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PROCEDURES FOR CONDUCTING INDEPENDENT PEER REVIEWS OF PROBABILISTIC SAFETY ASSESSMENT

GUIDELINES
FOR THE INTERNATIONAL PEER REVIEW SERVICE (IPERS)
PROGRAMME

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FOREWORD

Independent peer review should be an integral part of any Probabilistic Safety Assessment (PSA). The value of the benefits of a valid PSA may be many times the cost of the study, as demonstrated by a recent report in the United States (EPRI NP-5664) based on utility experience and USNRC perspectives in the practical application of probabilistic risk assessment (PRA). Independent peer review and revisions, as necessary, give a degree of assurance of validity.

The need for independent peer review has been demonstrated since the early days of PRA. The landmark PRA study, WASH-1400 (the Reactor Safety Study (RSS)) in the United States, even though focused on the development of PRA methodology, yielded many important safety related insights. For example, one conclusion of the RSS was that human error, small loss of coolant accidents and transients were important contributors to risk. In addition, the RSS analysed an accident sequence similar to that in the Three Mile Island accident. Although the probabilistic accident sequence and systems modelling part of the RSS was subjected to independent peer review, this took place after the study was completed and the peer review report was not published until three years later. Owing to real weaknesses in some parts of the analysis, disagreement over the treatment of some probabilities and an executive summary which did not reflect the main report, the study was controversial.

The controversiality undermined confidence in the RSS findings and as a consequence PSA methodology, and particularly the RSS insights, were not used in safety regulations. The key lessons of the RSS were valid and were quite unaffected by the weak areas identified in the analyses. Independent peer review before completion of the RSS would have allowed the weaknesses to be identified or remedied, thus facilitating the early acceptance and implementation of the very important safety significant lessons yielded by the study. Independent peer review is now recognized as an integral and essential step in a PSA.

Accordingly, the IAEA recently initiated the International Peer Review Service (IPERS) programme which brings international experience into the review process.

Depending upon the Level (1,2 or 3) and degree of completion of the PSA study, an IPERS would take three to five weeks and comprise three to five experts, each from a different Member State with an Agency technical officer leading the review. Preceded by a pre-IPERS mission to review the documentation and translation requirements and prepare a detailed schedule, the IPERS consists of four main steps:

- Preliminary review of PSA study documentation.
- Compilation of a detailed list of questions (probably in one week at IAEA headquarters, Vienna) and transmission of the questions to the host Member State.

- Mission to host Member State to discuss and receive responses to questions, to review more detailed documentation, to compile and resolve any further questions and to write the draft IPERS report.

- Discussion of the findings of the draft IPERS report with the host authorities before the review team returns to Vienna to finalize the report.

The basic disciplines typically covered in a review include event tree analyses, systems analyses, human reliability analyses, data analyses, quantification and uncertainty propagation and external event analyses (if these are included in the PSA).

This document is intended to serve as guidelines both for the conduct of an independent peer review of a PSA and for the IPERS programme. The document gives guidance on how an IPER service is conducted, the procedure and steps needed for preparation of an IPER and the technical areas normally covered.

CONTENTS

1. INTRODUCTION

This document presents guidelines for the review of a probabilistic safety assessment (PSA). The review guidelines presented are consistent with guidelines to be published in 1989 in the IAEA Safety Series on the conduct of a PSA (Guidelines for the Conduct of PSA in NPPs, Draft IAEA Safety Series Report, 1989). However, the present guidelines are for the review of a PSA and are organized according to specific areas and emphases in the review. The document deals with the following specific topics in the review of a PSA:

- the focus of the review
- the timing of the reviews
- the size of the review team
- the composition of the review team
- the length of the review
- preparation for the review
- specific areas to be covered
- conducting the review.

2. FOCUS OF THE REVIEW

A review of a PSA can focus on one or more of the following technical areas:

(1) The general validity of the assumptions, models, data and analyses used in the PSA.

(2) The validity of the results obtained in the PSA.

(3) The validity and applicability of the PSA models as tools to assist operations.

(4) The validity and applicability of the PSA models for meeting specific objectives for their use.

When the focus is the general validity of the PSA, the review is carried out to assess the general validity of the assumptions, models, data and analyses used in the PSA. The review can be carried out by selecting specific systems or specific accident sequences for review in depth. However, the systems or sequences are selected (sampled) with the objective of assessing the general validity of the PSA. The systems, sequences, data and analyses selected for review are those judged, on the basis of experience and other information, to represent the important parts of the PSA.

When the focus is on the results of the PSA, the review is centred on the qualitative and quantitative results obtained in the PSA. Emphasis is placed on the dominant contributors to the core melt frequency and to other results of interest in the PSA, which are concentrated on and are specifically assessed for their validity. The assumptions, models, data and analyses associated with the dominant contributors are selected for review in greater depth.

When the focus is the PSA as an operational tool, the review is carried out to assess the validity and applicability of the PSA as a tool for use in operational applications. These include applications to evaluate technical specifications, applications to evaluate precursors and other events that occur at the plant, and applications to monitor plant performance. The focus of the review is not only the validity of the PSA models and analyses as they represent the actual plant, but also the applicability of the PSA models and analyses for effective and efficient use in operational applications.

Finally, when a detailed objective of the PSA is the focus, the review is concentrated on specific purposes for which the PSA was performed. For example, if the PSA was carried out to evaluate the impacts of a proposed backfit, then the review is focused on evaluating the validity of the assumptions, models, data and analyses specifically related to the backfit modifications.

This Technical Document presents guidelines for reviews carried out with the first focus: to assess the general validity of the assumptions, models, data and analyses used in the PSA. The guidelines presented are also applicable to some degree to reviews carried out with other foci, which tend to be more specific. In this case, the guidelines would need to be supplemented by additional considerations relating to the more specific focuses of the review.

Instead of focusing on technical areas, the review can focus on managerial or documentational aspects of the PSA. Technical reviews focus on the technical validity of the assumptions, models, data and analyses of the PSA. Managerial reviews focus on the management and organization of the PSA activity. Documentational reviews focus on the formats used in documents that present the assumptions, models, data analyses and results of the PSA. The present Technical Document does not generally deal with managerial or documentational reviews; however, certain of the guidelines that are presented for technical reviews also pertain to managerial and documentational reviews.

3. TIMING OF THE REVIEW

If one review only is performed, it should be carried out when the PSA has been completed or when event trees and fault trees have been initially completed and initial PSA results have been obtained. In carrying out the review at this completion or initial completion stage, the basic assumptions, models, data and analyses of the PSA can be reviewed and the dominant contributors to the PSA results can be checked.

It is preferable to conduct two reviews, if possible: the first at an intermediate stage when the PSA is 50–75% complete, and the second when the PSA is complete. The first review can focus on whether the fault trees and event trees have proper bases and are being properly constructed, and whether the data collection and quantification analyses are being properly carried out. Any deficiencies found in the intermediate review can be identified and corrective measures taken in a timely and resourceful manner. The second review can be carried out with its focus on the final models and results and the issues identified in the first review.

4. SIZE OF THE REVIEW TEAM

The team should be large enough to cover the basic disciplines in the PSA. These basic disciplines are:

- event tree analyses
- systems analyses
- human error analyses
- data analyses
- quantification and uncertainty propagation
- external event analyses (if included in the PSA).

To cover these disciplines there should ideally be a team of four to six members. This constitutes a manageable group that can interact effectively and that can review the PSA in one or two review sessions. Team sizes may vary, depending on how many disciplines are represented by each team member. However, having a team of fewer than four persons would generally place a considerable burden on members in having to review several areas of the PSA. Review teams of more than six persons are generally less effective, and, if used, the responsibilities and interactions of the team members need to be especially well defined.

5. COMPOSITION OF THE REVIEW TEAM

The team members should themselves preferably have previously carried out PSA analyses of the types that they are to review. They should also preferably have carried out PSA analyses of these types on a reactor of the same type as that investigated in the PSA to be reviewed, although this is not absolutely essential. Preferably, at least one team member should have a good knowledge of the specific plant design. There should be a strong liaison with an individual who has intimate knowledge of the plant. This person may be an additional team member for liaison to whom questions about the plant may be addressed.

The team should have a leader with the responsibility for co-ordinating the individual members' reviews. If the team leader is not competent in the language in which the PSA was documented, there should be a translator available to the team, serving as an addition liaison member; the translator should preferably be a technical person.

6. PREPARATION FOR THE REVIEW

The individual review team members should obtain a knowledge of the design and operation of the plant in order to prepare for conducting the reviews and for liaison with the PSA analysts. The team members should also obtain a preliminary knowledge of the modelling and analyses carried out previously. In order for the members to obtain this understanding, the following material should be made available to them at least four weeks before the review.

(1) Functional descriptions of selected safety and support systems. These should describe: the function of the system; which components must operate; which components receive signals to change state; whether the operations of the components are manual or automatic; and what conditions must pertain for the automatic signals to be received.

(2) System schematics for selected systems. The system schematic should not be as detailed as the plant system diagram, but the schematic should show the system as modelled in the fault tree. The schematic should identify the components included in the system model and should show their normal configurations, but should not include instrumentation, piping that is not significant, or components that are not significant for system performance.

(3) Selected functional event trees describing the safety functions required for given initiating event groups. Performance of each safety function should be defined in terms of specific system success requirements. Functional dependences among the systems should be identified.

(4) Bases and approaches for analyses to be carried out in the different areas of the PSA (human error analyses, data analyses, etc.). The bases and approaches should be made available to the appropriate team members reviewing these areas.

The systems descriptions, event tree descriptions and analyses should be selected from the documentation available on the basis of experience in past PSAs of dominant contributors and problem areas. Appendix I lists sequences and systems that have been found to be important in past PSAs of pressurized water reactors (PWRs) and boiling water reactors (BWRs).

7. LENGTH OF THE REVIEW

The review of the PSA should preferably last at least five weeks in order to be able to cover the different areas effectively and to evaluate its assumptions, models, data, analyses and results effectively. These five weeks comprise two weeks in the host country and three weeks for the reviewers to study the analyses and to prepare their reviews. The time weeks can be scheduled as follows:

First week: Review the preparational material that has been received on the plant's design and operation. Also review the analyses received. Prepare a set of questions for the PSA analysts.

Second week: Liaise with the PSA analysts to obtain answers to questions and to review specific steps in the analyses. Obtain information from plant personnel if necessary and determine whether a visit to the plant is necessary. Document the information obtained from the liaison with the analysts.

Third week: Review the notes and documented material obtained from the liaison with the analysts. Prepare a second set of questions and prepare preliminary review findings.

Fourth week: Liaise for a second time with the PSA analysts to determine their responses to remaining questions and to the preliminary review findings. Visit the plant if necessary and liaise with the plant personnel if necessary. Also, identify how issues raised in the previous liaisons have been dealt with. Document the liaisons.

Fifth week: Prepare a review report on the PSA.

In the first, third and fifth weeks of this schedule, the review team assembles to review documented material and notes made, and to identify questions and issues. The questions should be put in writing to the PSA team. The review team leader should ensure that there is no duplication of questions. In the second and fourth weeks, the team members liaise with the PSA analysts to obtain their inputs on the issues and questions raised, and to gain an understanding from them of the assumptions, models, data and analyses used. It is preferable for the five weeks to run consecutively; however, it is acceptable for there to be intervals between the weeks if necessary.

This schedule can be applied whether only one review is performed on the PSA or whether two reviews are performed (as discussed in Section 3). If two reviews are performed, each review can follow this schedule.

The schedule is presented as guidance; it can be modified if necessary to meet constraints on the review. For example, if it is not possible to liaise with the PSA analysts on two separate occasions, the third week can be omitted from the schedule and the second and fourth weeks, including liaison with the analysts, can be combined in a single two week session. This shortens the review by a week and will make it less comprehensive, but it can still be effective.

8. SPECIFIC AREAS TO BE COVERED

The specific areas to be covered in the review should include:

- an initiating event review
- an event tree review
- a dependent failure analysis review
- a human reliability analysis review
- a component data analysis review
- a sequence quantification review
- an external event analysis review (if this was in the PSA).

In addition to these areas, the following related areas may also be covered by the review:

- The assurance in the PSA that the design and procedures are up to date and reflect the plant as it is.
- The internal quality assurance process instituted as part of the PSA to validate the analyses and results.
- Liaisons set up in the PSA with plant personnel and the contributions of plant personnel to the performance of the PSA.
- Liaisons set up in the PSA with regulatory personnel.

9. CONDUCTING THE REVIEW

This section presents specific guidelines for conducting the technical review of a PSA. The IAEA has published guidance for performing a PSA. The review guidelines presented here are consistent with that guidance. The guidelines are organized according to the areas to be reviewed, as identified in Section 8.

9.1. Identification and grouping of initiating events

The PSA should identify the two major types of initiating events:

-- loss of coolant accidents (LOCAs)
-- transients.

The PSA should identify the different sizes of LOCAs considered, which should be based on the different sizes of piping that can be breached. The reviewer should pay particular attention to the criteria used to identify and group the LOCA initiating events. The sizes of LOCAs should be categorized and grouped according to the different systems required for the prevention or limitation of core damage. Appendix II gives the LOCA sizes that are generally considered for PWRs and BWRs. The bases for system requirements should be documented and based upon plant response analyses or safety analyses reports. The reviewer should check that this information was identified and documented in the PSA.

For transient initiating events, the PSA should identify the bases for the set of transients considered. Attention should be paid in the review to the bases for identifying and grouping the transient initiating events. The reviewer should check that the transient reference source is consistent with standard sources of transient definitions. Appendix III gives transients that are generally considered for PWRs and BWRs. The generic set of transients should have been reviewed by the PSA analysts to determine those events that are relevant for the specific plant. The selected transients for the plant should be grouped according to the systems required to respond to the transient. The bases for the grouping should be clearly defined. The reviewer should check that this information was identified and documented in the PSA. The reviewer should also select specific transient events to check the bases for the selection and the grouping.

In addition to generic, or standard, sources used to identify transient events, plant specific transients should be covered in the PSA. These plant specific transients should include, where relevant:

-- loss of an AC or DC bus that can cause a plant trip
-- loss of instrument air that can cause a plant trip
-- loss of service water that can cause a plant trip
- interfacing loss of coolant initiating events occurring when high pressure coolant flows back through low pressure piping
-- steam generator tube ruptures.

The reviewer should check that, where relevant, these types of plant specific initiating events are identified and considered in the PSA.

Since loss of off-site power resulting in station blackout has been a dominant contributor in PSAs, the reviewer should check that particular attention was paid to this type of initiating event in the PSA. The bases for the frequencies of the initiating events and the durations of outage times should be clearly documented and there should be clear connections with the database tasks. Special attention should be paid to pump seal failures that result from loss of power and that depend on how long power is lost. There should be clear connections between the descriptions of the initiating event for and the duration of the loss of power, and the associated event trees defining the loss of power sequences and resulting effects such as pump seal failures. The reviewer should check that these areas are clearly identified and are considered.

The issue of plant specific initiating events is especially important in the PSA. Further points that should be specially considered in relation to plant specific initiating events are as follows:

-- The PSA should include analyses of plant specific initiating events caused by loss of support systems and by system actuations. Losses of feedwater, of instrument air, of condenser vacuum and of control of pressure operated relief valves should be included in the potential initiators.

-- The PSA should also include analyses of the effects of losing normally operating systems, or their subsystems, that also have safety functions after a reactor trip. Examples of such systems include service water systems, power supply buses, direct current systems and air systems. The fault tree approach for identifying potential initiating events, or its equivalent, should be used in the PSA to identify the candidate events that can cause a trip.

-- Spurious actuation by instrumentation should be assessed for its trip implications in the PSA. Loss of cooling and loss of ventilation, as support functions, should also be assessed. Loss of cooling to solid state components associated with instrumentation should especially be considered.

-- Breaks of secondary circuit piping, especially relevant for PWRs, including steam line breaks and feedwater line breaks, should be considered as special types of transients.

-- The effects of a candidate failure or candidate actuation should be analysed in the PSA by systematic approaches such as failure mode and effects analysis (FMEA). The reviewer should check that such systematic analyses were performed for all the support systems, systems that can be actuated and normally operating systems that can potentially cause a trip.

-- The reviewer should select particular plant specific initiating event analyses for further review. The analysis of a support system whose loss is not generally considered a plant specific initiating event should be included in the cases selected.

-- Although analysis of plant specific initiating events is sufficient to evaluate whether the loss of a system or component can cause a reactor trip, the logic is generally insufficient to determine whether a failure or actuation increases the unavailability of a safety system and to what degree. This question must be answered by means of the event tree analysis tasks and systems analysis tasks. The reviewer should check that adequate interfaces have been set up between the systems analysis tasks, the event tree analysis tasks and the initiating event identification tasks to deal with this question. These additional analyses and interfaces are further considered in the review guidelines on dependent events that are given in section 9.4.

-- Finally, the reviewer should check whether plant experience has been reviewed to identify which trips were caused by systems and components, and whether these were included in the definitions of initiating events. The plant experience should be analysed on this basis by the PSA team, if it has not already been.

9.2. Accident sequence (event tree) analysis

Event trees should be devised for the groups of initiating events that are included in the PSA. To form the basis for the detailed event trees devised, functional event trees should first be devised in the PSA for each of the different groups of initiating events. The success requirements for the system to satisfy each function in the event tree should be defined. The reviewer should determine whether these functional event trees and system success requirements are clearly identified and whether the bases are documented in the event trees.

In the PSA, the detailed event trees with the system failure modes should then be devised on the basis of the functional event trees. Specific points to review in the detailed event trees are the following:

-- The event tree descriptions should include descriptions of conditions created by the initiator and the chronological requirements of systems for the different event tree branches.

-- Success criteria for the systems required in each event tree should be explicitly defined and should be justified. The success criteria for front line systems should be expressed in terms of performance criteria (flow, response time, etc.) related to functional requirements. These should in turn be expressed in terms of hardware requirements (number of trains required, etc.). Mission time requirements should be justified from functional and operational standpoints. Support system requirements should be based on success criteria for front line systems.

- The success criteria may be based on requirements in Final Safety Analysis Reports (FSARs). However, these may be conservative, and more realistic criteria are preferable. If more realistic criteria are used, they should be justified by the appropriate analyses. Sensitivity analyses should be performed if the effects of different success criteria are in question.

-- Criteria for what constitutes core melt and for which sequences are identified as causing core melt should be clearly stated. For each sequence so identified, it should be explained why it is identified as causing core melt.

-- If, in an event tree, the success criteria of a system depend on the prior success or failure of other safety systems, the criteria should be documented and justified. An example of this is the requirement for one-of-two or two-of-two trains of the low pressure injection system (LPIS) after the success of two-of-three or one-of-three accumulators in the case of a large LOCA event tree for PWRs.

-- If simplifications or assumptions are made in the event trees, their effects should be clearly identified and should be justified. PSA project members should be aware of all the assumptions and simplifications made, and should list and file them.

-- In the sequence descriptions, one of the most important aspects is the timing for system actuations and operator actions. The timing is an important input for the human reliability analysis task and should therefore be explicitly identified for the different sequences.

-- The rationale for the timing for systems actuation or operator actions should be documented and references for it should be given.

-- If expert judgement is used to estimate timings, the qualification of the assessor must be checked. Personnel from the operations organization of the plant should have taken part in the estimation process. The participation of personnel experienced in accident analysis is also desirable.

- After reviewing the event tree preparation process and documentation, the reviewer should select an event tree and go through its preparation process in detail to assess the adequacy of the modelling, assumptions, simplifications and timing estimations. Event trees that are generally important contributors to the core melt frequency for PWRs and BWRs are given in Appendix I.

- The reviewer should check that the personnel who prepared the event trees communicated with the personnel who participated in the systems analyses, human reliability analyses and sequence quantifications, which require the event tree inputs.

- If the different system success requirements in the event trees are modelled by means of house events in the system fault trees, then the house event descriptions should be reviewed and the interfaces with the respective event trees should be checked.

- If support system states are identified in the event trees, the documentation of the system states and the interfaces with the fault trees should be checked.

9.3. System (fault tree) analysis

Fault trees should be developed for each system failure mode identified in the event trees. To provide a valid and auditable basis for the fault trees, the reviewer should determine that functional descriptions are clearly documented for each system for which a fault tree is devised. The functional descriptions should describe the function of the system; the components that must operate and their normal configuration; the components that must change state and their normal configuration, whether the component operations are manual or automatic; and the conditions that must exist for automatic signals to be received by the components.

In addition to the functional descriptions, a schematic system diagram should preferably also be drawn for each system for which a fault tree is devised. This system schematic should be a simplification of the plant system diagram and should show the system as modelled in the fault tree. The schematic should show the components and their normal configurations identified in the fault tree and should show (as simple lines) the pipe segments or wiring segments connecting the components. The support interfaces (power, cooling, etc.) should be clearly identified in the system schematic. It is also useful to have simplified schematics for the control wiring of remotely operable components. Instrumentation is generally not included in the schematics; however, it is useful to have identification tables for the instrumentation in each system that identifies the power supplies and other significant support systems. The reviewer should assess whether all this information is clearly identified in the schematic. The reviewer should also check that interfaces with plant personnel were established to check the accuracy of the schematic.

Additional, specific points requiring attention in the systems analysis review are as follows:

- Hardware dependences should be explicitly modelled in the fault trees. These hardware dependences include all the functional dependences within the same system. The hardware dependences should not be included in the 'residual' common cause failure dependences that are reserved for more ambiguous dependences and are quantified by means of beta factors and similar approaches.

- Shared component dependences should be explicitly identified in the fault trees for different systems (or different system failure modes) containing the same component.

- If the limit of resolution for the fault trees is based on consistency with available component reliability data, the reviewer should check that the component boundaries and component failure modes are consistent with those defined in the component failure database. The reviewer should check that the fault tree analyst liaised with the database analyst on these points.

- The reviewer should also check that the degree of resolution of components is not so gross so as to hide hardware dependences. This hiding of hardware dependences should also be checked for if components are grouped together into 'super components', or modules. Super components or modules should all be functionally independent and should not contain the same components. One important example is for the cooling of a pump. The pump failure mode caused by cooling equipment failure is generally included in the overall pump failure rate. However, cooling sources and cooling interfaces still generally need to be explicitly modelled in the fault tree to identify possible dependences caused by the use by multiple pumps of the same cooling water system or water sources.

-- Hardware dependences can also enter through the support systems for components and subcomponents. Examples of support systems are cooling systems for pumps and rooms, oil systems, power supplies to control circuits or to instrumentation circuitry, air systems and support systems to components in the support systems. The reviewer should check that all these support interfaces are clearly identified and are documented in the fault trees. In reviewing selected fault trees, the reviewer should especially concentrate on the modelling of these support interfaces.

- Within the systems analysis tasks, the search for hardware dependences requires interfaces with the initiating event identification task and the event tree production task. The reviewer should ensure that such interfaces exist.

-- The reviewer should choose selected fault trees and review in detail their development. The system functional description and the system schematic should be sufficiently clear to allow the fault tree to be developed. Appendix I gives the systems that are generally important contributors to the core melt frequency for PWRs and BWRs.

9.4. Analysis of dependent failures

Dependent failures are often dominant contributors to core melt frequency and to other PSA results. The PSA should therefore verify and document that all the different major types of dependent failure are considered. The different common cause contributors can be categorized as:

-- common cause initiators
-- functional dependences
-- human interaction dependences
-- component failure dependences.

This categorization is somewhat different from that defined in the IAEA Guide for Conducting a PSA, which focuses on the step by step process of carrying out a PSA. The categories given here represent a different cross-cut for review purposes.

Common cause initiators

Common cause initiators are initiating events that can simultaneously degrade or fail safety systems required to respond to the initiating event. Common cause initiators that have been particularly important in PSAs are plant trips that simultaneously degrade systems required to respond to them. It should be assessed whether common cause transient initiating events have been dealt with in the PSA and whether they have been properly modelled. The common cause transient initiators to which particularly attention should be paid include:

- Loss of an AC or DC bus that causes a plant trip and also degrades a safety system or causes it to fail.
- Loss of instrument air that causes a plant trip and causes to fail or degrades instrumentation or air operated components.
- Loss of service water that causes a plant trip and a loss of water supply or flooding.
- Interfacing loss of coolant initiating events (interfacing LOCAs) that occur when high pressure coolant flows back through low pressure piping owing to a valve failure.
- Stream generator tube rupture with a failed open relief valve that can cause core melt and produce a pathway for radioactive release.

Functional dependences

Functional dependences and support dependences are dependences between systems or components that occur because of the functional requirements of systems or components. Functional dependences include physical interaction dependences between systems or components, which can occur when the loss of function of a component or system causes a physical change in the environment of another system or component.

The reviewer should check that the PSA clearly shows that the following functional dependences have been considered in the event trees and fault trees:

- shared component dependences
- actuation requirement dependences
- isolation requirement dependences
- power requirement dependences
- cooling requirement dependences
- ventilation requirement dependences
- phenomenological effect dependences.

The reviewer should request that these dependences be identified and should select specific dependences for review in more detail.

Human interaction dependences

Human interaction dependences are dependences between different human errors or are dependences between component failures due to a common human interaction. The reviewer should check that the following human interaction dependences have been addressed by the PSA:

- tests or maintenance that require multiple components to be reconfigured
- multiple calibrations performed by the same personnel
- post-accident, manual backup initiations by the operator that require the operator to interact with multiple components
- post-accident, manual operation of components that require the operator to interact with multiple components.

The reviewer should check that all these activities have been identified, evaluated and documented. The reviewer should determine in particular how the activities were screened and assessed for human interaction dependences. Specific assessments should be investigated for the data used and the quantifications that were carried out. The reviewer should determine that these data and quantifications are consistent with accepted data sources and quantification approaches.

Component failure dependences

Component failure dependences are dependences between component failures that are treated quantitatively by common cause failure probabilities or other dependence quantification approaches. Common cause failure probabilities are usually quantified by utilizing beta factors or other similar factors to increase the probabilities of failure of other components given that one component has failed.

The most important component failure dependences on the basis of past PSA experiences are:

- components of the same type that are calibrated by the same calibration procedure
- components of the same type that have the same maintenance procedure
- components of the same type that experience harsh or abnormal environments.

The reviewer should check that these potential dependences have all been covered in the PSA, and have been evaluated and documented. The reviewer should determine how the above potential dependences were screened for and how their probabilities were assessed. Specific assessments should be selected for further review of the data and quantification techniques used.

9.5. Human reliability analysis

Human reliability analysis in a PSA consists of evaluating both pre-accident and post-accident human actions. To assess pre-accident human actions validly, the PSA should have clearly identified and documented all the following:

- all the components with which the operator or another person interacts
- the tasks and restoration actions that are specifically involved in each interaction
- the relative locations of the different components when the operator interacts with multiple components

- the components that need to be restored and that are alarmed in the control room if not restored
- the times required to restore the components that are in a reconfigured state;
- the type of post-test or post-maintenance validation that is performed after a test or maintenance.

The reviewer should check that all this information is given in the PSA. Specific evaluations of the probabilities of human error should be reviewed to assess the data and quantification techniques used. The reviewer should check that the data and quantification techniques are reasonable and are consistent with accepted data sources and approaches to human error quantification.

To assess post-accident operator actions validly, the PSA should have clearly identified and documented:

- post-accident operator actions required for systems to operate successfully
- post-accident operator recovery actions associated with specific accident minimal cut sets.

The first set of operator actions, those required for systems to operate successfully, includes manual operations of components and manual initiations of components as backups to automatic initiations. The PSA should clearly identify and document all these operator actions, including whether or not the actions can be taken from the control room, the alarm and feedback indicators, the times required for the actions and the stress levels of the actions. The reviewer should check that all this information was available in the PSA and has been properly documented. The reviewer should review specific evaluations of human error probabilities to assess the data and quantification and to determine their consistency with accepted approaches.

The second set of operator actions, those attached to specific minimal cut set accident sequences, include those recovery actions that are intimately linked to combinations of events (the minimal cut set events). The PSA should identify the specific rules used for excluding and including recovery actions and their bases. The PSA should clearly identify and document all the minimal cut sets that have recovery actions and the recovery action included.

In the recovery actions that have been included, the time to diagnose and correct the failures, the indicators of the failures, the location in which the recovery can be performed, and the stress level, together with their bases, should all be identified and documented. The reviewer should check that this information was available and has been properly documented. The reviewer should assess certain recovery actions to check that the data and quantification techniques used are acceptable.

9.6. Component data analysis

Guidelines are given in this section for the review of the component data analysis of the PSA. The component data cover initiating event frequencies, component failure rates, surveillance test intervals, maintenance intervals and maintenance durations (length of maintenance).

The following specific points should be assessed in reviewing the component data analysis of the PSA:

-- Selection of generic data for each type of component must be justified in the PSA documentation. A standard generic database should be used as a basis and justification should be given for specific selections from alternative values or for values used that vary from stated values.

-- If a combination of generic references is used, the method used for selection of the specific reference or for integration of the references should be given.

-- Standby component failure rates should all be rates per hour. If rates are given per demand (per cycle), it must be specifically explained why this is appropriate.

-- If standby component failure rates are given per demand in the generic data sources, they should be translated to per hour failure rates by dividing them by one half the surveillance test interval for the generic database. The selection of the appropriate test interval for the generic per demand data should be documented.

- Once generic point estimates and uncertainty parameters have been estimated for each component and failure mode, the PSA should use plant specific experience, where available, to update the generic data for final use in the PSA quantification. Bayesian approaches should preferably be used to update the generic prior distributions with plant specific data to obtain posterior distributions.

- If conjugate gamma and beta distributions are used for the prior distributions, the method of fitting generic information to the gamma and beta functions should be checked and reviewed. If the distributions are made discrete, the accuracy of the number of discrete points selected, their spacing and the discrete probabilities assigned to the discrete points should be checked.

- The reviewer should audit how the analyst used plant records to make plant specific estimates of the number of events or failures. The reviewer should also check the consistency between the definitions of failure modes used in the PSA and the definitions used in the data records.

- Poisson distribution approaches for time related events should be used for the time independent or demand independent frequency estimation (for the likelihood function). Binomial distributions should be used for demand related events, when this is justified.

- The estimation of the number of demands, operating hours or standby hours is important in the analysis of specific plant records. The reviewer should check this estimation for selected components.

- Consistency between generic and plant specific component boundary definitions is important. Specific cases should be checked to ensure this consistency.

- The basis for the type of components and failure modes analysed in the plant records should be stated explicitly in the PSA documentation. The database reviewer must be able to understand, directly or by means of translation within the review group, the plant record information to ensure that it has been properly used in updating the generic data.

- The results of the generic and specific data analyses should be shown in a table that gives the median and mean estimates and associated 95% and 5% probability limits. Both prior and posterior values should be given. The probability distributions used for the data should be identified. Assumptions made in the generic and specific data analysis should also be documented.

- Mission times that are used for operating failure rates need to be justified. The mission time definitions should include considerations of minimal times to access or replace the components.

- Special quantification of the frequencies of initiating events should be carried out for those caused by failure or spurious actuation of systems. The initiating event frequency (in units of number per year) should be equal to the frequency of failure or actuation. If a fault tree is produced to define the component causes of system failure or spurious actuation, it should be quantified to give the frequency of occurrence and not the unavailability, which is what is usually calculated. The reviewer should check that these special initiators are properly quantified.

9.7. Quantification of accident sequences

The review guidelines for PSA sequence quantification that are presented in this section address the quantification of internal plant contributors (transients and LOCAs). The quantification of external event contributors (e.g. seismic events, fires and floods) is addressed in Section 9.8.

The quantification process for PSA sequences uses initiating event definitions, event trees, fault trees, dependent failure analyses, human reliability analyses and data analyses to produce quantified PSA results. The reviewer should first of all check that the PSA quantification process is systematically consistent with all the other PSA analyses to yield the quantified PSA results.

The PSA reviewer should next check that sufficient PSA results are calculated in the accident sequence quantifications to quantify the PSA comprehensively. The PSA results that are calculated should include:

- the mean core melt frequency with 95% and 5% bounds
- the mean accident sequence frequency for each accident sequence, with 95% and 5% bounds
- the mean system unavailability for each system failure mode in the event trees, with 95% and 5% bounds
- the percentage contribution of each mean accident sequence frequency to the mean core melt frequency
- the contributions of the dominant minimal cut sets to the mean core melt frequency, each mean accident sequence frequency and each mean system unavailability
- the Birnbaum importances and Fussell-Vesely importances of the dominant component contributors to the mean core melt frequency, each mean accident sequence frequency and each mean system unavailability
- Results of sensitivity studies on all questionable assumptions and models or data used that are not covered by the uncertainty analyses.

Specific points that the review should deal with can include the following:

- The reviewer should review the computer codes used to ensure that they are capable of correctly determining the minimal cuts and correctly quantifying the PSA. It should be checked that the codes are being properly run by checking specific inputs to and specific outputs from the codes.

- The reviewer should check that there is a systematic, quality controlled process for determining the minimal cut sets to be used to quantify the system unavailabilities, accident sequence frequencies and core melt frequency. The reviewer should specifically check that the support systems are validly included in the minimal cut set determinations, and that the different fault trees are validly combined to obtain the minimal cut sets for the accident sequence.

-- The reviewer should check that the proper quantification formulae are used to calculate the frequencies of system unavailabilities and accident sequences from the component unavailabilities, initiating event frequencies and human error probabilities. Accepted codes and accepted procedures should be used for this quantification.

-- The Boolean reduction for sequences with system success states and system failure states should eliminate the minimal cut sets in which the failed states of some components are not compatible with the success states of the same or other components. For example, a pump's failure to start and then succeeding in operation (long term running) are incompatible. The reviewer should check that these incompatibilities have been identified in the PSA and have been dealt with.

-- With regard to incompatibilities, the reviewer should specifically check the modelling and quantification of relays with pairs of contacts in the control circuits of components of different systems. If these components are not modelled and quantified in sufficient detail to identify the contacts, there will be errors in the quantification of the sequences, with successful and failed systems containing such components. The reviewer should check whether the project found means to account for these instances of multiple contacts.

- If common cause failures and human dependences are quantified at the sequence level after a truncated set of minimal cut sets has been obtained, the reviewer should check that the truncation criteria used in the PSA do not lead to cut sets being truncated that could be important if common cause failures, dependences and uncertainties are considered.

-- The reviewer should check the process of quantifying dependences at the sequence level to ensure that all dependences identified are systematically quantified with their associated uncertainties. The reviewer should also check the process of including recovery factors after the initial sequence quantification to check that they are systematically included together with their uncertainties.

9.8. External event analyses

The IAEA has prepared guidelines for conducting external event analyses as part of the PSA. These guidelines for the review of the external event analyses performed are divided into review guidelines for the external events selected, review guidelines for seismic analyses, review guidelines for fire analysis and review guidelines for internal flood analysis. The review guidelines for the external events selected in the PSA cover the screening of external events to determine which are potentially important contributors to core melt frequency. The subsections on seismic analysis, fire analysis and internal flood analysis cover additional points for review for these more specific external event analyses, which are often the external event analyses included in a PSA.

External events selected

The PSA should clearly identify the bases for selecting the external events that are analysed in the PSA. If external events are selected (screened) according to their potential contribution to core melt frequency, the screening criteria for selecting the external events should be clearly identified. These screening criteria should be based on an estimate of the frequency with which the external event exceeds the design basis limit of the plant. The reviewer should check whether there are valid bases for the estimate of the external event frequency, and that the design base limits are clearly documented and are justified.

In the screening process, the estimated frequency of an external event beyond the design basis should be compared with the core melt frequency from internal event contributors to determine whether the external event frequency is negligible under the conservative assumption that if the design base limit is exceeded, core melt occurs. If the external event frequency is negligible compared with other contributors to the core melt frequency, the external event can be neglected. Otherwise, more detailed analysis of the external event should be performed, including estimation of the actual likelihood that core melt occurs if the design limit is exceeded. The reviewer should check that such a valid screening approach has been taken.

If more detailed analyses are performed, the reviewer should assess their validity. This means assessing whether the curve of external event frequency versus the severity characterization of the external event is consistent with the appropriate historical data. It also requires an assessment of whether the probabilities of failure of components for external events of given severities have been estimated with valid data. Finally, the probabilities of failures should be properly combined using the accident sequence minimal cut sets of the PSA, and should account for dependences between the failures in the same minimal cut set. The following sections deal with more specific points in reviewing seismic analysis, fire analysis and internal flood analysis, which are often the external events treated in most detail.

Seismic analysis

Seismic analysis in a PSA should include the following steps:

(1) Estimation of the frequency of seismic events as a function of their severity, which is generally characterized by the peak ground acceleration.
(2) Calculation of the transmission of the seismic severity (peak ground acceleration) from the source to determine the severity at the plant.
(3) Estimation of component and structural failure probabilities (fragilities) as a function of seismic severity.
(4) Evaluation of physical dependences among components due to the seismic event.
(5) Estimation of the effects of the seismic event on the possibilities for and probabilities of human error.
(6) Calculation of the core melt frequency due to the seismic event by combining the frequency of a seismic event of a given severity with the probability that the accident sequences occur.

The reviewer should assess that each of these steps is clearly identified in the PSA and that the bases are given for the data and models used in each step. The data and models used should be reviewed to determine that they are consistent with accepted data and models that are used in these areas.

Additional specific points that should be reviewed are the following:

-- The estimation of the curve of the seismic frequency as a function of severity (peak ground acceleration) should be based on relevant historical experience for the regions around the plant or for regions of similar seismicity. The estimation of the curve should consist of a parametric fit to data, with an associated uncertainty distribution. The maximum peak ground acceleration cutoff for the curve should be identified and should be justified.

-- The model used for the transmission of the peak ground acceleration should account for the structure of the soil around the plant. The possibility of soil liquefaction should be considered.

-- The estimation of component and structural fragilities should utilize accepted log-normal approaches or accepted stepwise approaches. Uncertainties for the fragility curves should be quantified and documented. Sources for the fragility curves should also be documented.

-- Evaluation of physical dependences among components should cover all cases in which tanks, walls and ceilings can collapse and fall on critical components and cause their failures. These are often the dominant failure contributors in seismic events. The evaluations should also cover support structures, tables and instrument racks that can fail as a result of the seismic event and cause the failure of critical components.

-- Estimation of the effects of the probability of human error due to the seismic event should identify human error probabilities that are increased by the seismic event and those that are not, with the rationale for these assessments. Human error dependences in the PSA should also be assessed for possible increases in their probabilities due to the seismic event. The recovery actions should be reviewed to identify changes in any conditions due to the seismic event that result in higher non-recovery probabilities.

-- The calculation of the core melt frequency should combine the initiating seismic frequencies and minimal cut set probabilities with sufficient resolution of the peak ground acceleration to provide for an accurate numerical integration over the peak ground acceleration values. The maxima of the component fragility and the component unavailability due to internal plant causes should be used as the component unavailability in these calculations.

- The reviewer should select specific accident sequences in order to review in greater depth the steps used to obtain the contribution to the accident sequence frequency from seismic events. Accident sequences due to loss of off-site power are generally dominant contributors to the core melt frequency from seismic events and should be included in the sequences examined.

Fire analysis

Fire analyses in a PSA should comprise the following steps:

(1) Estimation of the frequency of fires of different size starting in different rooms of the plant.
(2) Calculation of the propagation of the initiated fire and propagation of fire effects to affected components and operators.
(3) Estimation of non-detection and non-suppression probabilities for the initiated, propagating fire.
(4) Evaluation of component dependences and component failure probabilities due to fire effects.
(5) Estimation of the effects of the fire on the possibilities for and in increasing the probabilities of identified human errors.
(6) Calculation of the core melt frequency due to fires by combining the fire initiation frequency with the component failure probabilities.

The reviewer should assess that each of these steps has been clearly documented and that the bases for the data and models are clearly given.

Specific points to address in the review are the following:

-- The documentation should clearly state what initiating event is considered for the initiation of a fire in each area in which a fire is considered. When more than one initiating fire can occur, the PSA should describe the basis for their differentiation.

- If a screening process is carried out, for example to identify critical locations or compartments, the screening technique, including any screening fire initiation frequencies used, should be assessed for its validity.

- Databases used for the fire initiation frequencies should be referenced so that the reviewer can check for consistency between the databases and the data for the plant analysed.

- If generic databases are used to derive frequencies of fires that are not detected and become established, then differences in fire detection efficiencies should be considered in applying the generic data to the specific plant.

- Plant specific data or data from plants similar to the one in question should be reviewed in the PSA to determine whether plant specific fire initiating frequencies can be estimated. If plant specific data exist, plant specific initiating frequencies should be estimated by means of accepted Poisson approaches describing the likelihood and Bayesian approaches describing the uncertainties in the parameters.

- The propagation and the effects of the fire should be calculated by means of one of the accepted fire propagation approaches. Input parameters to the calculations should be reviewed to determine whether they represent the actual plant. These parameters to be reviewed should include the amount of permanent or transient fuel available in each zone. The transmission of smoke through ventilation ducts and the heating of instrument and component compartments should be included in the propagation analyses.

- The probabilities of non-detection and non-suppression should be incorporated into the propagation analysis to determine the probability that the fire propagates to critical equipment without detection or suppression. Account should be taken of the physical layout and of manual as well as automatic actions in determining non-detection and non-suppression probabilities.

-- The estimation for multiple components that can simultaneously fail owing to the fire should include consideration of heat effects, smoke effects and water effects due to the working of fire suppression systems.

-- The evaluation of operator and human error effects related to the fire should take account of the effects of smoke (through ventilation ducts) and hazardous effects due to materials in fire suppression systems.

-- The quantification of barrier efficiency should be documented in the PSA. The reviewer should check whether penetrations in the barriers, such as doors that may have been left open, have been taken into account in probability assignments.

-- If fault trees are developed for fire suppression systems, the treatment of dependences caused by the fire should be reviewed.

-- The results of the fire analysis should be clearly presented and structured as the rest of the PSA analysis. Sensitivity analyses should be performed on the areas of the analysis where especially questionable assumptions have been made. The results of this sensitivity analysis should be presented in the documentation.

Internal flood analysis

The internal flood analysis should comprise the following steps:

(1) Identification of the possible water sources that can cause flooding by releasing water into lower levels.
(2) Evaluation of the frequency of occurrence of an initiating event caused by these sources.
(3) Estimation of the likelihood that the operator does not detect the effects.
(4) Identification of the components that are affected by the flooding.
(5) Calculation of the frequency of core melt due to internal flooding by combining the initiating event frequencies with the probability of occurrence of the accident sequence.

The reviewer should check that all these steps are clearly identified, that the data used are documented and that the calculations performed are clearly presented.

Specific points to consider are the following:

- The initiating event evaluations should include operator errors of inadvertently opening valves as well as tank and valve ruptures.

- Frequencies of initiating events due to human error should have the units of number per year and not the standard human error units of per act. Thus, the frequency of the human activity in question must be included and must be multiplied by the probability of commitment of an error.

- The frequencies of initiating events should first be screened for their potential contribution to the core melt frequency. Initiating event frequencies that are lower than the frequencies of internal event contributors can be screened out.

- Consideration of components affected by flooding should take into account elevations, barriers, doors and drains. Drain blockage should be considered. A conservative approach is to assume that all components fail in the compartment that is affected. If this assumption does not cause a significant contribution to the core melt frequency, the initiating event can be screened out.

- All potentially contributing initiating event frequencies should be evaluated with regard to the means of detecting the event. The means of detecting the event should be considered in estimating the non-detection probability.

- Additional human errors that can occur because of the flooding sequence should be identified and be assessed for their probability. These include, for example, inadvertent isolation of the power conversion system.

Appendix I

SEQUENCES AND SYSTEMS FOUND TO BE IMPORTANT IN PAST PSAs

Tables I and II show accident sequences found by past PSAs to be significant contributors to the core melt frequency for PWRs and BWRs respectively. Tables III and IV tabulate the systems that have been found to be important. Comments are given with the entries in these tables.

TABLE I. SEQUENCES FOUND TO BE IMPORTANT IN PSAs FOR PWRs

Sequence	Comments
Station blackout	Probability distribution for non-recovery from loss of power important. Sensitive to account taken of extraneous power supplies (e.g. gas turbines). Resulting pump seal LOCAs should be considered.
Loss of coolant accidents (LOCAs)	Small LOCAs and interfacing LOCAs generally dominant. Safety injection system failures generally dominant. Failure of long term decay heat removal often involved in dominant sequences. Human errors in reconfigurations and transfers should be considered.
Loss of component coolant water (and similar sequences)	Resulting pump seal LOCAs need to be considered.
Transients	Failure of power conversion and failure of safety injection systems generally involved in dominant sequences. Pressure operated relief valves important. Feed and bleed an important consideration.

TABLE II. SEQUENCES FOUND TO BE IMPORTANT IN PSAs FOR BWRs

Sequence	Comments
Anticipated transients with scram (ATWS)	Credit for manual scram and other alternatives (e.g. standby liquid control) are important considerations. Human error probabilities can have significant impacts.
Transients	Sequences involving failure of long term decay heat removal are generally significant. Sequences involving failure of the power conversion system can be important. Reconfiguration and transfer errors can be dominant contributors.
Station blackout (LOCAs)	See comments for PWRs in Table I.

TABLE III. SYSTEMS FOUND TO BE IMPORTANT IN PSAs FOR PWRs

System	Comment
Auxiliary feedwater	Success criteria vary with sequence. Turbine pumps are generally dominant contributors for loss of power sequences. Common cause failures of redundant motor driven pumps should be considered. Steam binding of pumps can be important.
High pressure recirculation	Success criteria vary with sequence. Human errors involved in transfer and reconfiguration are often dominant contributors. Mission time and repair considerations are important.
Emergency power	Common cause failures of diesels and batteries often dominant. Diesel cooling and battery depletion time are important considerations.
High pressure injection	Non-recovery probabilities are an important considerations. Common cause failures of motor operated valves and pumps are sometimes dominant contributors.
Component cooling water	Success criteria may not be well defined. Common cause failures of pump and maintenance contributions are sometimes dominant.

TABLE IV. SYSTEMS FOUND TO BE IMPORTANT IN PSAs FOR BWRs

System	Comment
Reactor protection	Common cause failures of rods and circuit breakers are generally dominant contributors. Human errors in ATWS procedures should be considered.
Power conversion	Hardware failures and maintenance contributions are often dominant.
Service water	Hardware failures are often dominant. Common cause failures of pumps and valves are sometimes dominant. Maintenance contributions are sometimes dominant.
High pressure coolant injection	See comments in Table III on high pressure injection for PWRs.
Feedwater system	See comments in Table III on auxiliary feedwater for PWRs.
Emergency power	See comments in Table III on emergency power for PWRs.

APPENDIX II

LOCA SIZES GENERALLY CONSIDERED IN PSAs

LOCA initiating break sizes generally considered in PSAs are as follows:

Large LOCA:	Liquid ≧ 0.25 m^2 Steam ≧ 0.25 m^2
Intermediate LOCA:	Liquid 0.005--0.25 m^2 Steam 0.075- 0.25 m^2
Small LOCA:	Liquid ≧ 0.005 m^2 Steam ≧ 0.075 m^2

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Appendix III

TRANSIENTS GENERALLY CONSIDERED IN PSAs

The following tables list the generic transients generally considered in a PSA.

TABLE V. TRANSIENT INITIATING EVENTS FOR BWRs

1. Electric load rejection	21. Loss of FW heater
2. Electric load rejection with turbine bypass valve failure	22. Loss of all FW flow
3. Turbine trip	23. Trip of one FW or condensate pump
4. Turbine trip with turbine bypass valve failure	24. FW, low flow
5. Main steam isolation valve (MSIV) closure	25. Low FW flow during startup or shutdown
6. Inadvertent closure of one MSIV	26. High FW flow during startup or shutdown
7. Partial MSIV closure	27. Rod withdrawal at power
8. Loss of condenser vacuum	28. High flux due to rod withdrawal at startup
9. Pressure regulator fails open	29. Inadvertent insertion of rods
10. Pressure regulatory fails closed	30. Detected fault in protection system
11. Inadvertent open relief valve (IORV)	31. Loss of offsite power
12. Turbine bypass fails open	32. Loss of auxiliary power (transformer)
13. Turbine bypass or control valves cause increase pressure by (closing)	33. Inadvertent startup of high pressure coolant injection (HPCI) or high pressure core spray (HPCS)
14. Recirculation control failure, decreasing flow	34. Scram due to plant occurrences
15. Recirculation control failure, decreasing flow	35. Spurious trip via instrumentation, reactor protection system (RPS) fault
16. One recirculation pump trip	36. Manual scram, no out-of-tolerance condition
17. Recirculation pump trip (all)	37. Cause unknown
18. Abnormal startup of idle recirculation pump	
19. Recirculation pump seizure	
20. FW increasing flow at power	

TABLE VI. TRANSIENT INITIATING EVENTS FOR PWRs

1. Loss of reactor coolant system (RCS) flow (one loop)
2. Uncontrolled rod withdrawal
3. Control rod drive mechanical problems and/or rod drop
4. Leakage from control rods
5. Leakage in primary system
6. Low pressure pressurizer
7. Pressurizer leakage
8. High pressurizer pressure
9. Inadvertent safety injection signal
10. Containment pressure problems
11. Chemistry and volume control system (CVCS) malfunction: boron dilution
12. Pressure, temperature, power imbalance: rod position error
13. Startup of inactive coolant pump
14. Total loss of RCS flow
15. Loss or reduction in FW flow (one loop)
16. Total loss of FW flow (all loops)
17. Full or partial closure of MSIV (one loop)
18. Closure of all MSIV
19. Increase in FW flow (one loop) condition
20. Increase in FW flow (all loops)
21. FW flow instability: operator error
22. FW flow instability: miscellaneous mechanical causes
23. Loss of condensate pumps (one loss)
24. Loss of condensate pumps (all loops)
25. Loss of condenser vacuum
26. Steam generator leakage
27. Condenser leakage
28. Miscellaneous leakage in secondary system
29. Sudden opening of steam relief valves
30. Loss of circulating water
31. Loss of component cooling
32. Loss of service water system
33. Turbine trip, throttle valve closure, EHC problems
34. Generator trip or generator caused faults
35. Loss of power to power
36. Pressurizer spray failure
37. Loss of power to necessary plant systems
38. Spurious trips: cause unknown
39. Auto trip: no transient condition
40. Manual trip: no transient
41. Fire within plant

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