IAEA
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Atoms for Peace and Development

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P15. Evaluation and Rating of Operational Events

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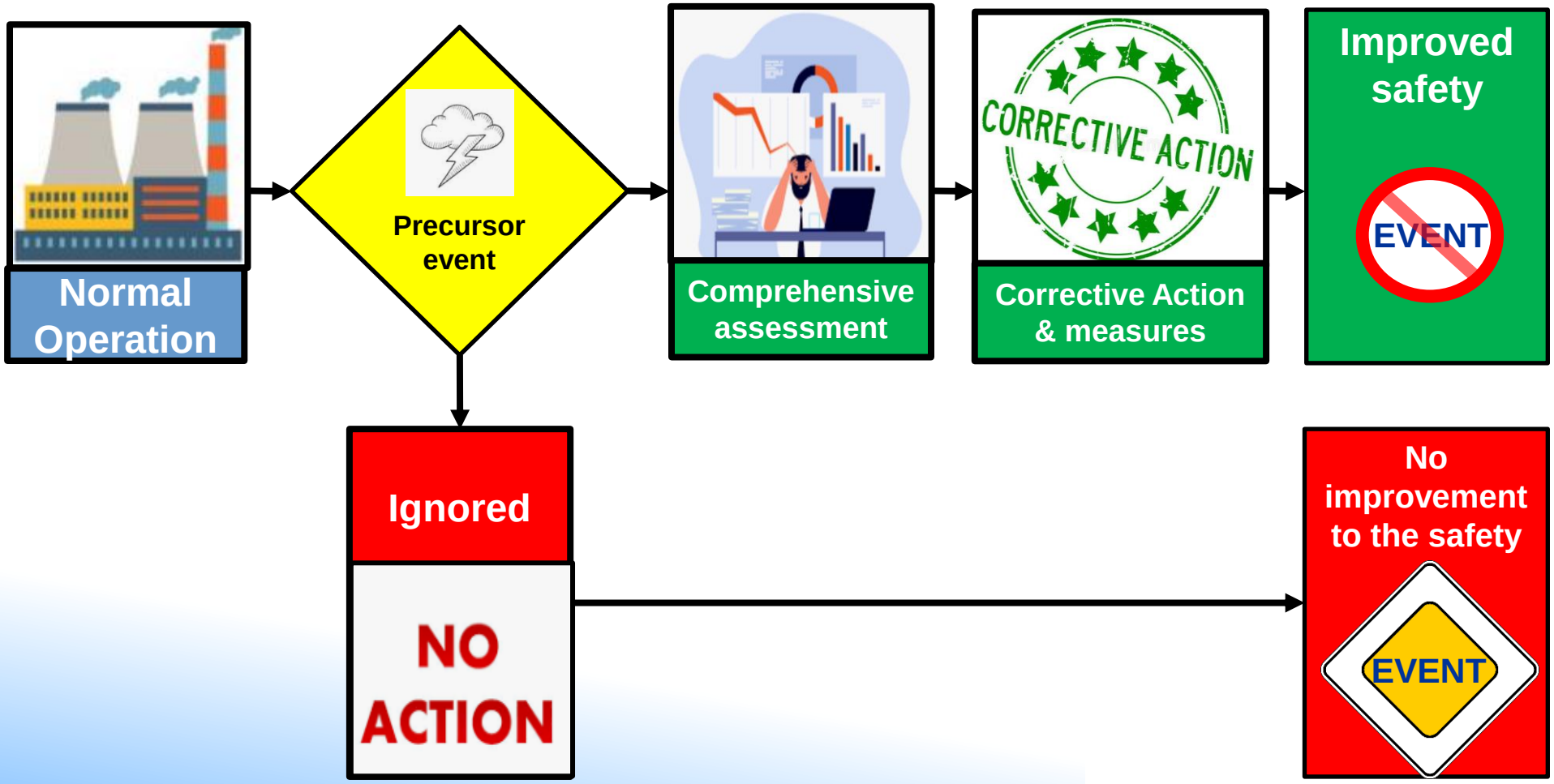
Outline

- Introduction

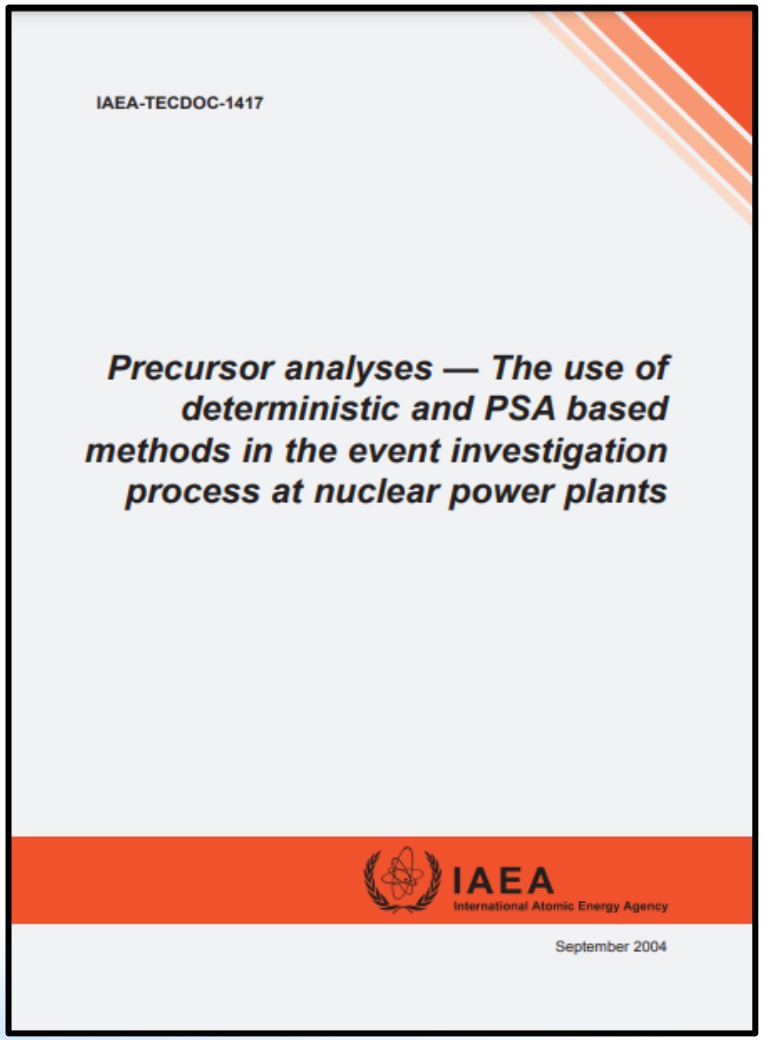
- Overall process
  - Initial Screening of Events
  - Deterministic & probabilistic screening
  - Detailed Deterministic OE Investigation
  - Detailed Probabilistic OE Investigation
  - Consideration & Implementation of Corrective Measures
- Case study
- Conclusions

Introduction

- Precursor is an event that could lead to accident conditions.



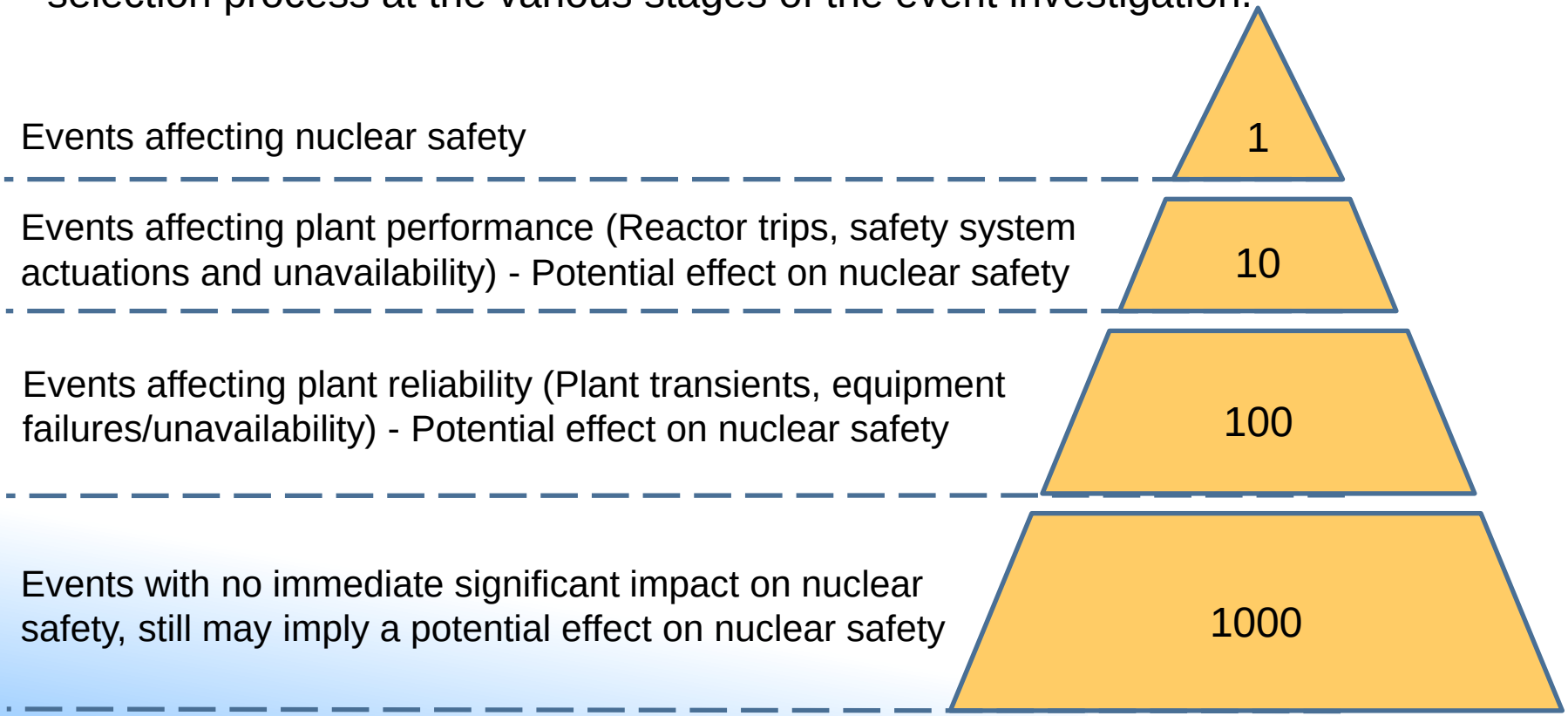
Introduction



- The presentation is focused on the role of PSA based operational event assessment
- The purpose of TecDoc-1417 is to outline process that makes more effective use of operating experience event information by combining the insights and knowledge gained from:
  - traditional root cause event investigation
  - PSA based event analysis.

Introduction

- Large number of events at a plant during a year
- Selection of the few events which are sufficiently significant for detailed evaluation and analysis.
- It is crucial that no events are screened out that are relevant to plant safety.
- Bringing in a different perspective, the PSA-based view helps to support this selection process at the various stages of the event investigation.



Overall process

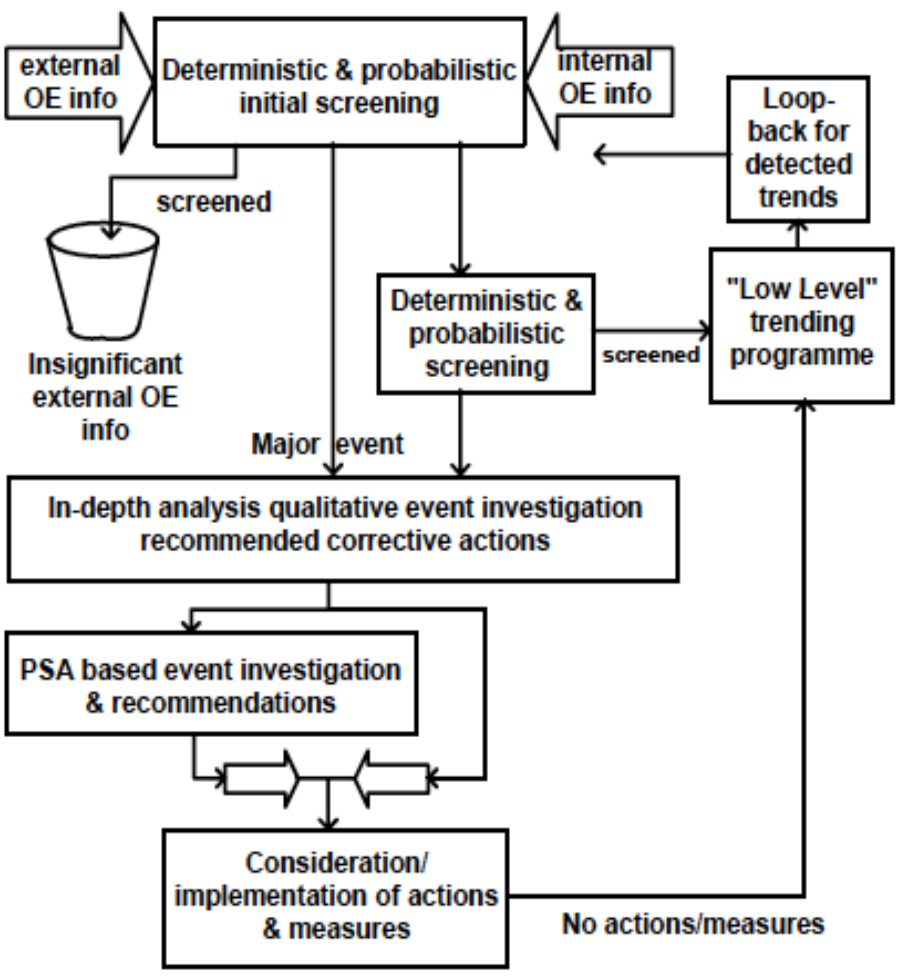
Two main sources of operating experience (OE) information:

1. Off-site or external OE
2. On-site or internal OE

Sources for external OE:

- IAEA/NEA incident reporting system (IRS)
- World Association of Nuclear Operators (WANO)
- Institute of nuclear power operations (INPO)
- Reactor type owners groups etc.

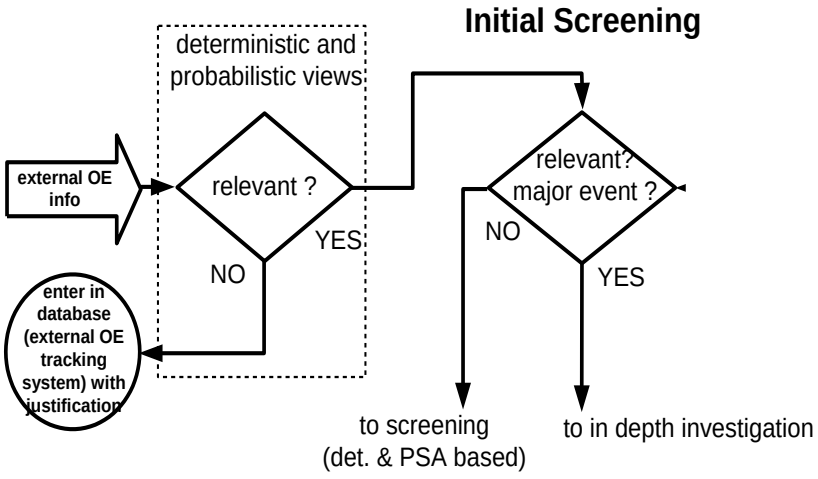
Majority of relevant OE information is from on-site



Overall process

external OE:

- Initial screening of external OE is usually done by dedicated group of staff in a power plant or the utility headquarter (Operating Experience Group).
- other specialists from the plant are involved if necessary.
- The two crucial points for the initial screening and selection are:
  - event is not applicable to the target plant (e.g. differences in plant design and operational features),
  - event is applicable to the target plant (e.g. external OE, from similar plants, is most probably applicable).

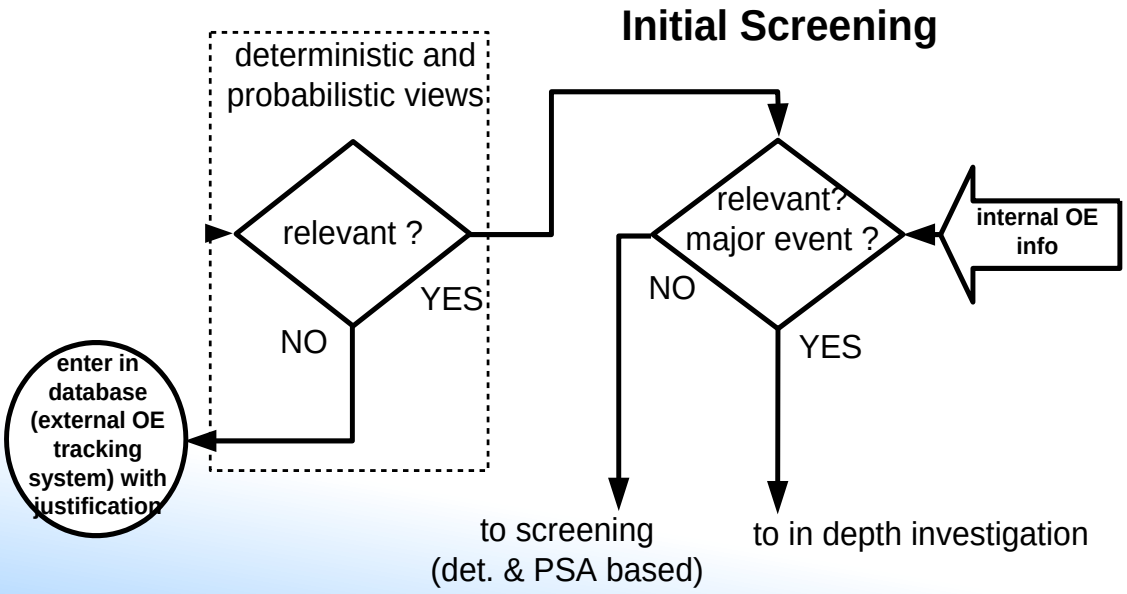


For other external OE applicability might not be straightforward (e.g. shortcomings in procedures). In these cases the related lesson should be learned from event information and transfer it in a useful form to the target plant.

Overall process

internal OE:

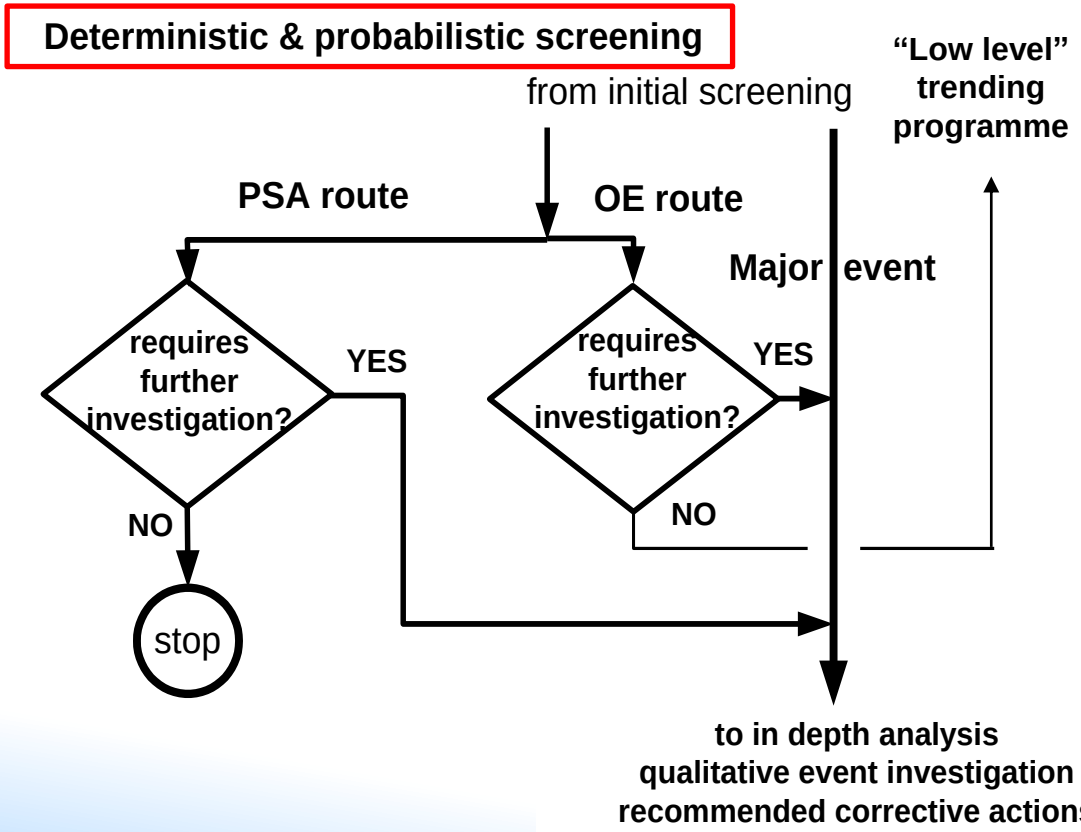
- The majority of relevant OE information arises on-site
- Includes event reports of all types
- In initial screening, “major events” are sorted out and sent to the detailed investigation directly
- All other OEs are forwarded to screening (deterministic and PSA based)



Overall process

Deterministic & probabilistic screening

- The events surviving the initial screening are processed in parallel through deterministic and probabilistic screening
- Deterministic screening is carried out according to established techniques and procedures - not described here
- On-site events which does not result in further detailed investigation are sent “low-level” Trending Programme events database.
  - This database is periodically examined to identify trends and patterns in the data.
  - Adverse trends are identified are treated as events and guided back to the feedback loop.



Overall process

Low Level Trending Programme

- The information for low level events is entered in a database which contains, for example, the following:
  - Date, short event description and event classification such as: nuclear plant event, conventional plant event, radiological event, industrial safety event, nonradiological environmental event and refined subdivision if necessary.
  - Key words from a thesaurus characterizing the event, e.g. identifier for systems and equipment, types problems encountered etc.

- Based on this information the database can be periodically sorted and evaluated to support the detection of trends.

Overall process

Screening: PSA route

List of "PSA equipment":

- Ordered list of PSA related items, such as equipment, structures and human interactions. Today these lists are normally in electronic format and structured in a way to enable a quick check whether or not an event affects PSA related items.
- Note: spatial dependencies

Importance lists:

- Numeric values for the importance of PSA items such as equipment, structures and human interactions.
- Importance measures, e.g.:
  - Fussell-Vesely: contribution of the failure of a particular item to the overall core damage frequency
  - Risk Increase Factor: CDF increase if PSA items are failed

Overall process

Screening: PSA route

Sensitivity calculations:

- Change in the results of the PSA (e.g. CDF) when a parameter, for example the failure rate of a component is increased by a factor of 10.

Simplified precursor modeling for screening:

- PSA Level 1 software has become more user friendly and efficient. Therefore, a precursor event can be evaluated at this stage using the full size precursor approach as explained below, but with simple models, such as failing affected equipment or human interactions.

Judgment of the PSA team using the PSA expertise.

Overall process

- Simplified or condensed representations can be derived from the PSA to carry out a quick and approximate estimate for the risk induced by an operational event:

Example, EdF France

More information TecDoc-1417

- Table in matrix form derived from the PSA.
- Horizontal axis listing safety functions (called lines of defence)
- Vertical axis with initiating events.
- Based on the PSA, “fragilities” (or impacts) have been calculated for the matrix allowing to estimate the risk impact of events involving an initiator or a degradation of lines of defence, or both in combination.

More information TecDoc-1417

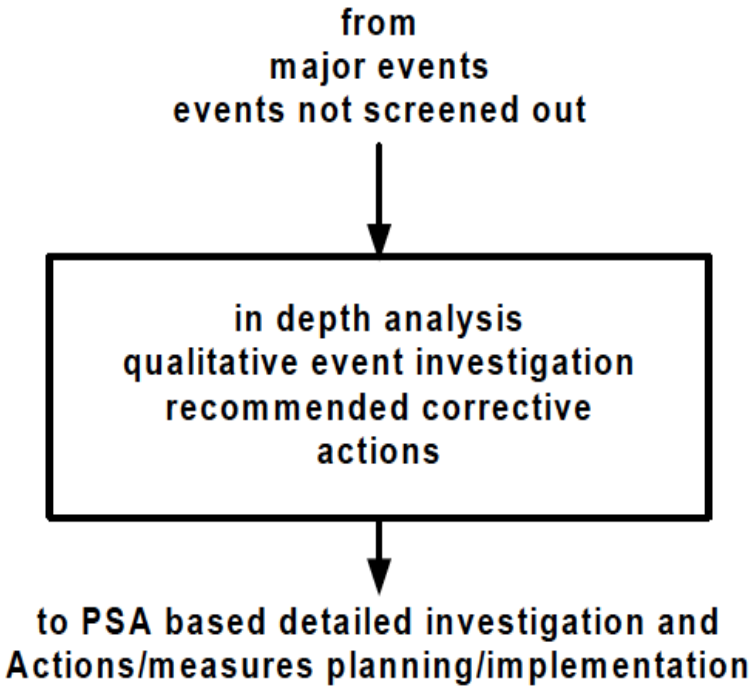
Example: US NRC

- Plant systems vs. Initiators, Support Systems vs. Frontline Systems (dependency matrix)

Overall process

IN-DEPTH EVENT INVESTIGATION

- OE investigations include the elaboration of improvements and corrective measures from:
  - deterministic
  - probabilistic
- Finally the results of both investigations including proposed measures are forwarded to consideration and implementation



Overall process

IN-DEPTH DETERMINISTIC EVENT INVESTIGATION

Examination of the traditional Event Investigation process will identify stages where decision-making can be greatly enhanced by the introduction of supplementary information from PSA based analysis. Consider the basic Event Investigation process in five stages:

1. Establish the facts – **what** happened?
2. Analyse data to determine **how** it happened, and the causes or **why** the event occurred.
3. Develop recommended corrective preventive actions.
4. Report the lessons learned, internally and externally.
5. Conduct an Effectiveness Review.

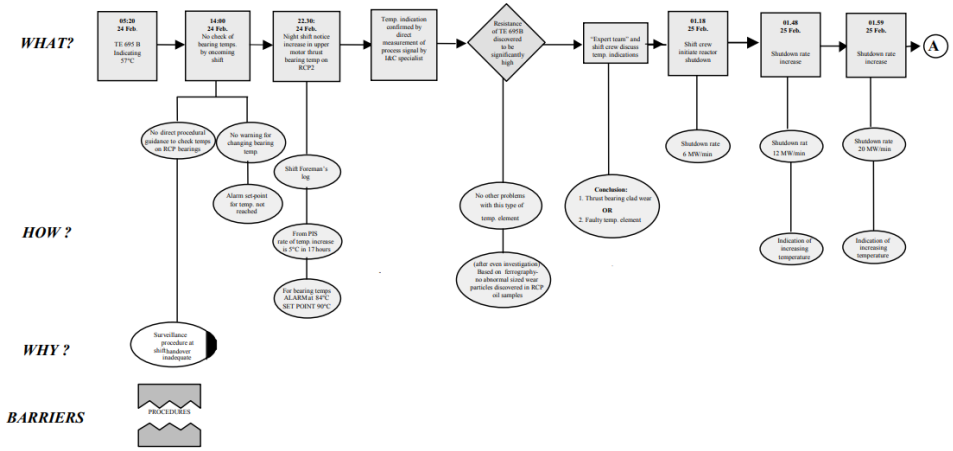
1 and 2 can be undertaken using selected techniques from a number of root cause analysis methodologies (produced guidance on the selection of “Incident Analysis Methodologies” from a toolbox of techniques available to identify causal factors in IAEA-TECDOC-1278)

Overall process

IN-DEPTH DETERMINISTIC EVENT INVESTIGATION

What happened must be determined before How can be established. Only then can Why be deduced.

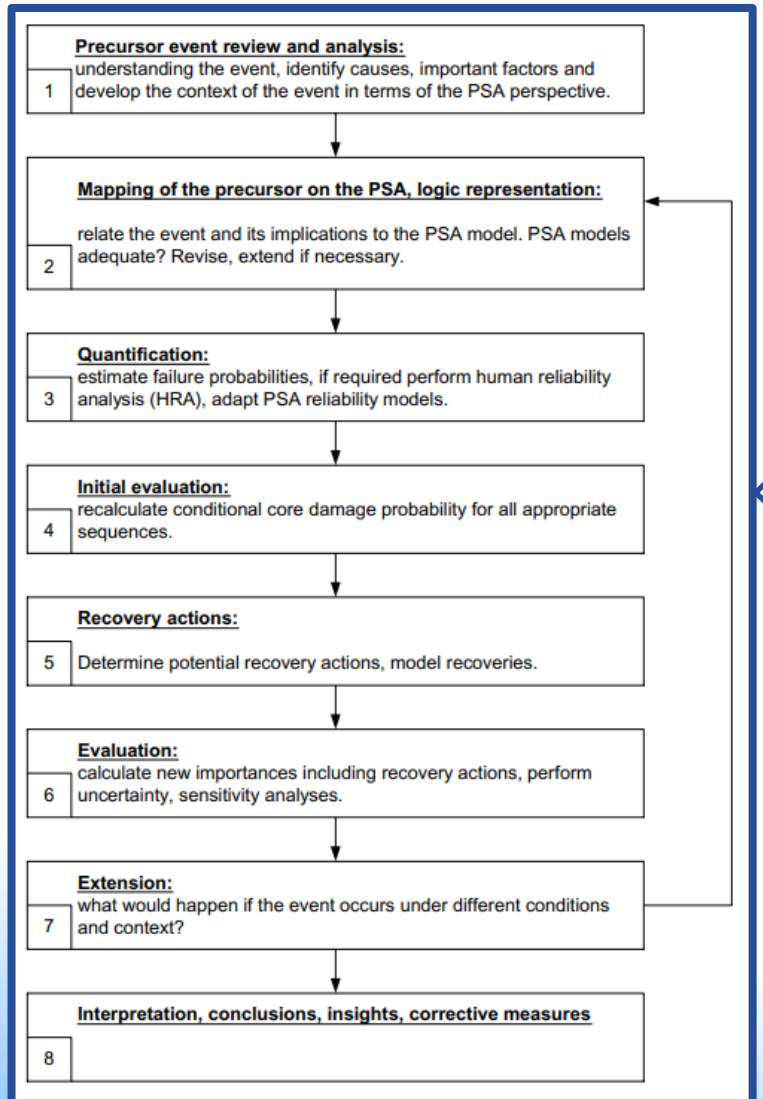
An event and causal factor chart (ECFC) is one way to graphically display an entire event.

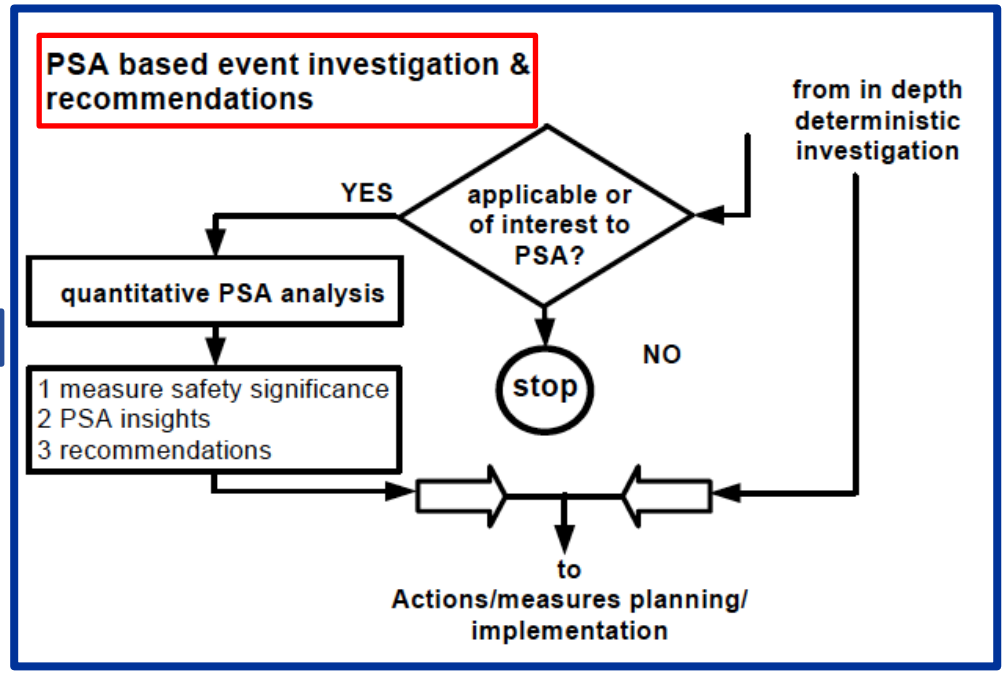


Corrective actions based on causal factors, pro-active preventive actions based on weak barriers and other findings will ensure sufficient reduction of the number of repeat problems

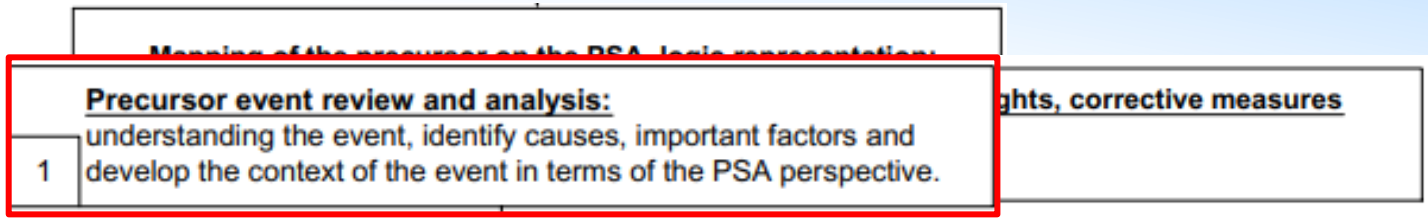
Overall process

PSA-BASED IN-DEPTH EVENT INVESTIGATION





Overall process



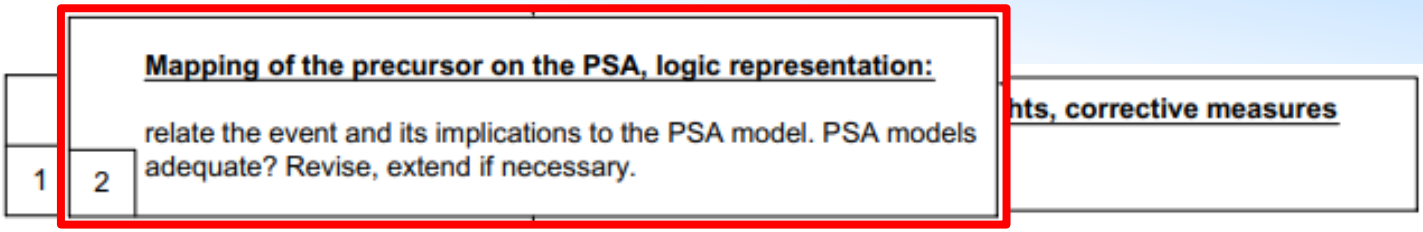
Objectives:

- Develop a thorough understanding of the precursor event and of its context.
- Gathering of additional information regarding the event, related plant design and operational features

Information typically needed:

- Initial status of the plant
- Chronology of events
- Equipment and system deviations, failures and unavailabilities
- Operating staff behavior, actions, deviations and errors, especially actions not covered by procedures and training
- Status of related procedures, whether they were adequate, inappropriate or even missing
- Favorable events, systems which worked successfully, fast detection, successful recoveries
- Conditions or events of interest which occurred or were identified for some time period (like 1-2 weeks) before and after the incident to be sure that hidden complications are not left unaccounted for in the analysis.

Overall process



Mapping of the precursor on the PSA, logic representation: Relate the event and its implications to the PSA model. PSA models adequate? Revise, extend if necessary.

- Which accident sequences are involved or could be involved?
- What fault tree models, basic events or operator actions are affected?
- What recovery actions could be applied?

Mapping process:

Establish the relation between the observed precursor events and the events described in the PSA models.

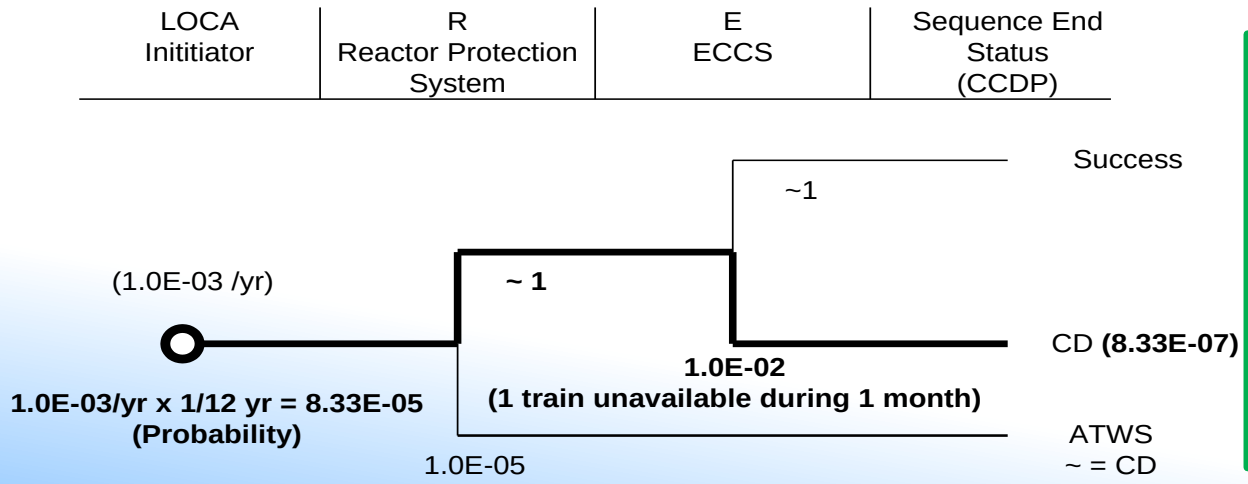
Overall process

		Mapping of the precursor on the PSA, logic representation:	**hts, corrective measures**
1	2	relate the event and its implications to the PSA model. PSA models adequate? Revise, extend if necessary.	

Basically there are the two following types of precursor events:

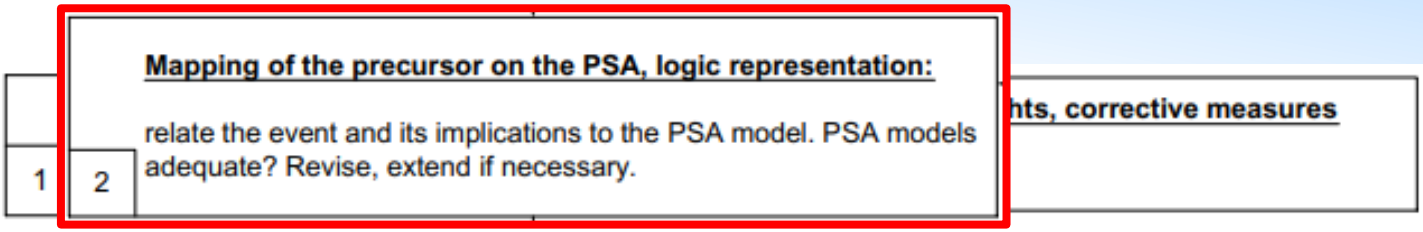
1. The precursor event represents a transient which interrupts normal operation of the plant, thus there is a real effect on plant operation.
2. The precursor event involves the unavailability or a degradation of equipment or systems without an immediate impact on plant operation.

In the example of the introduction both event types appeared together.



CCDP > 1.E – 6	Precursors
CCDP > 1.E – 4	Important Precursors
CCDP > 1.E – 3	Significant Precursors

Overall process

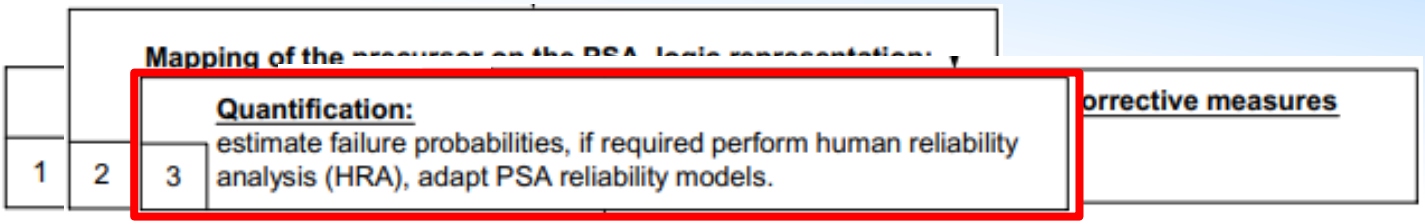


Depending on the type of the given operational event, it is sometimes necessary <u>to adapt or extend the models</u> of the reference PSA due to the following reasons:

- Simplifications and truncation of non-contributing events and sequences in the PSA.
- The level of detail of the PSA events and models is insufficient for directly depicting the operational event in the PSA. In this case, additional considerations are necessary to establish the connection between the operational event and the PSA events and models.
- The PSA is incomplete or inadequate. This would also mean that the reference PSA should be revised ,if necessary.

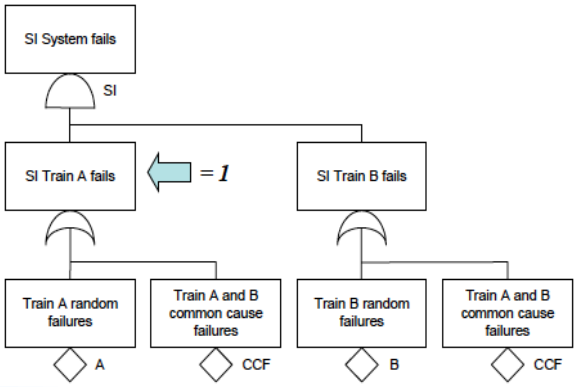
The result of this task is the logic event model for the OE

Overall process

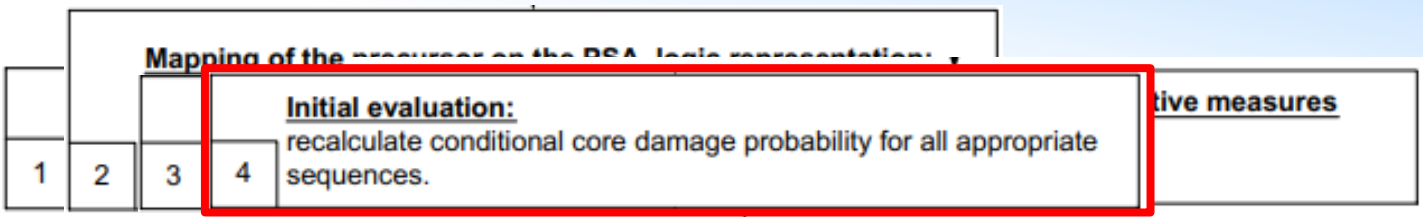


Estimate failure probabilities, if required perform human reliability analysis (HRA), adapt PSA reliability models.

- Map the quantitative precursor data onto the model developed in the previous Task 2.
- Objective: Carry out the quantification reflecting the conditions given for the precursor event.
- This quantification may be conservative, but not excessively conservative. In practice this is done by:
  - Listing the characteristics of each event or sequence (time duration, probability, mission time, failure rate, recoveries)
  - Determining those parameters which reflect the specific conditions of the precursor event.
  - The probabilities of the basic events, in the model which had happened during the incident are set to logical failed or a failure probability of one is used.
  - The probabilities of basic events which did not happen remain at the standard values of the reference PSA.



Overall process

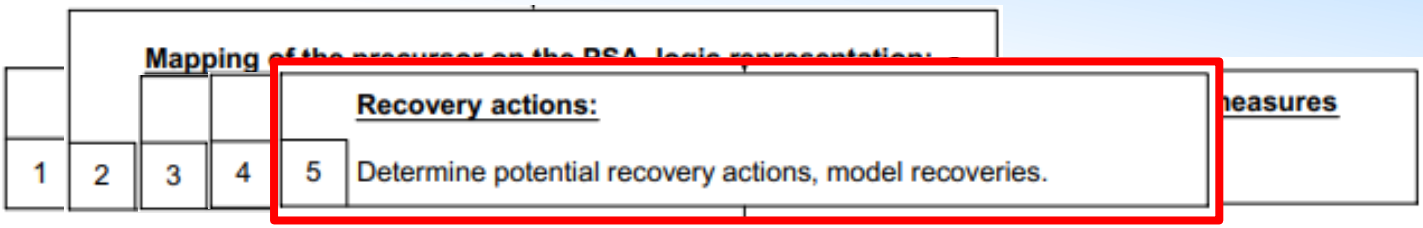


Recalculate conditional core damage probability for all appropriate sequences.

- After assigning the appropriate failure data to the basic events and initiating events, the accident sequence conditional probabilities are calculated.

- The result of the initial evaluation are accident sequence expressions (MCS) sorted according to their conditional probability. At this point, potentially important sequences which may be affected by incident recovery actions should be identified

Overall process

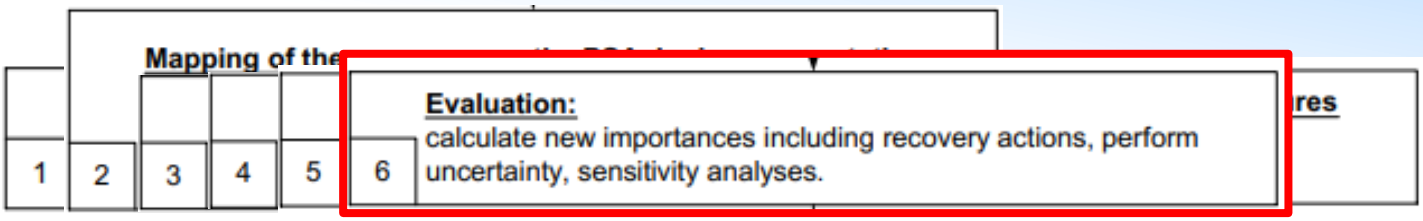


Determine potential recovery actions, model recoveries

- Determination of appropriate recovery actions to be applied to the accident sequences in terms of cutsets based on the conditions of the incident, personnel available, and plant operating and emergency procedures.

- Modeling of recoveries is done using similar techniques as for the „Base Case“ PSA (Consistency should be maintained).

Overall process

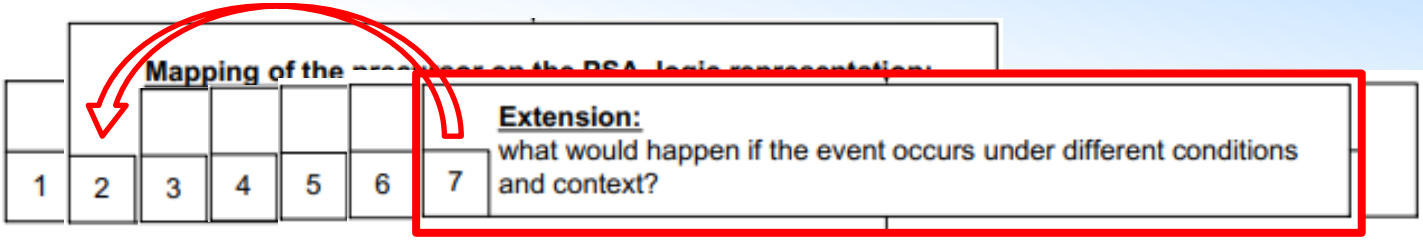


Calculate new importances including recovery actions, perform uncertainty, sensitivity analyses

Objectives:

- Evaluation of conditional probabilities for the accident sequences, including the recoveries identified in the previous task.
- Evaluation should include consideration of uncertainties and calculation of importance, usually the Fussell-Vesely importance and risk increase importance.
- The Fussell-Vesely importance indicates the percentage contribution to the conditional accident probability involving the event, for which it has been calculated.
- The risk increase ratio indicates the factor by which the conditional accident probability would increase if the event is assumed to happen with certainty (failure probability 1.0).
- Sensitivity studies should be carried out to obtain an appreciation of the variability induced by the key modelling and other background assumptions .

Overall process



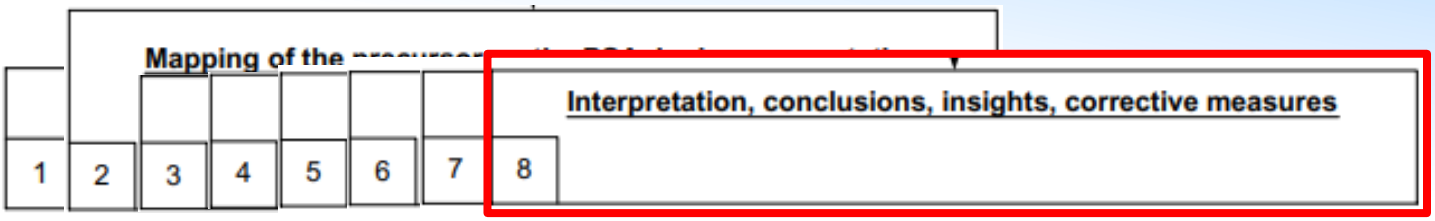
What would happen if the event occurred under different conditions and context?

An operational event occurs within a specific context and situation. The objective of this task is to ask the question what would happen if the event would occur under different conditions or in a different way.

Typical parameters for which this question could be raised include:

- Initial condition of the plant
- Chronology of events in the incident
- Environment for common mode failures
- Different human behaviour
- Different context for human interactions
- …

Overall process



Interpretation, conclusions, insights, corrective measures, documentation

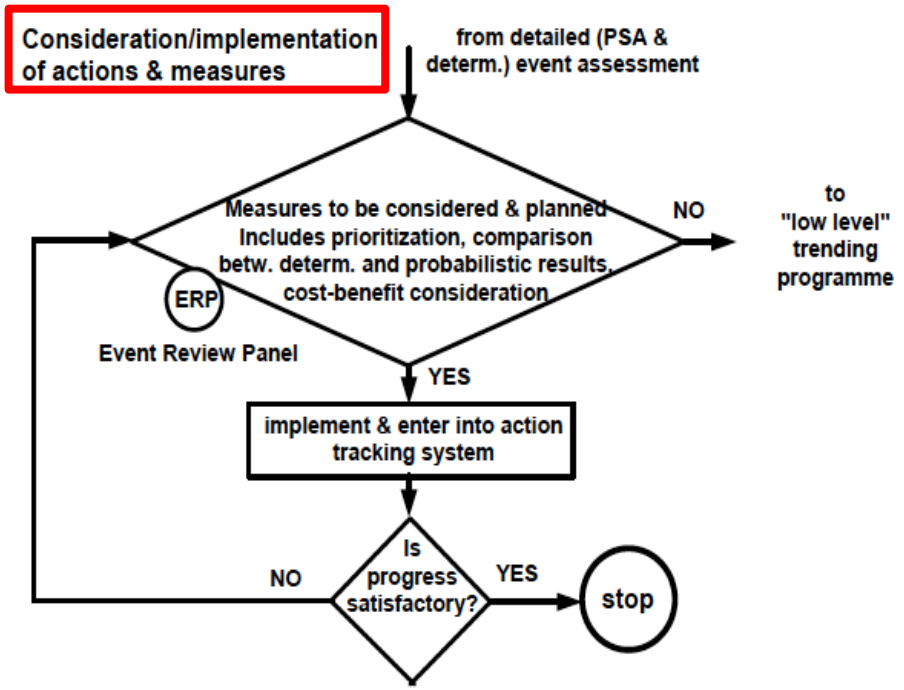
- The objective of this task is to interpret, apply and document the precursor analysis.
  - Review of the information and results to determine key contributors in terms of dominant accident scenarios, important components or operator actions. The importance measures obtained in the evaluation can be used to guide the review.
  - Identification of the key features that prevented the event from becoming more risk significant by using the risk increase importance measure.
  - Corrective measures are specifically designed and evaluated.
  - The quantitative interpretation is based on the evaluation of the conditional accident probability.
- Thorough documentation of the results and the analysis process.

Overall process

- Both, deterministic and probabilistic investigations usually come up with corrective measures and actions.

Includes if applicable:

- Prioritisation (probabilistic: quantitative)
- Cost-Benefit considerations
- Comparison and harmonization of deterministic and probabilistic findings.
- Implementation and implementation tracking. (If no measures/actions are proposed here, the OE goes nevertheless to the Low Level Trending Program)

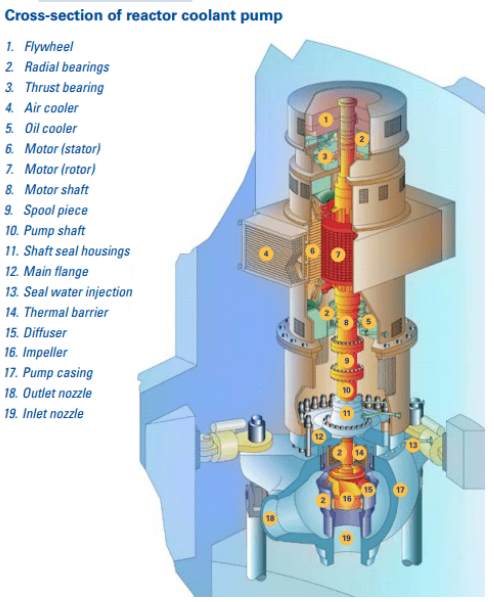


Case study (IAEA-TECDOC-1417)

14:00 24 Feb. No check of bearing temps. by oncoming shift	22.30: 24 Feb. Night shift notice increase in upper motor thrust bearing temp on RCP2	Temp. indication confirmed by Direct measurement of process signal by I&C specialist	“expert team” and shift crew discuss temp. indications	01:18 25 Feb. Shift crew initiate reactor shutdown	High RCP bearing temp.	Manual reactor trip

Plant shutdown due to reactor coolant pump (RCP) bearing temperature high indication:

- increase in upper motor thrust bearing temperature of RCP No 2
- transfer to the Abnormal Operating Procedure (AOP)
- Used AOPs required trip the reactor manually
- Transfer to EOPs
  - Reactor Trip or Safety Injection
  - Reactor Trip Response



Case study (IAEA-TECDOC-1417)

Manual reactor trip

Failure of 3 inch pipeline

FPS pipe become detached at T-joint, FPS pump started to operate

Cable tray deformed by steam leak

Cables exposed to steam leak

Steam/water impinges on 400 V cabinet

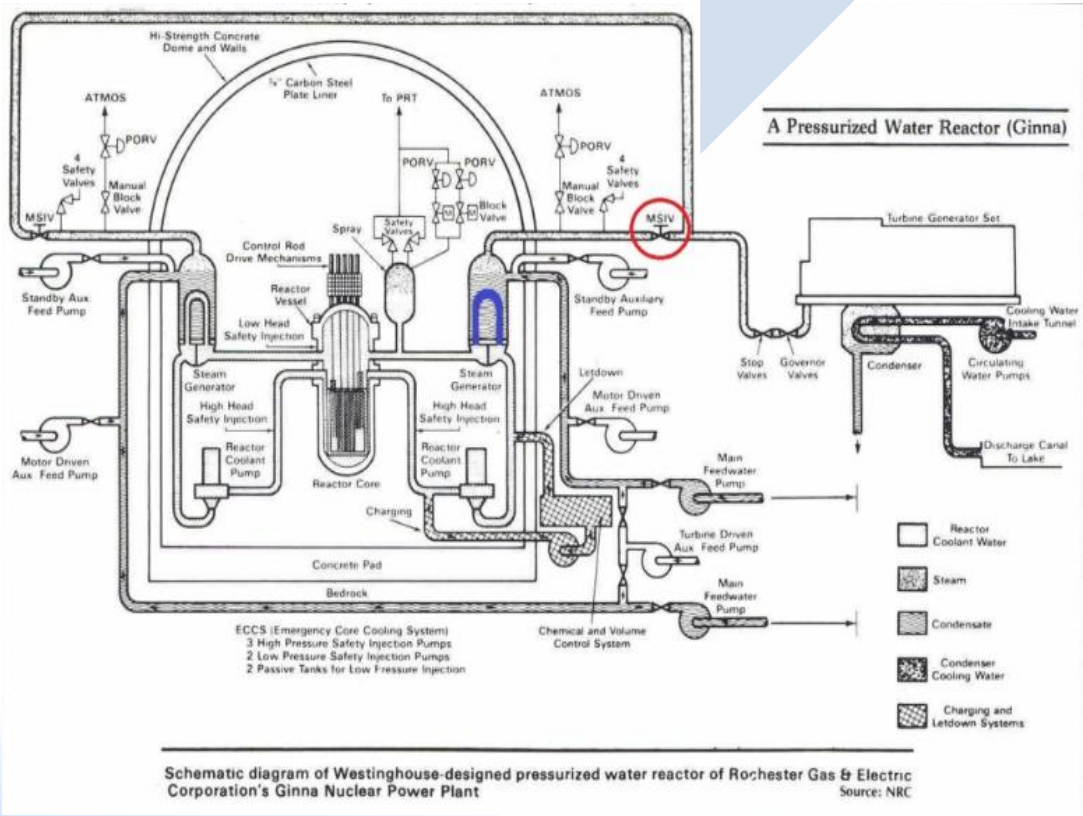
02:10 25 Feb. MSIVs closed

02:16 25 Feb AFWS pumps manually started

Three-inch steam pipe rupture following plant shutdown:

Following the fast plant shutdown:

- The TB operator reported a steam leak
- Fire Protection System (FPS) pipeline
- MCR operators consequently performed main steam isolation (requires AFWS pumps manually started)
- Discovering and isolation of leak



Schematic diagram of Westinghouse-designed pressurized water reactor of Rochester Gas & Electric Corporation's Ginna Nuclear Power Plant

Source: NRC

Case study (IAEA-TECDOC-1417)

PORV failed to operate prior to SV lifting (Reasonable assumption)

SV1 lifted twice as result of increased pressure in SG

PORVs in manual operation

High axial bearing temp. on AFW pumps 1 & 2

09:30 25 Feb. 2MDAF pumps stopped, TDAF pump started

Power-operated relief valve operation:

- Due to the pressure rise in the secondary side resulting from Main Steam Isolation Valve (MSIV) closure, Steam Generator Safety Valve Number 1 opened and closed twice.
- It is expected that small pressure increases would be controlled by automatic operation of a Power-Operated Relief Valve (PORV), however, it could not be confirmed that the PORV had actually performed this function.

Case study (IAEA-TECDOC-1417)

Auxiliary feedwater system (AFWS) pump problems:

- AFWS motor-driven pumps (MDPs) were started. Pump 2B was stopped at and restarted again after 2.5h.
- Due to the unusual axial bearing temperature increase, both motor-driven pumps were stopped and the turbine driven pump 03C was started.
- The axial bearing of Pump 02B was replaced and the gap of the "balancing drum" was reduced from 0,11 mm to 0,05 mm.
- AFWS motor-driven pumps were resorted.

Note: The AFWS consists of three 100% redundant AFW pump trains, two with motor driven pumps and one with a steam turbine driven pump.

Info: it appeared that in the periodical tests during power operation the pumps are run for 15 minutes (not sufficient) only and via a recirculation line to the condensate tank.

Risk-informed surveillance test interval verification

Collection of plant specific information

- Operation and maintenance procedures
- site-specific information was collected in cooperation of NPP,
- Information for components of selected systems,

System Component	Periodicity of the surveillance test	Duration of the surveillance test
System: Normal make-up system **Pumps:** 2PN1-4	1 per month	30 min
System: ECCS **Pumps:** 2APN1-6	1 per month	40 min
System: Spray system **Pumps:** 2NBS1-3	1 per month	30 min

represents the minimum required time periods for stabilization of the monitored parameters

Case study (IAEA-TECDOC-1417)

Qualitative assessment results

Reactor scram due to fault of temperature detector TE 695 B

Root cause: No procedural guidance on bearing temperature parameters inspection at shift hand over. In addition, chosen bearing temperature alarm settings were not reached to alert operators of changing trends in a timely manner to allow for the gradual reactor shutdown.

Three-inch steam pipe rupture

Root cause: Failure of the surveillance programme to detect wall thinning of pipe knees d 4-inch diameter.

Auxiliary feedwater system (AFWS) pump problems

Root cause: The “balancing drum” clearance on both motor driven AFWS pumps were out of adjustment. The monthly testing of AFWS was too short to stabilize bearing temperatures, and so could not detect the overloaded bearings.

Case study (IAEA-TECDOC-1417)

Quantitative assessment

Tasks 1 to 8 should be conducted for precursor event analysis, considering:

- Initial status of the plant
- Initiating event
- Failures following IE
  - Non-opening of the Steam Generator Power Operated Relief Valves
  - High bearing temperatures in the electrically driven Auxiliary Feedwater System pumps
  - Break of a steam line

Case study (IAEA-TECDOC-1417)

Malfunction of AFWS motor driven Pumps

- The event and conditions regarding the AFWS motor driven pumps (AFWS MDPs) are considered to be not directly connected to the initiating event of the transient being considered, but have been obviously existing for some time before the event, and they became apparent only during the transient.
- The PSA based evaluation considers the malfunction of the both AFWS MDPs, for the applicable event tree which is the general transient event tree “TRA” and for other initiating events where the AWFS MDP play a role within the overall model for internal initiating events.

Case study (IAEA-TECDOC-1417)

Malfunction of AFWS motor driven Pumps

- For the preliminary assessment AFWS pumps 1&2 assumed failed.

- For the refined assessment the probability Pt is multiplied with a recovery probability which describes intermittent start-stop operation of the two AFWS MDPs to keep the bearing temperatures at an acceptable level. The recovery term is composed of two contributions:
  - an increased start and run failure probability for this cyclic operation procedure, based on the nominal pump failure parameters but increased by a judgmental factor, and
  - a human error probability for failing this procedure.

- In the PSA, the whole failure expression is mapped into one event in which both AFWS MDPs are failed simultaneously.

- For the plant trip evaluation Pt set to one (observed)

Case study (IAEA-TECDOC-1417)

Malfunction of AFWS motor driven Pumps

Calculation (plant trip):

CCDP from the applicable general transient tree TRA: 3.00E-05

(base case CCDP: 2.16E-06, initiating event probability set to one)

Calculation (latent unavailability):

The CCDP from the overall model assuming one year exposure time is estimated as follows: Base case CCDP: **3.17E-05**

- With the additional AFWS MDP malfunction model described above: **7.25E-05**

- Retaining only the malfunctions or effects observed:

  7.25E-05 - 3.17E-05 = 4.08E-05

- The estimated overall CCDP therefore is:

  3.00E-05 + 4.08E-05 = 7.08E-05

Case study (IAEA-TECDOC-1417)

Malfunction of AFWS motor driven Pumps

Interpretation:

- According to the CCDP, the AFWS MDP malfunction is a significant sub-event.
- Compared to the other issues which appeared subsequent to the initiating event, it is the most important one (See IAEA-TECDOC-1417).
- A part of the impact is directly related to the particular initiating event
- Another important part relates to the pre-existent exposure to potential initiators which require the AFWS.

More information on case study can be found in TecDoc-1417

Overall process

Carried out on a regular basis in:

- France (EdF)
- Germany (GRS)
- USA (ASP-Accident Sequence Precursor Programme) - Oak Ridge
- Belgium, Finland, Spain, Switzerland and a number of other countries

Focus is different:

- Operator and plant: best place to carry out very specific and detailed precursor analysis.
- Licensing organization, research institution: more generic, events are usually filtered, plant information is limited.

Conclusion

- Precursor analysis provide the efficient method for determination of safety significance of events
- Not all events are alike and careful consideration should be given as the evaluation of a particular event
- The process described establishes a common basis for understanding, discussion and investigation, synergistically bringing together non-PSA and PSA staff contributions
- The process provides a good example of the application of PSA to ensure necessary focus on safety related issues in events and corrective/preventive actions

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Thank you!