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RANKING SIGNIFICANT PHENOMENA IN PHYSICAL SYSTEMS[a]

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ABSTRACT

The analysis of any physical system requires a thorough understanding of the principal phenomena affecting the behavior of that system. In a complex application such as a nuclear reactor, identifying the principal phenomena in an accident transient can be a formidable task. This paper describes the use of the analytical hierarchy process to assimilate engineering judgements that relate and rank the thermal-hydraulic phenomena affecting the response of a nuclear reactor. The analytical hierarchy process is described to acquaint the reader with the methodology. The importance criterion against which phenomena are selected, measured, and ranked is discussed and defined for the example application described here. The purpose of the analysis, in this case to determine the applicability of a computer code to represent the system phenomena, is defined. The hierarchy used to structure the pairwise decisions is developed in terms of both the importance criterion and the goal of assessing computer code applicability. The methodology is applied to a loss-of-feedwater transient in a nuclear reactor as an example. The analysis shows the application of engineering judgement based on experimental and calculational experience to rank both the system components and the local phenomena within those components relative to each other on a pairwise basis. The same engineering experience is used to assess the validity of the final results. The application of the overall ranking to a code applicability and uncertainty assessment is then discussed.

INTRODUCTION

A code applicability methodology is presented to address how code calculational results of reactor transient simulations can be determined applicable in the absence of data comparisons at the scale of application. The pieces include:

1. A determination of the significant phenomena--transient evaluation.
2. Code assessment--code evaluation--includes a detailed assessment of the computer code to determine its ability to represent the phenomena identified as important above.

Methods of transient evaluation rely upon engineering judgement. This is the basis of the entire methodology. None of the methods described are a magic formula or crystal ball. Judgement is based on:

1. Understanding of the underlying phenomena,
2. Understanding of the physical system, and
3. Understanding of the interactions of phenomena with each other and with the physical system, including especially the boundary conditions.

The current subject is the determination of the significant phenomena. This includes a determination of the phenomena against which the code

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will be evaluated. It also requires a ranking of the phenomena. This ranking process is accomplished by developing an importance criterion, developing a hierarchy, performing a pairwise ranking among the phenomena, and generating a global ranking for the entire system.

The analyst must recognize from the outset that the process described is a useful tool with which to assimilate a large number of individual judgements into an overall conclusion. It adds information only in the sense that the analyst is guided to consider interactions that might otherwise be neglected, and that the final results must be weighed carefully to ensure the conclusion is reasonable from either an existing or a revised point of view.

BACKGROUND

Traditional code assessment has been accomplished by comparisons of calculated results with the measured phenomena in integral and separate effects experiments. Code applications to full scale (real) reactor plants have been defended on the grounds that the scaled benchmark calculations demonstrated a basic code capability to represent the phenomena of interest, and that the effects of scale that might change the specifics of the system response would be correctly handled by the computer code. The current subject of identifying the significant phenomena in a given reactor transient is a step toward quantifying the statement that the thermal-hydraulic code can correctly represent the effects of scale. Its purpose is to identify those specific phenomena that are particularly important to calculating the transient response in the system, such that a code evaluation can address those particular phenomena to ensure that the code does, indeed, include the necessary scale effects. In this way, the benchmark at a small scale is defended as a demonstration of code calculational capability at a scale where data are not available.

The decision making process used to identify the most important phenomena relies on engineering judgement. Traditionally, engineering judgement was applied at the system level to determine, to the best of the analyst's capability, the most significant of many competing phenomena in a complex system. The method described here, the analytical hierarchy process (AHP),[1] simplifies the process by reducing the level of decision making to pairwise comparisons between candidate phenomena, each phenomenon being judged against every other phenomenon, one at a time, for its impact on a carefully chosen importance criterion, such as the impact of the phenomenon on the ability to maintain an acceptable liquid level in the core. The AHP quantifies the assimilation of the pairwise decisions into a overall ranking by combining the effects of all the local rankings. In addition, the AHP allows a structured means of recording the reasons used for each of the local decisions, thereby encouraging the analyst to document the decisions and making assessment of the results easy.

METHODOLOGY

The AHP is a structured decision making process whereby competing variables in a complex system can be assessed against each other on a pairwise basis, and the total effect of each on a system-wide basis can be determined. The method requires that the analyst identify each element in the system to be ranked. These elements can be at different levels of significance in the system analysis. For example, the reactor transient being evaluated in this analysis was divided into time intervals during which significant characteristic phenomena occurred. The reactor system itself was first broken into significant components such as the steam generator, pressurizer, etc. A lower level of elements was identified as the phenomena that occur within each of the components identified in the immediately higher level, phenomena such as boiling heat transfer or generation of voids.

At a given level, the elements are arranged into a square matrix. The value of each matrix element is the rank of one member of the matrix against another. The ranks are determined based on an arbitrary scale, some discussion of which will follow. When all the elements of the matrix have been filled with ranks, an eigenvector is determined. For the purpose of determining the element ranks, the principal eigenvector is used. In general, the arbitrary scale used to rank the elements against each other will not affect the ordering of the elements based on the eigenvalue of each, but the distribution of the eigenvalues will depend on the scale used, and this, in turn, can affect global ranks when the eigenvalues are used later as weighting factors to determine the relative importance of lower level phenomena. An example of this effect will be given later in this section.

The arrangement of the entire analysis into a hierarchy is perhaps the most difficult part of the process, for it will affect the final results. There is no prescribed methodology by which the hierarchy can be developed. The analyst must be aware of the importance criterion chosen, and must ensure that the hierarchy will allow each of the phenomena to influence the final result with equal weight. Saaty[1] gives some guidelines and examples to assist in the development of the hierarchy.

Analyzing a given problem requires first that the goal of the analysis be carefully defined. Saaty describes this goal as the topmost level in the hierarchy, which he calls the "Focus" in his example problems. The level is aptly named, for it guides the purpose of the decision making that follows in the lower levels of the hierarchy. The next level represents a division of the problem into major categories used to group the various factors affecting a decision. For example, a hierarchy developed to guide the purchase of a new car might use as its focus, the best car to buy. The Level 2 factors used to group variables might then be the criteria upon which each car would be evaluated, factors such as price, comfort, etc. The third level might be a further subdivision to allow local grouping of influences within the divisions described in Level 2, or it might simply be each of the candidate variables, if Level 2 represents an adequate definition of the problem. Again using the car example, Level 3 might be the cars under consideration. In the example to be used later in this section, this car problem will be formulated in terms of a hierarchy. Numbers will be assigned to all the rankings to demonstrate the method, as well as to show the effects of different scales used to generate the ranks.

A few notes about the AHP are in order. First, there is no requirement that the ranks assigned to the various elements in the analysis be consistent. The typical example of inconsistent ranks is that of sports teams in which Team A can beat Team B, Team B can beat Team C, but Team C can beat Team A. A ranking to find the strongest team would rank A greater than B, B greater than C, and C greater than A. The AHP is equipped to handle this situation. It provides a measure of the consistency of the matrix by comparing the magnitude of the maximum eigenvalue to that which would result from a perfectly consistent matrix. A relative consistency measure is determined by comparing this result to that obtained for a completely random input. A mathematically consistent matrix would give a consistency measure of zero.

A second note is that the number of elements included in a given matrix affects the global weight of each of those elements compared to the weights of elements in the other matrices at that level. This distortion introduced when different numbers of elements are in the various matrices is accommodated in the weighting procedure by normalizing the local weights in each matrix to a value of one before the weighting factors are applied. This ensures that the most highly ranked element of each matrix takes on the weight of the matrix assigned by its elemental position in the next higher level of the hierarchy. Therefore, the highest ranked element takes on an undistorted value in the global ranking. The distortion introduced from having different numbers of elements is then taken at the low end, since the low ranked elements have their significance artificially increased by the normalizing procedure. This distortion is recognized and accepted because the principal purpose of the AHP application is to identify the highly ranked phenomena. Distortions at the low end are of little concern, since those phenomena are, in general, dismissed from further consideration in the code applicability analysis.

An example of the AHP process will help to clarify the method. The car selection problem described above will be cast in terms of a hierarchy. The matrices used to evaluate the weighted decisions will be developed, and some of the sensitivities discussed. The purpose of this example is to show the mathematical aspects of the AHP, such that more meaning can be derived from the more complex application to reactor safety analysis to be described in the next section. Note that the ranks assigned to the decisions in this example have no meaning other than to demonstrate the method. The selection of automobiles and criteria affecting their relative merits represent the first thoughts that came into this author's head, and cannot be interpreted as having any meaning beyond that.

Suppose that the AHP is to be used to guide the selection of a new car. The focus described in Level 1 can be "Best

Car." Level 2 can then be the criteria upon which a car will be chosen. For simplicity, three criteria will be used, price, comfort, and dealer service. Assuming these are the only criteria to be used to guide the purchase, the third level is the candidate cars. For this example, the three cars to be considered will be Cars A, B, and C. The hierarchy used to structure the decisions is shown in Figure 1.

Level 1		BEST CAR		
Level 2	PRICE	COMFORT	DEALER SERVICE	
Level 3	Car A	Car B	Car C	

FIGURE 1. BEST CAR HIERARCHY

The ranking process begins at Level 2, with each element of the Level 2 matrix ranked with respect to each other element. The ranking process follows the convention that the element on the left side of the matrix is ranked with regard to its importance, or influence on the Focus, compared to the importance of each of the elements across the top of the matrix. The ranking table recommended by Saaty[1] is shown in Table 1.

TABLE 1. AHP RANKING TABLE

1-9 Rank	1-5 Rank	Definition
1	1	Equal importance of both elements
3	2	Weak importance of one element over another
5	3	Essential or strong importance of one element over another
7	4	Demonstrated importance of one element over another
9	5	Absolute importance of one element over another

The 1-9 scale is employed to rank the elements shown in Figure 1. The input values are shown in Figure 2.

Each input is based on the judgement of the analyst or group of analysts assessing the problem. When a group of analysts is used to assess the relative importance of the various elements to the question of interest, a consensus can be

	INPUT			RESULTS
BEST CAR	Price	Comfort	Service	
Price	1	4	3	.63
Comfort	1/4	1	2	.22
Service	1/3	1/2	1	.15
Price	CarA	CarB	CarC	
Car A	1	5	2	.58
Car B	1/5	1	1/3	.11
Car C	1/2	3	1	.31
Comfort				
Car A	1	1/3	1/2	.15
Car B	3	1	4	.63
Car C	2	1/4	1	.22
Service				
Car A	1	1/3	1	.21
Car B	3	1	1	.55
Car C	1	1/2	1	.24
Overall Weighted Result				
CarA				.43
CarB				.29
CarC				.28

FIGURE 2. MATRICES OF RANKS FOR THE CAR PROBLEM

used to generate a single ranking matrix. The ranks shown in Figure 2 are evaluated with the AHP program presented in an appendix of Reference 1. The results of this evaluation are shown as column 1 in Table 2. For each individual matrix, the results of the AHP program were compared to the results from an eigenvector program[2] and found to correspond to the principal eigenvector. The process of determining the weighted rank for each of the Level 3 elements, the particular cars being evaluated, is to add the local weight for each element at Level 3 with respect to each Level 2 criterion, weighted by the rank of the Level 2 criterion. The weighted ranks found in this manner are then normalized to ensure the sum of the weights is unity.

The ranking table used to interpret the numerical value assigned to each qualitative decision affects the results of the mathematical weighting. Although a qualitative nature is assigned to each of the values 1 through 9 shown in Table 1, the use of each of the ranks in

TABLE 2. SUMMARY OF RESULTS FOR BEST CAR PROBLEMS

	NORMALIZED WEIGHTED RANK	
CAR	1-9 Scale	1-5 Scale
Car A	.53	.43
Car B	.23	.29
Car C	.24	.28

the ranking process is strictly mathematical. Therefore, a rank of 3 is interpreted mathematically as a phenomenon three times more significant than that against which it is being ranked, the qualitative interpretation from Table 1 of, "weak importance of one element over another," notwithstanding. Saaty defends the use of the 1-9 scale,[1] but the results of analyses performed in this study have shown that the 1-9 scale tends to overwhelm elements of medium or low importance. This effect is shown by performing the car comparison again, but using the 1-5 scale shown in the second column of Table 1. Using the same qualitative ranks as the previous example, one obtains the results shown in column 2 of Table 2. The effect of the lower scale is to reduce the relative importance of the top ranked car relative to the lower ranked cars. This reduction in the spread between the top and bottom ranks provides more discrimination of phenomena in a larger hierarchy. Additionally, the results of the simple car problem show that the scale can even affect the qualitative ranking; the two low ranked cars reverse their relative ranks for the two scales. It is not expected that this particular effect has much significance in the larger hierarchies. The qualitative nature of the entire ranking process would indicate that discrimination between closely ranked elements in the final weighting is not justified.

APPLICATION TO REACTOR SAFETY

The purpose of this paper is more to discuss the AHP application to a physical system than to analyze a specific reactor transient. The Babcock and Wilcox (B&W) loss-of-feedwater (LOFW) transient is used as an example to demonstrate the use of the method to analyze a complex technical problem. Detailed results are included in Reference 3.

As described above, one of the most difficult aspects of the AHP is developing the hierarchy into which the various elements will fit. The first step in the process is to gain a thorough understanding of the transient. The current application is a LOFW transient in a B&W reactor plant employing a once-through steam generator. The objective of the analysis is stated to provide a goal with which to structure a hierarchy, and a scale against which each element in the hierarchy can be measured. The objective reflects the purpose of the analysis. For the current problem, it is stated as follows:

> Determine the most significant processes and phenomena in the reactor plant based on their impact on the ability of a primary system feed-and-bleed recovery to maintain a liquid level above the core.

The carefully worded objective leads directly to a statement of the focus for the AHP, the Level I element. In light of the objective, the focus for the current analysis is, "Significant Processes or Phenomena."

Development of a suitable hierarchy depends on a careful description of the transient. The specific B&W LOFW transient chosen for this analysis is defined in Reference 3 by the following conditions:

1. Complete loss of feedwater with no auxiliary feedwater (AFW) available,
2. Reactor scram occurs at the time of the event causing the LOFW,
3. Primary system coolant pumps trip and begin a coastdown at the time of reactor scram,
4. Operation of the pressurizer spray, the pressurizer heaters, and the primary coolant makeup and letdown systems is not considered, and
5. The operator locks open the pressurizer power-operated relief valve (PORV) when it is initially actuated on high pressure, and the high-pressure injection (HPI) system is actuated simultaneously, consistent with initiating a feed-and-bleed cooldown.

The most appropriate hierarchy structure is one that based on an engineering evaluation, will effect a reduction of the amount of transient analysis required. As a guide to assist in identifying processes and phenomena, a schematic of a B&W reactor coolant system is shown in Figure 3. A convenient mechanism for grouping phenomena is to employ the following hierarchy structure:

1. Time intervals,
2. Components,
3. Phenomena and processes, and
4. Lower order parameters and variables.

A brief description of the transient is useful to identify phenomena.

A. Steam Generator Dryout (Time Duration < 10 min)

The initiating event is assumed to result in a LOFW, a reactor scram, and a concurrent reactor coolant pump trip. The reactor plant response to these initiating events is as follows.

Reactor scram causes an immediate decrease in reactor power. The coastdown of the reactor coolant pumps, which lasts for approximately 30 s, maintains significant coolant flow through the primary side of the steam generators (Figure 4) to prevent exceeding critical heat flux in the core. Heat transferred to the steam generator secondary exceeds the energy transferred to the coolant from the core, initially causing a decrease in the primary system pressure (Figure 4) and temperature (Figure 4).

The primary system coolant volume shrinks because of the net energy loss, initially lowering the pressurizer liquid level (Figure 5).

Vapor generation in the steam generator secondary causes a rapid increase in pressure until the steam line safety relief valves (SRVs) and modulating atmospheric dump valves (MADVs) are activated (Figure 5) at 5 s. The energy transferred to the steam generator secondary is rejected to the environment by the mass leaving the secondary through the steam line SRVs and MADVs.

After the initial opening and closing of the SRVs, flow through the MADV is sufficient to control the steam generator secondary pressure. The heat transferred to the steam generator secondary decreases as the mass lost through the SRVs and MADVs decreases the tube surface area in contact with secondary liquid (Figure 5).

The heat transfer process in the core is that for single-phase liquid and possibly a two-phase mixture. When core

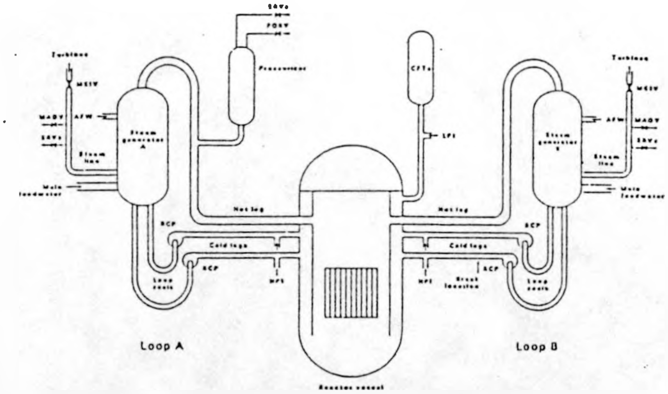

FIGURE 3. GENERAL SCHEMATIC OF A B&W REACTOR COOLANT SYSTEM

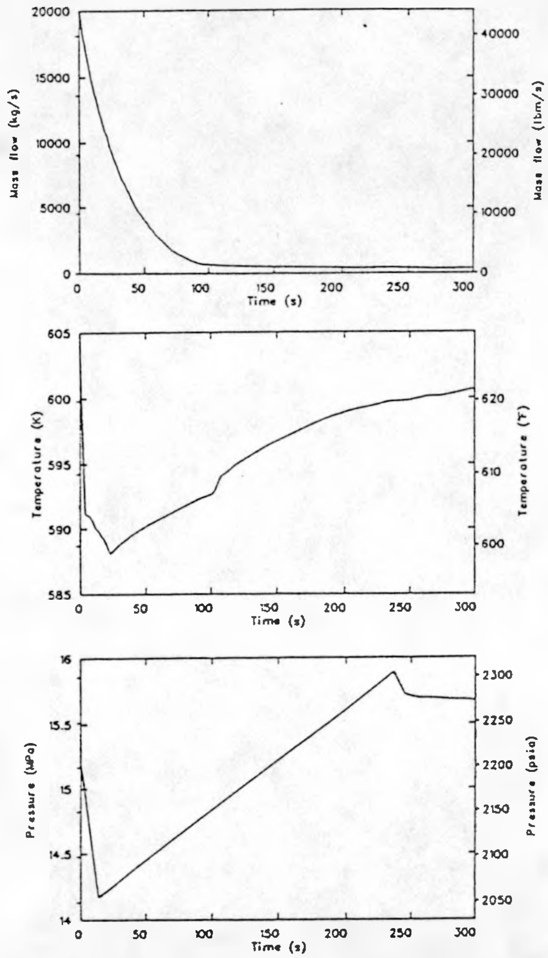

FIGURE 4. TIME INTERVAL 1 PRIMARY SYSTEM RESPONSE

heat transfer rate exceeds the steam generator secondary heat transfer rate at 30 s, the primary system begins to heat up (Figure 4).

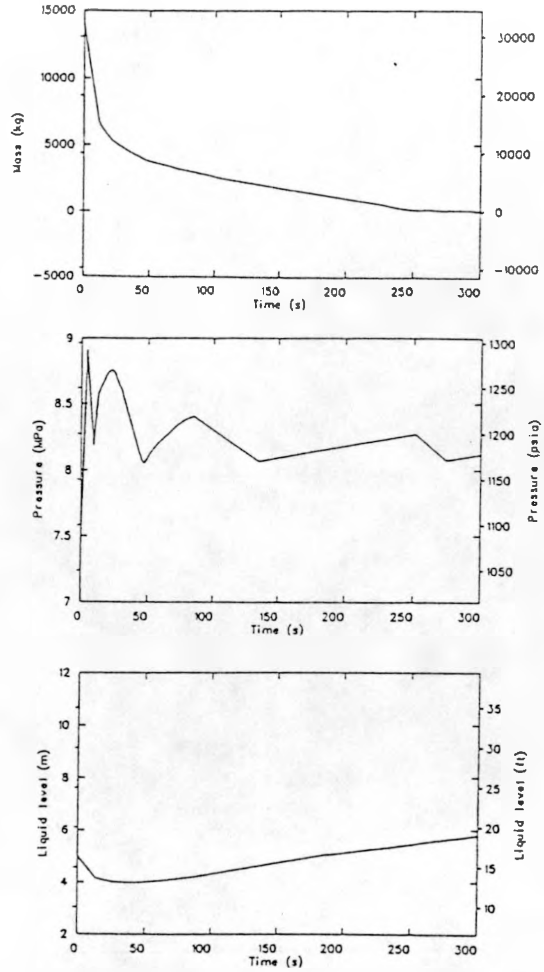

FIGURE 5. TIME INTERVAL 1 PRIMARY AND SECONDARY SYSTEM RESPONSE

The minimum pressure is reached at 30 s, but it is not low enough to activate the HPI. The increase in primary coolant temperature causes the primary system coolant to expand into the pressurizer and compress the steam space (Figure 5) after 30 s.

After the reactor coolant pumps complete their coastdown at 150 s, natural circulation (Figure 4) resulting from differences between the density of liquid in the steam generator primary and the reactor vessel core is sufficient to maintain core cooling.

The pressurizer pressure increases to the PORV opening set point (Figure 4) at 240 s. The steam generator secondary mass decreases to zero (Figure 5) by 250 s.

The dominant processes during this phase of the transient are the decay heat, the stored energy, and single-phase liquid convection.

B. Primary System Cooldown (Time Duration Several Hours)

By 300 s, as a result of the opening of the pressurizer PORV and the resultant actuation of HPI, a two-phase mixture is discharged from the pressurizer dome with considerably more volume escaping the system than enters. At 300 s a rapid reduction in primary system pressure occurs (Figure 6) until the liquid volume injected by the HPI and the liquid volume displaced by voiding of the vessel upper head displaces the pressurizer vapor dome.

Loop circulation continues (Figure 6) after the steam generator drys out at 250 s, driven by the density difference between the injected coolant and the coolant in and exiting the core. The circulation is sufficient to cool the core by single-phase convection and subcooled nucleate boiling. No net vapor is generated.

When the pressurizer fills (Figure 6) at 650 s, the pressure increases and the PORV passes liquid until the primary system begins voiding. A two-phase mixture then enters the pressurizer and limits flow out the PORV. A near balance is achieved between the PORV flow and the injected flow by 1000 s, which results in a gradual decline in the pressurizer pressure.

Small pressure disturbances in the system after 1500 s may cause a sufficient pressure differential between the upper plenum and the downcomer to actuate the reactor vessel vent valve (RVVV) in a cyclic manner. The hot liquid transferred to the downcomer mixes with the liquid in the cold leg and recirculates through the core. The gradual system cooldown continues due to a decrease in the decay heat and the addition of cold HPI water. Flow out the pressurizer PORV is replenished with slightly cooler liquid, thereby permitting a continued depressurization (Figure 6).

The dominant processes during this phase of the transient are the phase distribution and voiding throughout the system, HPI injection into the cold leg, decay heat generated in the core, and the critical flow and the resultant exit enthalpy of fluid leaving the PORV.

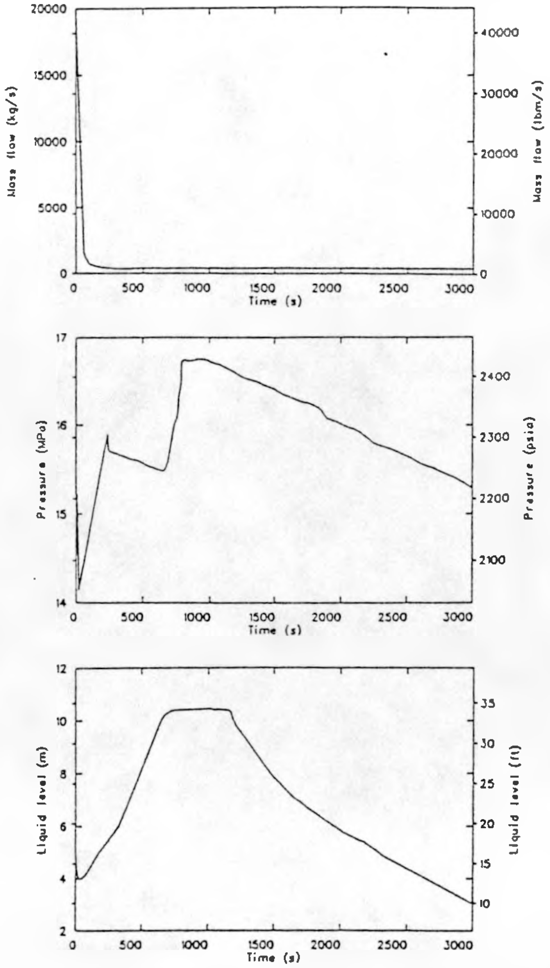

FIGURE 6. TIME INTERVAL 2 PRIMARY SYSTEM RESPONSE

C. Process Identification and Ranking

The LOFW was evaluated by means of a process which included consideration of related large-code calculations and experiments. The assumptions for and a description of the scenario were discussed earlier. A detailed table was then constructed, listing all processes and phenomena occurring during the transient. A portion of the detailed table is shown in Table 3. Its purpose is to guide the analyst in assessing the LOFW transient.

For the core component, the decay heat generation, stored energy, and single-phase liquid convection are designated as important phenomena. The energy generated in the fuel must be removed to maintain core integrity. The steam generator primary tubes and coolant circulation facilitates the transfer process for removal of energy from the primary system. The pressure settings of

TABLE 3. B&W LOFW TRANSIENT PROCESS AND PHENOMENA IDENTIFICATION

Component	Process	System Response	Significant Phenomena	Transient Initiating Events
Steady-State Full Power—Time Interval Δt_0				
Steam generator secondary	$1\phi_f$, 2ϕ flow friction and form losses phase distribution heat transfer	α from 0 to 1	—[a]	Turbine trip MFW off MSIV closed AFW off
Steam generator primary	$1\phi_f$ flow friction and form losses heat transfer	T_f, P decrease	$1\phi_f$ flow ΔP_f $\Delta P_{K/n}$ $1\phi_f$ convection	—
Intermediate leg	$1\phi_f$ flow letdown flow friction losses	P decrease	$1\phi_f$ flow ΔP_f	Letdown flow off
Pump	$1\phi_f$ flow driving head	P increase flow constant	$1\phi_f$ flow $\Delta P_{pump\ head}$	Pumps tripped off
Cold leg	$1\phi_f$ flow makeup flow friction losses	P decrease	$1\phi_f$ flow ΔP_f	Makeup flow off
Downcomer	$1\phi_f$ flow friction and form losses	P decrease	$1\phi_f$ flow ΔP_f $\Delta P_{K/n}$	—
Lower plenum	$1\phi_f$ flow form losses	P decrease	$1\phi_f$ flow $\Delta P_{K/n}$	—
Core	$1\phi_f$, 2ϕ flow friction and form losses heat transfer	T_f increase P decrease	—[b]	Reactor tripped off
Core bypass	$1\phi_f$ flow form losses heat transfer	P constant	$1\phi_f$ flow $\Delta P_{K/n}$ $1\phi_f$ convection	—
Upper plenum	$1\phi_f$ flow form losses	P decrease	$1\phi_f$ flow $\Delta P_{K/n}$	—

the secondary pressure relief valves, specifically the SRVs and the MADVs, determine the sink temperature. The phase distribution, liquid entrainment, and steam quality then determine the efficiency and time duration of the dryout process. The most important phenomena designated in the table for the cooldown interval are the decay heat generation in the core, HPI mass flow rate in the cold leg, critical flow and the resultant exit enthalpy of the fluid through the pressurizer PORV, and the phase distribution and voiding throughout the system. These phenomena control the availability of the coolant to cool the core and the resultant subcooling or exit quality.

The process of determining the important phenomena described above relies on the ability of the analyst to assess the relative significance of each individual phenomenon to the overall system response. The Process Identification and Ranking Table (PIRT) process described in Reference 4 uses this method, as well as the more structured method of determining the global importance of each phenomenon. Figure 7 shows the hierarchy of components and the processes and phenomena used to structure the pairwise omparisons needed as input to the ranking process. The application of this procedure to the processes identified in the transient description resulted in the PIRT shown in Table 4 and summarized in Table 5. The advantage of performing the ranking of phenomena in this manner is

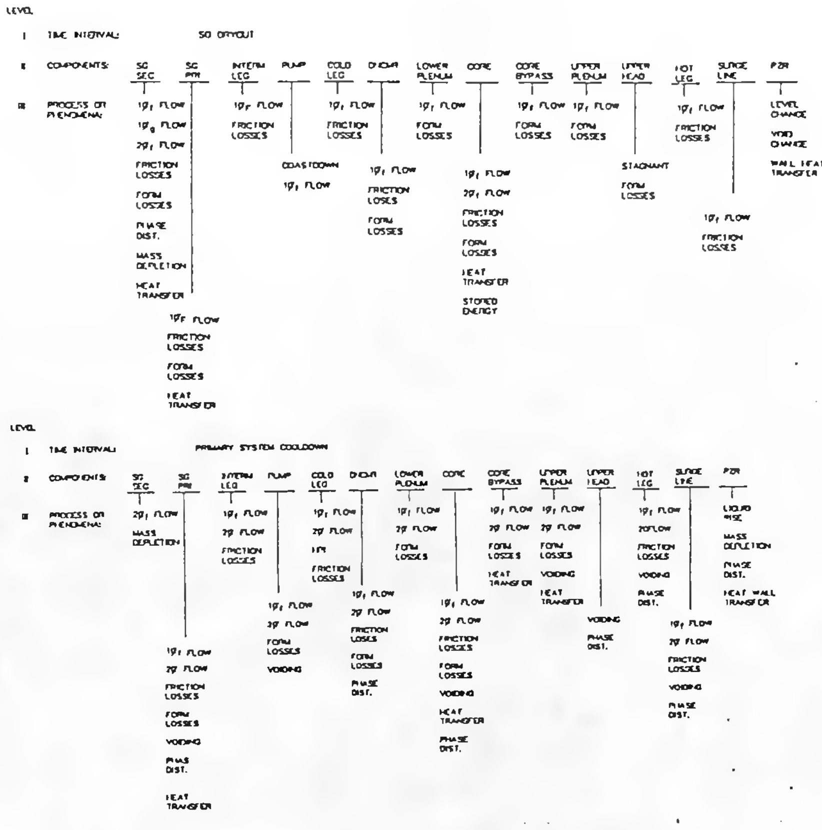

FIGURE 7. SIGNIFICANT PROCESSES AND PHENOMENA FOR THE B&W LOFW TRANSIENT

TABLE 4. PROCESS AND PHENOMENA RANKING FOR A B&W LOFW TRANSIENT

Component	High (7-9)	Medium (4-6)	Low (1-3)
Ranking During Steam Generator Dryout—Time Interval Δt_1			
Steam generator secondary	(L) dryout location	(H) $1\phi_f$,2ϕ flow phase separation (Q) sat nucleate boiling (L) incipient boiling	(H) $1\phi_g$,2ϕ critical flow $\Delta P_{f,g,2\phi}$ $\Delta P_{K(f,g,2\phi)}$ mass depletion
Steam generator primary	(Q) $1\phi_f$ convection	(H) $1\phi_f$ flow	(H) ΔP_f; ΔP_{Kin}
Core	(Q) decay heat stored energy (Q) $1\phi_f$ convection	(H) $1\phi_f$ flow	(H) 2ϕ flow; ΔP_f; ΔP_{Kin} (Q) sub nucleate boiling sat nucleate boiling rod internal heat transfer (L) CHF limit
Pressurizer		(Q) wall heat transfer (L) HPI level setpoint	(H) flashing condensation level change
Ranking During Primary System Cooldown—Time Interval Δt_2			
Downcomer	(H) voiding phase distribution	(H) $1\phi_f$,2ϕ flow	(H) $\Delta P_{f,2\phi}$ $\Delta P_{K(f,2\phi)}$
Core	(H) voiding phase distribution (Q) decay heat	(H) $1\phi_f$,2ϕ flow (Q) 2ϕ convection Sub nucleate boiling Sat nucleate boiling	(H) $\Delta P_{f,2\phi}$ $\Delta P_{K(f,2\phi)}$ (Q) $1\phi_f$ convection (L) CHF limit
Upper plenum	(H) voiding phase distribution	(H) $1\phi_f$,2ϕ flow 2ϕ convection	(H) $\Delta P_{K(f,2\phi)}$ (Q) $1\phi_f$ convection
Pressurizer	(H) PORV critical flow voiding phase distribution exit enthalpy	(H) $1\phi_g$,2ϕ flow (Q) sat nucleate boiling	(H) mass depletion

TABLE 5. PROCESS IDENTIFICATION AND RANKING TABLE (PIRT) FOR A B&W LOFW TRANSIENT

Component	Phenomenon	Importance Rank
Time Interval 1: Steam Generator Dryout		
Steam generator secondary	Boiling heat transfer	6
	Phase Separation	6
	$1\phi_f$ flow	5
	2ϕ flow	4
Core	Decay heat and stored energy	9
	$1\phi_f$ convection	7
	$1\phi_f$ flow	5
Hot leg	$1\phi_f$ flow	5
Pressurizer	Wall heat transfer	6
Steam generator primary	$1\phi_f$ convection	7
Pump	$1\phi_f$ flow	5
	Coastdown	4
Cold leg	$1\phi_f$ flow	5
Time Interval 2: Primary System Cooldown		
Downcomer	Voiding	9
	Phase distribution	8
	$1\phi_f$ flow	5
	2ϕ flow	4
Lower Plenum	Voiding	9
	Phase distribution	8
	$1\phi_f$ flow	5
	2ϕ flow	4
Core	Voiding	9
	Phase distribution	8
	Decay heat	7
	Boiling	6
	$1\phi_f$ flow	5
	2ϕ convection	4
	2ϕ flow	4

TABLE 5. (CONTINUED)

Component	Phenomenon	Importance Rank
Time Interval 2: Primary System Cooldown (continued)		
Upper plenum	Voiding	9
	Phase distribution	8
	1ϕ, flow	5
	2ϕ convection	4
	2ϕ flow	4
Upper head	Voiding	9
	Phase distribution	8
Pressurizer	Voiding	9
	Phase distribution	8
	Critical flow	7
	Exit enthalpy	7
	Boiling	6
	1ϕ, flow	5
	2ϕ flow	4
Cold leg	Voiding	9
	Phase distribution	8
	HPI	7
	1ϕ, flow	5
	2ϕ flow	4
Hot leg	Voiding	9
	Phase distribution	8
	1ϕ, flow	5
	2ϕ flow	4
Surge line	Voiding	9
	Phase distribution	8
	1ϕ, flow	5
	2ϕ flow	4

that a consistent set of individual ranks is combined to produce a defensible global ranking. The mathematics of the AHP provides a quantitative measure of the consistency of the ranking process, and the record of input kept by the analysis ensures traceability for each decision made in the analysis.

The B&W LOFW analysis being addressed here used both of the ranking processes described above. The results were combined and assessed to determine the important phenomena, which were determined to be:

1. Stored energy and decay heat generation in the core,
2. HPI mass flow rate,
3. Critical flow rate through the PORV, SRV and MADV,
4. Fluid conditions exiting the system through the PORV (exit enthalpy), and
5. The phase distribution and voiding throughout the system.

These phenomena and fluid states control the circulation of core coolant and its subcooling, as well as the energy discharge rate from the primary system.

CONCLUSIONS

The following conclusions were drawn from this work. Our conclusions focus on the use of the methodology, and not on the results obtained for a particular application. Those results are presented in the nature of an example application.

1. The AHP is a useful tool for guiding the decisions of technically savvy people in the assessment of the important components and phenomena in complicated physical systems.

2. The results can be critically assessed to determine whether they correctly represent the general feelings of the people ranking the phenomena on a pairwise basis.

3. The records of the reasons for each pairwise rank provide a traceable path to assess the final results.

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