THE 4TH INTERNATIONAL TOPICAL MEETING ON
NUCLEAR THERMAL HYDRAULICS, OPERATIONS AND SAFETY
April 6-8, 1994, Taipei, Taiwan

RISK IMPACT OF PLANNED MAINTENANCE CONFIGURATION AT SOUTH TEXAS PROJECT ELECTRIC GENERATING STATION

W. T. Loh, K. N. Fleming
PLG, Inc.
4590 MacArthur Blvd., Suite 400
Newport Beach, California 92660
(714) 833-2085

C. R. Grantom
Houston Lighting & Power Company
South Texas Project
P.O. Box 289
Wadsworth, Texas 77483
(512) 972-8081

ABSTRACT

This paper is based on a study done for the Houston Lighting & Power Company[1]. The purpose of this study is to estimate the risk impact of planned maintenance configurations at South Texas Project Electric Generating Station (STPEGS). To date, the focus of the STP probabilistic safety assessment (PSA) program has been to analyze risk in terms of estimates of accident frequencies that are expressed on a time-averaged basis. Thus, estimates of quantities such as severe core damage frequency have been made such that the temporal variations of this frequency with changing plant configurations are averaged out over time. The only condition that has been imposed on these estimates is that the plant is initially operating at full power when potential initiating events might occur.

I. BACKGROUND AND OBJECTIVES

Planned maintenance and testing activities that are needed to meet planned maintenance requirements and Technical Specifications have been accomplished since startup at STPEGS according to a "12-week rolling maintenance schedule." In each of these 12-week periods, all planned maintenance, all corrective maintenance that can be scheduled, together with all scheduled surveillance testing that is performed in conformance with Technical Specifications, are conducted according to a predetermined schedule. According to this schedule, the plant evolves through a sequence of configurations with a specific set of equipment taken out of service or placed into a "tripped" condition for test or maintenance purposes, interspersed with the nominal state in which all equipment is in its normal configuration. While the beginning of each new configuration occurs according to a preplanned schedule, the duration of each test or maintenance configuration is variable and depends on the time required to complete the necessary work and to perform all tests needed to ensure that the equipment has been restored to the correct operability state.

Superimposed on this sequence of planned test and maintenance states of variable duration are randomly occurring events in which equipment is removed from service for corrective maintenance. The need for such corrective maintenance can occur as a result of failures of normally operating equipment, routine inspections and walk-throughs, and test-induced demand of a standby equipment that results in failure on demand and entry into a limiting condition of operation (LCO).

The risk of a severe accident exhibits temporal variations that result from the time-dependent sequence of test and maintenance activities through this 12-week rolling maintenance schedule. For example, if a loss of offsite power were to occur when one train of diesel generators or essential cooling water were out of service for maintenance within the allowed outage time (AOT) permitted by Technical Specifications, the likelihood of the event progressing to a full station blackout and core damage, however small, would be temporarily greater than if a loss of offsite power were to occur when all three trains of diesel generators and essential cooling water trains were in service. Conversely, when a solid state protection system (SSPS) instrument channel surveillance is in progress, the reliability of the SSPS system to perform its mission for a safety system actuation is temporarily higher than normal because the tested channel is placed in the tripped condition such that only one of the remaining three channels must function for success. This is true because the inherent reliability of a one out of three configuration is greater than a two out of four configuration when all support conditions are available. Thus, the temporal behavior of core damage frequency actually decreases from its average value in this case.

The STP PSA modeled many plant configurations that could exist at the time that the initiating events are postulated to occur. The PSA model assumed, with good justification, that initiating events occur at random points in time. In computing the annual average frequency of severe accidents, the PSA included estimates of the fraction of time that the plant is in each possible configuration. These fractions are stored separately for each system and are expressed in terms of the frequency and duration of each of these test and maintenance configurations as well as the temporary increases and decreases in plant performance in each of these configurations. These configurations include those for preventive and corrective maintenance, test-induced maintenance (i.e., a test that challenges a piece of equipment to operate on demand in which the test induces a failure that must be repaired immediately following the test) as well as testing impact on system and plant operability and performance.

The primary objective of this study is to determine the time-dependent risk behavior due to the 12-week rolling maintenance schedule at STPEGS, making full use of the models and information that were developed during the PSA and with full accounting for the plant-specific data that have been collected and analyzed for component maintenance at STPEGS. A secondary objective is to define ways to answer future questions about the risk impact of specific maintenance configurations so that efforts to optimize maintenance with respect to risk and refinements to Technical Specifications based on the PSA can be made. In meeting the first objective, information from currently available RISKMAN® models is used to develop the time-dependent risk information. In meeting the second objective, small changes were made to the STP PSA risk models[2,3] to reveal more explicitly the likelihood and impacts of specific maintenance configurations based on the latest information and data.

The 12-week rolling maintenance schedule is described below. In Section II, the use of the current risk models to develop the desired time-dependent risk profile is presented, together with a brief description of the changes that were made to the models. The results are presented in Section III. The results include estimates of the risk reduction that could be achieved with less frequent planned maintenance.

The 12-week rolling maintenance and surveillance schedule is described in Reference 1 in terms of specific trains of systems as a function of the week when the work is performed. It should be noted that only part of the equipment listed in the schedule for test or maintenance is actually unavailable for service. Another important observation is the fact that functionally interdependent systems are maintained in parallel such that the impact on plant redundancy is minimized. For example, work on diesel generators, essential cooling water trains, essential chilled water (ECH) trains, and fuel handling building heating, ventilating, and air conditioning (HVAC) trains is done in parallel. Without essential cooling water in train A, the corresponding trains of diesel generator and chilled water cannot function because of the functional dependencies between these systems. Essential cooling water provides component cooling for the diesel generator and the chillers. Thus, the impact on core damage frequency of performing maintenance on the diesel generator or chilled water train is limited to the impact of this equipment out of service only to the extent that the maintenance duration is extended. If the maintenance of these equipment is completed before the maintenance is finished on the essential cooling water pumps, there is no impact whatsoever of maintaining the diesel generator and chilled water trains. Conversely, if each system were maintained independently, the risk impact of the equipment out of service would be greater. The effect of minimizing the risk impact of maintenance by maintaining functionally dependent equipment in parallel is informally referred to as "risk shadowing."

It is important to note that both the coordinated and the uncoordinated options for performing planned maintenance would appear to be acceptable within Technical Specifications. The AOTs in the Technical Specifications impose separate limits on the duration of each maintenance event for each safety system without regard for functional interdependencies or with specific reference to the likelihood or frequency of each event.

Another key point to note is that during each maintenance outage in the 12-week cycle, not only planned maintenance but also part of the equipment's corrective maintenance is performed. Much of the so-called corrective maintenance involves the correction of problems that do not impair the ability of the equipment to function such as repacking leaking seals, repainting, and tightening of bolts. The ability to incorporate these types of corrective maintenance into the 12-week cycle and to take advantage of risk shadowing helps to minimize the impact of the maintenance on the risk of core damage.

II. DATABASE FOR RISK PROFILE

Based on information supplied in the previous section, the 12-week rolling maintenance cycle was defined in terms of a sequence of plant maintenance states interspersed with the baseline state in which no planned maintenance is being performed. A total of 15 maintenance states were defined as listed in Table 1. Each maintenance state consists of a unique combination of equipment out of service for a length of time determined by the maximum time estimated by Houston Lighting & Power Company[4] for that set of equipment from the plant-specific data; i.e., the maximum of the mean planned maintenance durations was used.

Also provided in Table 1 are the identification of the limiting equipment item of the set taken out, the initiating events and event tree top events that are impacted by the equipment out of service, and the frequency and duration of planned maintenance based on the actual schedule and the plant-specific data.

The analysis was performed using the STP system and plant models that have been updated relative to the STP Level 2 PSA/IPE model. The details of the changes made in this model relative to the Level 2 PSA/IPE model are documented in a letter report[5]. The cumulative changes include the integration of separate system and event tree models into a single risk model, and an updated and more accurate modeling of all planned maintenance activities at STPEGS.

Two versions of the updated model were used to provide supporting data for this study. These models are briefly described below:

- **STPMOD.** This model integrates the system/event tree models. Planned maintenance is modeled just as it was in the Level 2 PSA/IPE model[3]; i.e., same systems, frequencies, and durations.

- **STPNPM.** This model is similar to STPMOD except that all planned maintenance is zeroed out from both the initiating event frequencies and the system split fraction models. Corrective maintenance is left the same as STPMOD in the Level 2 PSA/IPE.

Table 1. Database for Estimating Time-Dependent CDF — 12-Week Maintenance Cycle

State	Equipment Out of Service	Limiting Equipment	Initiating Event Impact	Top Event Impact	Frequency per hour (FREQ)*	Duration (DUR) (hours)	f = FREQ*DUR
1A-1	Train A of DG, ECW, and ECH	ECW, ECH	LOECW; LOCCW; LOEABHV	GA, WA, CL	4.96-4	46.2	0.023
1A-2	Train A of CCW, CS, LHSI, RHR, and FH	LHSI, CCW	LOCCW	KA, CS, WI, PA, RX	4.96-4	25.8	0.013
1A-3	Train A of CCW, CS, RHR, FH, and AFW	LHSI, CCW, AFW	LOCCW	KA, CS, WI, PA, RX, AF, CD	4.96-4	7	0.003
1A-4	Train A of AFW	AFW	None	AF, CD	4.96-4	14.6	0.007
3C-1	CVCS Pump Train "A"	CVCS	None	CH	4.96-4	34.9	0.017
5A-1	CVCS Pump Train "B"	CVCS	None	CH	4.96-4	34.9	0.017
6B-1	Train B of DG, ECW, and ECH	ECW	LOECW; LOCCW; LOEABHV	GB, WB, CL	4.96-4	46.2	0.023
6B-2	Train B of CCW, CS, LHSI, RHR, and FH	LHSI, CCW	LOCCW	KB, CS, WI, PB, RX	4.96-4	25.8	0.013
6B-3	Train B of CCW, CS, RHR, FH, and AFW	LHSI, CCW, AFW	LOCCW	KB, CS, WI, PB, RX, AF, CD	4.96-4	7	0.003
6B-4	Train B of AFW	AFW	None	AF, CD	4.96-4	14.6	0.007
8D-1	Train D of AFW	AFW	None	AF, CD	4.96-4	21.6	0.011
11C-1	Train C of DG, ECW, and ECH	ECW	LOECW; LOCCW; LOEABHV	GC, WC, CL	4.96-4	46.2	0.023
11C-2	Train C of CCW, CS, LHSI, RHR, and FH	LHSI, CCW	LOCCW	KC, CS, WI, PZ, RX	4.96-4	25.8	0.013
11C-3	Train B of CCW, CS, RHR, FH, and AFW	LHSI, CCW, AFW	LOCCW	KC, CS, WI, PZ, RX, AF, CD	4.96-4	7	0.003
11C-4	Train B of AFW	AFW	None	AF, CD	4.96-4	14.6	0.007

*Exponential notation is indicated in abbreviated form; e.g., 4.96-4 = 4.96×10^{-4}.

The results of the model quantification runs that were made to support this study are listed in Table 2. The exact treatment of equipment out-of-service impacts was developed using a special version of the risk model in which all planned maintenance was zeroed out; i.e., STPNPM. (However, the corrective or unplanned maintenance was left in.) This was done to correctly measure the baseline risk, given that there is no planned maintenance in progress, and to measure the temporary risk increases, given that specified equipment is out of service (and given that the balance of the equipment is not out of service for planned maintenance).

It was noted that when planned maintenance was removed, nearly 4,000 of the sequences saved to the database in STPMOD dropped below the 10^{-10} per year cutoff, resulting in fewer sequences. The resulting sequences were found to be adequate to address all maintenance states except for those involving the component cooling water system (Top Events KA, KB, and KC). Because this system has very low risk importance at STPEGS, a large fraction of its risk-contributing sequences were below the 10^{-10} cutoff that was used. To correct this problem, a revised sequence database was developed by rerunning the STPNPM event trees with the train B CCW (Top Event KB) split fractions set to 0.5. This resulted in an adequate set of sequences for addressing the CCW maintenance states.

III. RESULTS FOR 12-WEEK MAINTENANCE CYCLE

The results of the evaluation of the current 12-week rolling maintenance cycle are presented in Figure 1. Figure 1 presents the results that were made using the STPNPM model in which all split fractions and initiating events were adjusted to correspond with a specific set of equipment out of service and no additional equipment out of service for planned maintenance. The core damage frequency estimates are normalized against the most recent estimate of CDF (obtained by STPMOD) of 4.59×10^{-5} per year. Note that individual charging pump maintenance has a negligible impact due to the low risk importance of this equipment at STPEGS.

The updated value of the average core damage frequency was estimated using the following formula:

$$CDF_p(ave) = f_0\, CDF_p(base) + \sum_{j=1}^{N} f_j\, CDF_j(PM)$$

$$= \frac{t_0\, CDF_p(base) + \sum_{j=1}^{N} t_j\, CDF_j(PM)}{T}$$

where

T = duration of maintenance cycle: 2,016 hours.

t_0 = duration of no planned maintenance in progress.

t_j = duration of maintenance state j.

It should be noted that the analysis presented here has an uncertainty of about $\pm$ 2% that is introduced because the importance sequence model only includes about 98% of the sequences used for the event tree quantification. The results here assume that the risk importance information from 98% of the model is applicable to the entire 100% of the CDF.

As a sensitivity study, an evaluation was made of an alternative maintenance scheme that is identical to the one considered in Section 2.1 except that the maintenance cycle is spread out over 24 weeks rather than 12 weeks. In this case, each maintenance state is entered at one-half the frequency of that assumed for the 12-week cycle, but the durations and instantaneous core damage frequencies remain the same.

The above equation was reevaluated by changing the values of t_0 and T to t_0 = 4,032 - 372 = 3,660 hours and T = 4,032 hours, respectively. The resulting average CDF was found to be 81% of the base case value of 4.59×10^{-5} per year. Thus, this study predicts that converting to semiannual planned maintenance, if it is confirmed that such reduced frequency maintenance has no adverse impact on equipment performance, would reduce the average CDF by about 13%.

IV. CONCLUDING REMARKS

As a final concluding remark, this study has resulted in a much better understanding of the impacts of planned maintenance activities on the risk of severe core damage at STPEGS. For the first time, a time-dependent risk profile of the planned maintenance cycle at STPEGS has been obtained. The STPEGS risk models on RISKMAN Version 4.0 have proved to be a useful tool to support ongoing efforts to optimize the planned maintenance program at STPEGS. It is not difficult to envision the natural progression from where we are today to the time when on-line dynamic risk monitoring is available to support the risk management program at this plant.

V. REFERENCES

1. PLG, Inc., "Risk Impact of Maintenance Configurations at South Texas Project Electric Generating Station," prepared for Houston Lighting & Power Company, PLG-0917, Revision 2, May 1993.

2. PLG, Inc., "South Texas Project Probabilistic Safety Assessment," prepared for Houston Lighting & Power Company, PLG-0675, 1989.

3. Houston Lighting & Power Company, "STPEGS Level 2 Probabilistic Safety Assessment and Individual Plant Examination," August 1992.

4. Houston Lighting & Power Company, "Responses to the NRC Regarding the Risk-Based Evaluation of STPEGS Technical Specifications," ST-HL-AE-4261, November 1992.

5. PLG, Inc., "Summary of STPEGS PSA Model Changes and Updates through April 1993," letter report prepared for Houston Lighting & Power Company, to be published.

Table 2. Summary of RISKMAN Results for Various STPEGS Models

Model	Event Tree Quantification				Important Sequence Model	
	Truncation Frequency	Sequences Quantified	Sequences Saved (SDB cutoff)	Total CDF via Event Tree Quantification	Case	CDF × 10^{-5} per Year
Level 2 PSA/IPE	1×10^{-12}	826,162	603 (> 1×10^{-8})	4.44	Base	3.53
STPMOD	1×10^{-12}	832,194	10,272 (> 1×10^{-10})	4.59	Base	4.48
STPNPM	1×10^{-12}	627,060	5,988 (> 1×10^{-10})	3.11	Base ECW Train B Down Safety Injection Train B Down Motor-Driven AFW Train A Down Turbine-Driven AFW Train D Down Charging Pump Train A Down Motor-Driven AFW Train A and Safety Injection Train B Down	3.05 12.7 5.50 5.09 15.3 3.08 7.91
STPNPM with Top Event KB Split Fractions Set to 0.5	1×10^{-12}	762,248	6,633 (> 1×10^{-10})	3.17	Base CCW Train B Down CCW Train B and Safety Injection Train B Down CCW Train B, Safety Injection Train B, AFW Train B Down	3.10 3.15 6.15 8.38

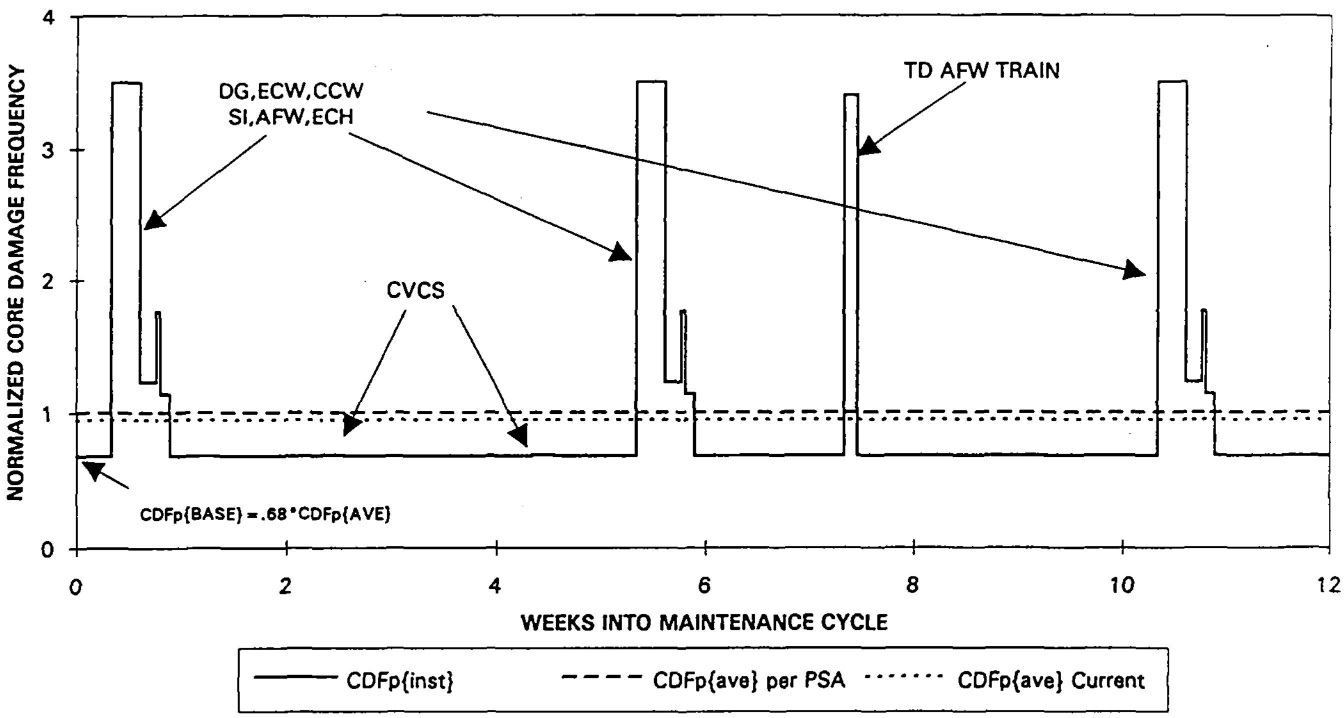

Figure 1. Risk Profile of 12-Week Rolling Maintenance Program at STPEGS

Session 22
Numerical Modeling in Thermal Hydraulics