END

IF TIM GE 30. S                     !1:35:30
```

Table 4
Davis-Besse Loss-of-Feedwater Event

```
  KEEP MAIN FEED ON AT SCRAM
  CHARGING PUMP SWITCH:  MAN ON
  MANUAL SCRAM
  LETDOWN SWITCH OFF
  PS MAKEUP ON
  ZWPZMU = 21. FT
  ZDEADB = 0.1
  ZDEADU = 0.1
  ZWCTLB = 3.0 FT
  ZWCTLU = 2.5 FT
END

IF TIM GE 35. S
  S/G MSIV:  FORCED CLOSED
END

IF TIM GE 45. S                    !1:35:45
  PZR SPR AUTO
  PZR SPRAYS FORCES OFF
  TFW = 400. F
END

IF TIM GE 150. S
  TFW = 300. F
END

IF TIM GE 300. S                   !1:41:08 FEEDWATER LOST
  ZWCTLB = 1.5 FT
  ZWCTLU = 1.5 FT
  TFW = 200. F
END

IF TIM GE 420. S                   !1:42:00
  ZWCTLB = 0.0 FT
  ZWCTLU = 0.0 FT
  PZR SPRAYS AUTOMATIC ON/OFF
  PZR SPR MAN ON
  TFW = 90. F
END

IF TIM GE 590. S                   !1:44:50
  CHARGING PUMPS FORCE OFF
END

IF ZWPZ GT 21. FT
  CHARGING PUMP SWITCH:  AUTO
END

IF ZWPZ GE 28. FT
```

Table 4
Davis-Besse Loss-of-Feedwater Event

```
  WWLET0 = 1.66E05
  LETDOWN SWITCH ON
END

IF TIM GE 689. S                              !1:46:29
  S/G PORV OPENED MANUALLY                    ! "SG BROKEN"
  UNBKN S/G PORV OPENED MANUALLY
  FARVUX = 0.0
  FARVBX = 0.0
END

IF TIM GE 788. S                    !1:38:08
  FARVUX = 0.2
  FARVBX = 0.0
END

IF TIM GE 840. S
  FARVUX = 0.03
END

IF TIM GE 913. S
  FARVBX = 0.3
END

IF TIM GE 978. S                    !1:51:18
  NPZRV = 1                         !S/G PORV OPENED MANUALLY
  NIPORV(1) = 1
  ISTUCK(1) = 1                     !PRESSURIZER PORV STUCK OPEN
END

IF TIM GE 1002. S                   !1:51:42
  APORV = .95 * 7.1025E-4           !95%
END

IF TIM GE 1003. S                   !1:52:42
  PZR SPRAYS FORCED OFF             !90%
  APORV = .9 * 7.1025E-4
END

IF TIM GE 1006. S                   !1:51:46
  APORV = 0.50 * 7.1025E-4          !50%
END

IF TIM GE 1009. S                   !1:51:49
  APORV = .2 * 7.1025E-4            !20%
  FARVBX = 0.0
END

IF TIM GE 1011. S                   !1:51:51
```

Table 4
Davis-Besse Loss-of-Feedwater Event

```
  ISTUCK(1) = 0
  APORV = 7.1025E-4                   !100%
END

IF TIM GE 1102. S
  MOTOR-DRIVEN AUX FEED WATER SWITCH:  AUTO
  ZWCTLU = 0.5
END

IF TIM GE 1130. S                              !1:53:50 STARTUP FEED TO #1
!                                              (BROKEN SG)
  KEEP MAIN FEED ON AT SCRAM
  MAIN FW SW:  AUTO
  WFWMX = 7.51E4              !STARTUP FEED PUMP FLOW RATE (LB/HR)
  ZWCTLB = 1.0                !B LOOP S/G LEVEL SET TO ISOLATE IT FROM FLOW (FT)
  ZWCTLU = 0.01               !A LOOP S/G LEVEL RISES DUE TO STARTUP FLOW (FT)
END

IF TIM GE 1140. S
  FARVUX = 0.0
END

IF TIM GE 1160. S
  LETDOWN SWITCH OFF
  MAIN FW SHUT OFF
  MAIN FEED OFF AT SCRAM
  MOTOR-DRIVEN AUX FEED WATER SWITCH:  AUTO
  ZWCTLB = 0.                         !B LOOP S/G LEVEL RISES DUE TO
!                                      AFW #2 FLOW
  ZWCTLU = 0.5                        !A LOOP S/G LEVEL RISES DUE TO
!                                      AFW #1 FLOW
END

IF TIM GE 1186. S                     !1:54:46
  ZWCTLB = 0.5
  ZWCTLU = 1.0
END

IF TIM GE 1220. S                     !1:55:20
  ZWCTLB = 3.0
  ZWCTLU = 2.0
END

IF TIM GE 1250. S                     !1:55:50
  FARVBX = 0.0
  FARVUX = 0.0
END

IF TIM GE 1318. S                     !1:56:58
```

Table 4
Davis-Besse Loss-of-Feedwater Event

```
  FARVBX = 0.4              !LOOP B S/G ATM VENT OPEN
  FARVUX = 0.4              !LOOP A S/G ATM VENT OPEN
  ZWPZMU = 21.33            !RESTOR MAKEUP INJ. CONTROL ON PZR LEVEL
END

IF TIM GE 1350. S
  ZWCTLB = 5.
END

IF TIM GE 1380.S            !1:58:00
  NHPIG = 1                 !ONLY 1 OF 2 HPI PUMPS IN 'PIGGYBACK'
  ZHDHPI(1) = 4257.7        !HEAD FOR 'PIGGYBACK' HPI (FT. OF WATER)
  ZHDHPI(2) = 3856.0        !NEXT ENTRY
  ZHDHPI(3) = 2967.8        !NEXT ENTRY
  ZHDHPI(4) = 461.5         !LOWEST HEAD FOR 'PIGGYBACK' HPI
  ZWCTLB = 5.0
  ZWCTLU = 6.0
END

IF TIM GE 1408. S           !1:58:28
  FARVBX = 0.0
END

IF TIM GE 1500. S
  FARVUX = 0.0
  FARVBX = 0.0
END

IF TIM GE 1500. S
  ZWCTLU = 8.0
  ZWCTLB = 4.0
END
```

IV. INTEGRAL EXPERIMENT BENCHMARKS

Several large scale experiments (Table 5) which have been performed illustrate the integral response of certain aspects of the reactor/containment behavior during different plant transients. An excellent example of a large integral experiment are the large scale containment tests in the HDR facility (Wolf and Valencia, 1989; Valencia and Wolf, 1990). Different types of loss of coolant accidents were investigated, some having the steam discharge (blowdown) into the lower regions of the containment while others were configured with the discharge into the upper regions. As a result, this set of experiments provides benchmarks for integral computer codes with regard to significant containment phenomena such as stratification in the upper regions. For one experiment (E11.2), hydrogen and helium were injected to represent the conditions that could be experienced if the core were sufficiently overheated that the Zircaloy cladding was oxidized.

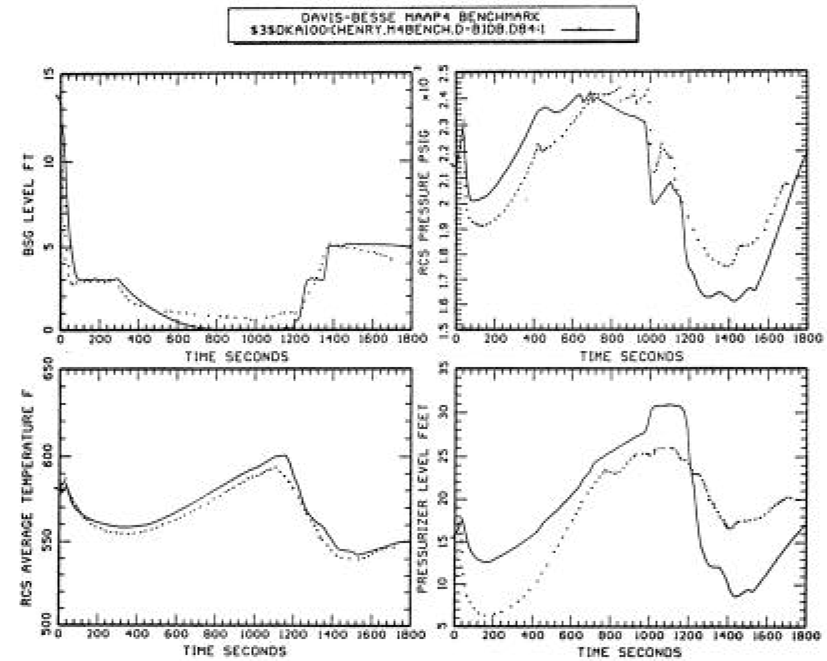

Figure 4, Davis-Besse loss-of-feedwater event (June 1985).

Table 5 **Integral Test Benchmarks**
• HDR Tests
• CSTF Tests
• EPRI/Westinghouse Steam Generator Tests

To perform this benchmark, a parameter file was developed to describe the HDR containment compartmentalization (Fig. 5), the flow junctions between the rooms, the heat sinks in each room, etc. Parameter file information also included the steel dome, that was externally cooled (late in time) during the E11.2 experiment, and the concrete liner on the inside of the steel shell for the lower containment elevations. This low conductivity liner effectively insulates against energy transfer through the steel wall in the lower regions. Figure 6 illustrates the comparison of the MAAP calculation for the one day E11.2 transient, including the duration of the steam injection period (approximately 45,000 seconds), H_2/H_e injection for 30 minutes, steam injection period into lower elevation from 47,000 to about 57,000 seconds, and the response when the external spray was initiated. As illustrated, there is some difference between the actual pressure and that calculated by the MAAP4 code, yet the general transient behavior is well represented by the MAAP model. Figure 7a illustrates the measurements of hydrogen and helium in the containment upper dome, and 7b shows these measurements for the dead-end rooms approximately mid-height of the containment. MAAP calculates hydrogen stratification in the containment dome and also closely represents the concentration in other compartments. Moreover, it calculates the rapid increase and subsequent turnover (decrease) of hydrogen concentration in the upper dome when this region is cooled by the external spray. Consequently, this representation of the containment behavior, particularly that associated with the potential for stratification, is well represented by the MAAP4 code. To assure that this important modeling capability is maintained through subsequent versions, this containment nodalization and the injection histories associated with the various HDR tests are integrated into the MAAP dynamic benchmarking (source code). Therefore, this can be conveniently tested for future code versions. A similar strategy (input and experimental data files) is used for the ice condenser experiments at the CSTF facility and the EPRI/Westinghouse natural circulation experiments characterizing the core-to-upper plenum and steam generator flows.

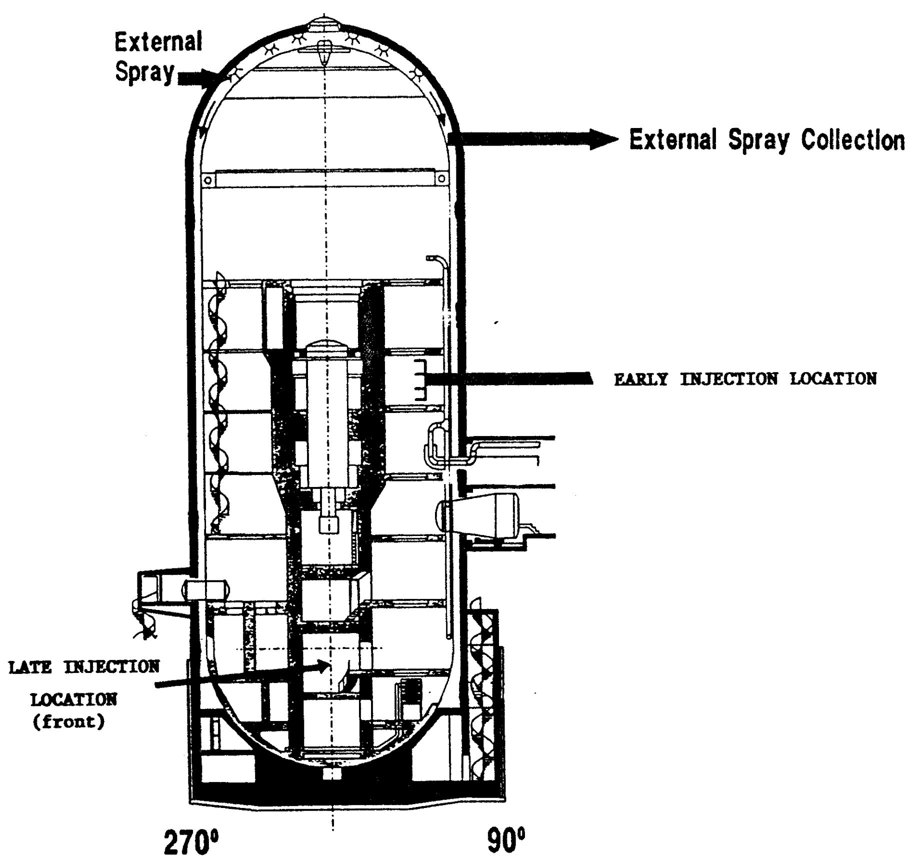

Figure 5, HDR facility with source locations for E11.2.

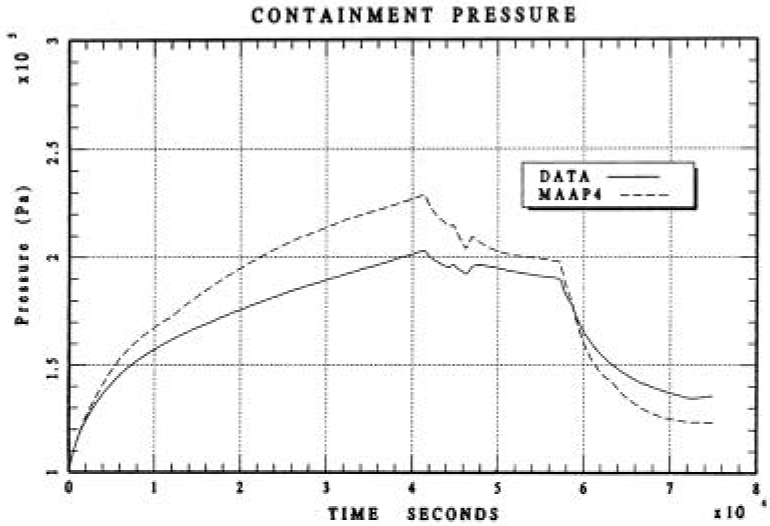

Figure 6, E11.2 containment pressure.

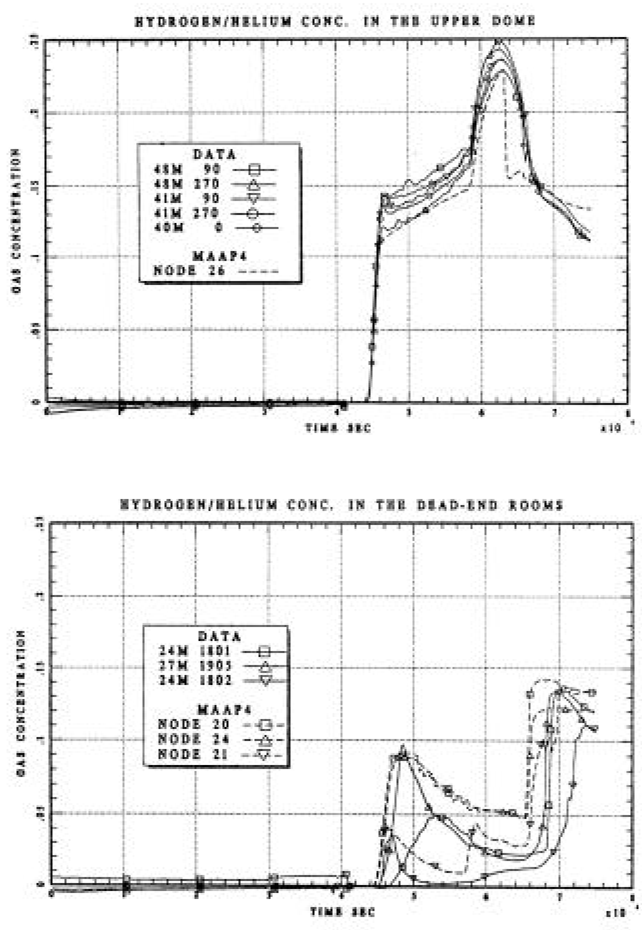

Figure 7, E11.2 hydrogen/helium concentrations in the upper dome (a) and dead-end rooms (b).

V. SMALL SCALE SEPARATE EFFECTS BENCHMARKS

With the extensive list of phenomena represented in the integral code, there are numerous separate effects tests that can be used to benchmark individual models. Since these models typically only use a small number of MAAP routines, it is much more convenient to create benchmark specific routines for each separate effects test. As illustrated in Fig. 1, benchmark specific routines such a BENCHHL contains all the information for the hot leg creep rupture experiments performed by Maile et al. (1990), and also carries out the benchmark calculation, including the integration of time dependent behavior while calling the MAAP specific routines, i.e. subroutine CREEP for this specific benchmark. As part of the experimental program, separate effects tests were performed to characterize the creep properties of the hot leg material. Figure 8 compares these properties with the TMI-2 vessel steel creep properties reported by Wolf et al. (1993). It is seen that the properties are almost identical. In this experiment, the hot leg was heated externally and had a significant temperature difference through the wall with the outside surface being the hottest. The time dependent inside and outside temperatures, as well as the internal pressure, are input as boundary conditions for the MAAP calculation. Furthermore, the experimental test apparatus was suspended freely in space, i.e. there were no axial supports. Hence, the total stress was a combination of hoop and longitudinal loadings. Therefore, the MAAP calculations are performed in two ways, the first uses only a hoop stress loading for the steel wall, while the second utilizes the vector addition of hoop and longitudinal stresses, which increases the total stress by 10%. Table 6 shows the results of these two approaches with the MAAP4 calculated failure times bracketing the experimental observation of about 1100 seconds. Thus, the MAAP4 model for evaluating material creep is consistent with the significant scale experiments performed using reactor grade steel. To assure that this calculational behavior is retained in the MAAP structure, this information is integrated into the MAAP software.

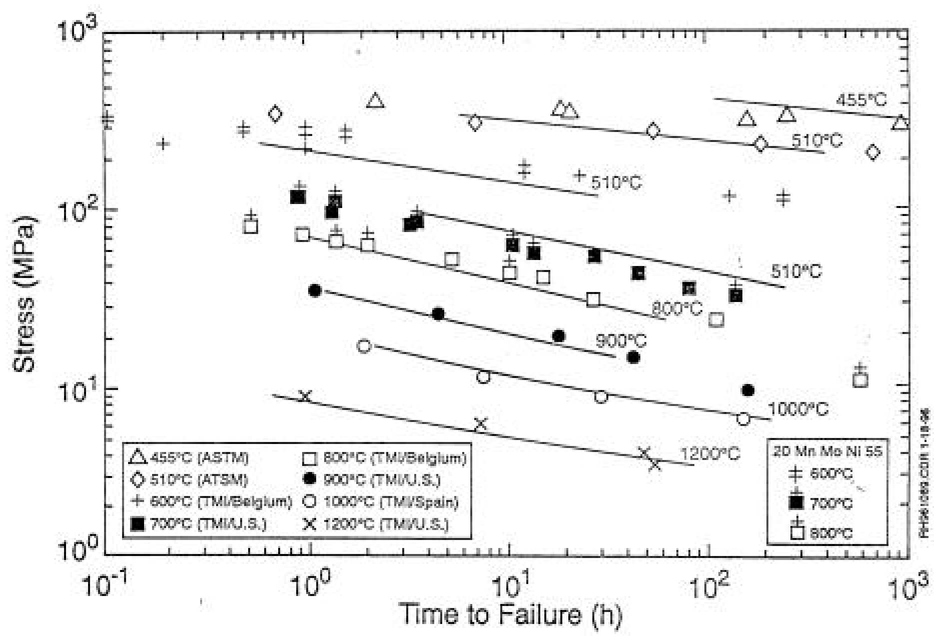

Figure 8, Comparison of TMI-2 vessel steel and 20 MnMoNi 55 for the material creep properties.

Table 6 Comparison of the MAAP4 Model for Creep Rupture With the Full Scale Experiment	
Approach I •	Use the measured internal pressure.
•	Use hoop stress only.
•	Use measured material properties at 700°C.
•	Use measured transient surface temperatures.
•	MAAP4 calculates a failure time of 1225 secs compared to the observed 1100 secs.
Approach II •	Same as Approach I except that the longitudinal stress is added to the hoop stress as a vector addition. This increases the total stress by 10%.
•	MAAP4 calculates a failure time of about 600 secs.
Conclusion:	The MAAP4 model is as accurate as the material information given in the reference.

VI. CONCLUSIONS

Large integral codes are an important part of the analytical assessment for plant response to a variety of transients, including those potentially leading to severe accidents. As a result, such large computer codes model numerous phenomena having substantial interactions during the transients. Thus, there is a continual need to assess the credibility of individual models, and the combination of models, by testing these with the available experimental information. Furthermore, interactions between these physical phenomena need to be compared to the available large scale integral experiments as well as the plant transients experienced in the nuclear industry.

Because integral analyses are a key part of RCS and containment evaluations, it is essential that these benchmarking activities be repeated on a regular basis, with the most desirable situation being repetition each time a new version is released.

The only way these important benchmarks and their perspectives relative to phenomenological uncertainties can be maintained is to integrate the benchmarking information directly into the integral code software. The MAAP4 code has developed such an approach to cover the various types of benchmarks to be performed. The comparisons shown in this paper illustrate the capability of the MAAP4 code to track plant transients, important integral experiments and separate effects tests. With this approach, these comparisons and the knowledge base represented by the spectrum of large scale and small scale experiments will be maintained and expanded as the MAAP4 code usage continues and grows.

VII. REFERENCES

Brown, W., Caldwell, G., Chexal, B. and Layman, W., 1981, "Thermal Hydraulic Analysis of Crystal River Unit-2 Incident," Nuclear Safety Analysis Center Report NSAC-15.

Maile, K., Klenk, A., Obst, V. and Strum, D., 1990, "Load Carrying Behavior of the Primary System of PWRs for Loads Beyond the Design Limits," Nuclear Engineering and Design, Vol. 199, pp. 131-137.

Nuclear Regulatory Commission (NRC), 1985, "Loss of Main and Auxiliary Feedwater Event at the Davis-Besse Plant on June 9, 1985," NUREG-1154.

Paik, C. Y., Henry, R. E. and McCartney, M. A., 1995, "MAAP 4.0 Benchmarking With the TMI-2 Experience," Proceedings of the Probabilistic Safety Assessment Methodology and Applications, PSA'95, Seoul, Korea, pp. 673-680.

Valencia, L. and Wolf, L., 1990, "Large-Scale HDR-Hydrogen Mixing Experiments Test Group E11," Paper Presented at the 18th Water Reactor Safety Information Meeting, Rockville, Maryland.

Wolf, L. and Valencia, L., 1989, "Hydrogen Mixing Experiments in the HDR-Facility," 17th Water Reactor Safety Meeting, Rockville, Maryland.

Wolf, J. R. et al., 1993, "TMI-2 Vessel Investigation Project Integration Report," NUREG/CR-6197 TMI V(93)EG10 EGG-2734.