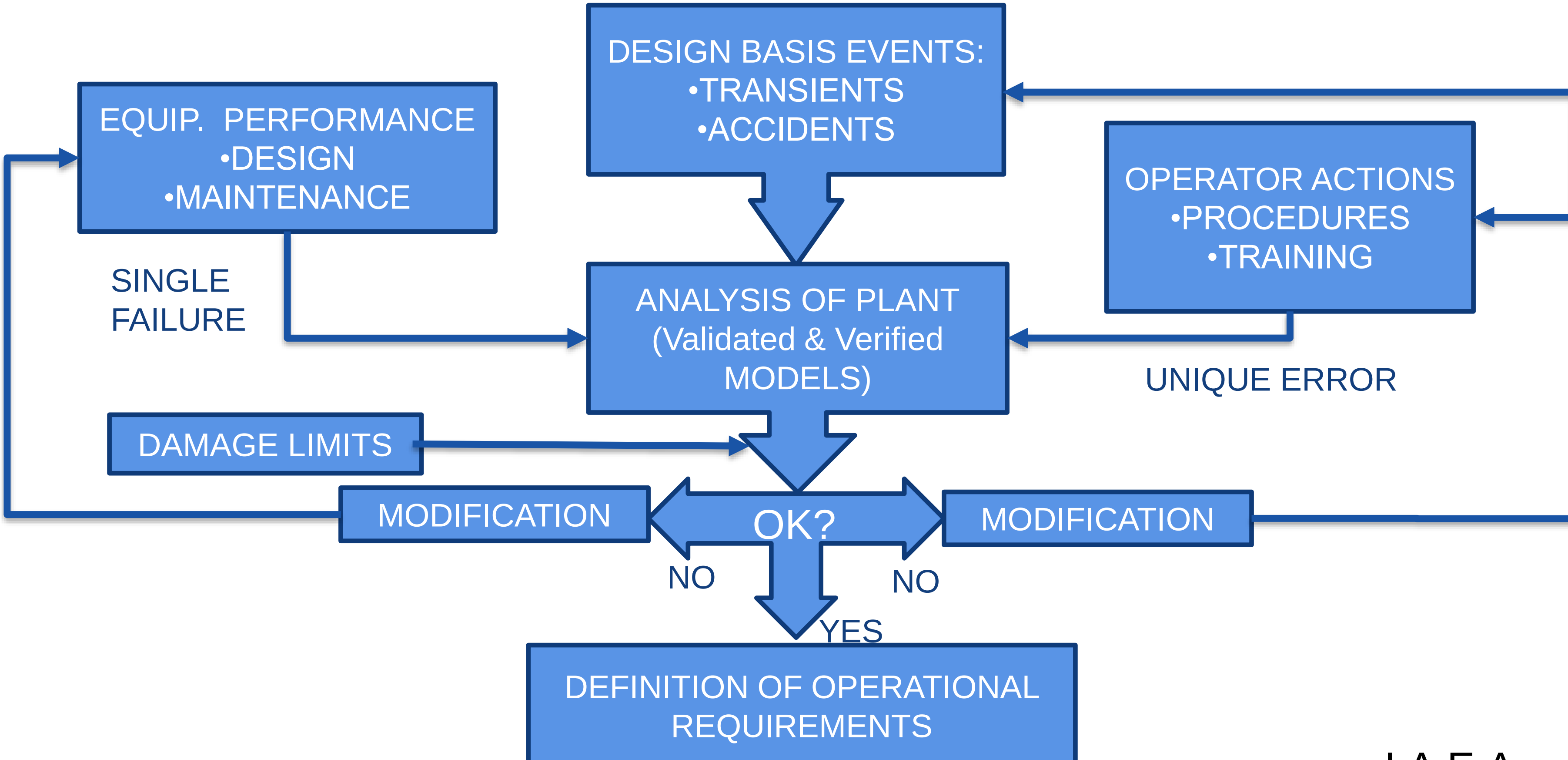
SH2705 Simulation Course

DSA input guidelines – Example

THE DETERMINISTIC APPROACH
SAFETY ANALYSIS -DETERMINISTIC



I.A.E.A

DSA APPLICATIONS

- **Design Applications**
  - Designer: as part of the design and construction process
  - Operating organization, to confirm the design

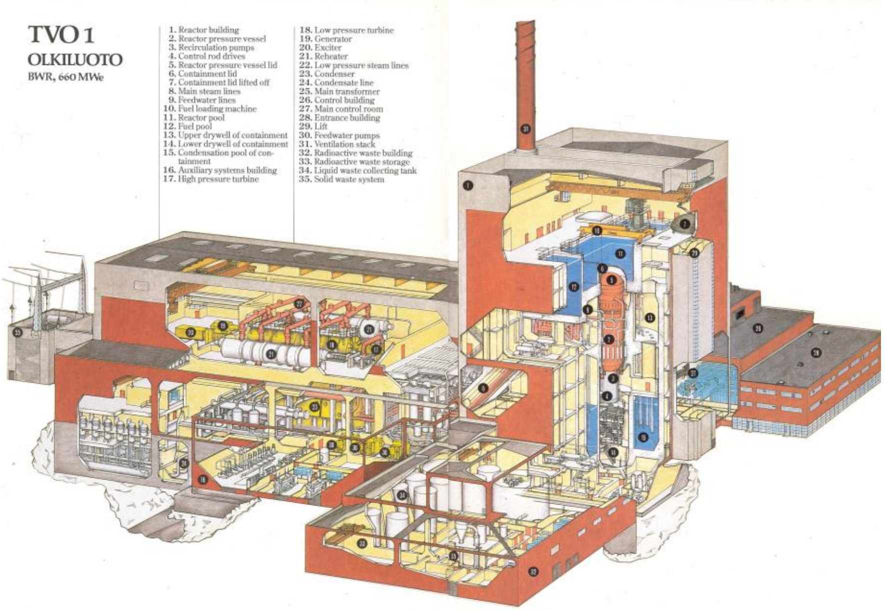
DSA must be parallel to the design process, with iteration between them.

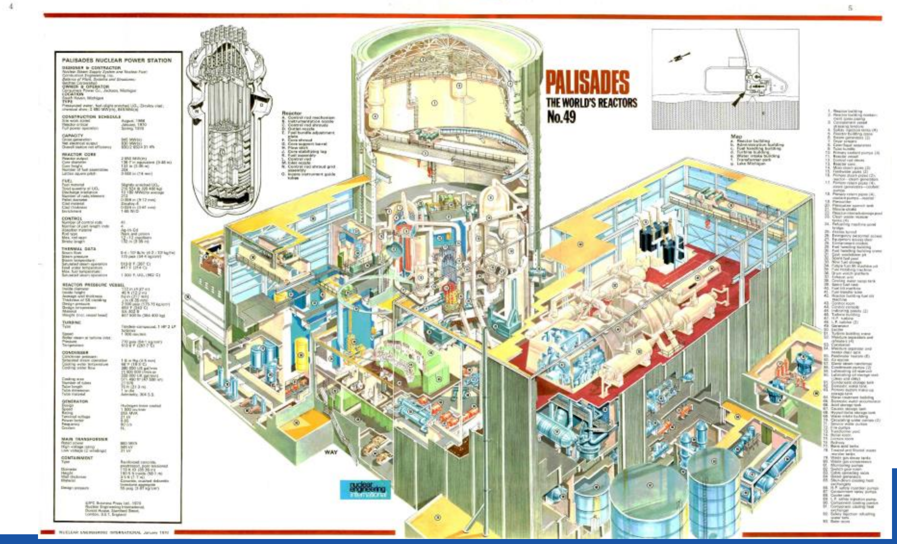
- **Licensing Applications**
  - Calculations for Final Safety Analysis Report (FSAR)
  - Fuel reload analysis
  - Periodic SA of an operating plant
  - Safety justification of a design modification

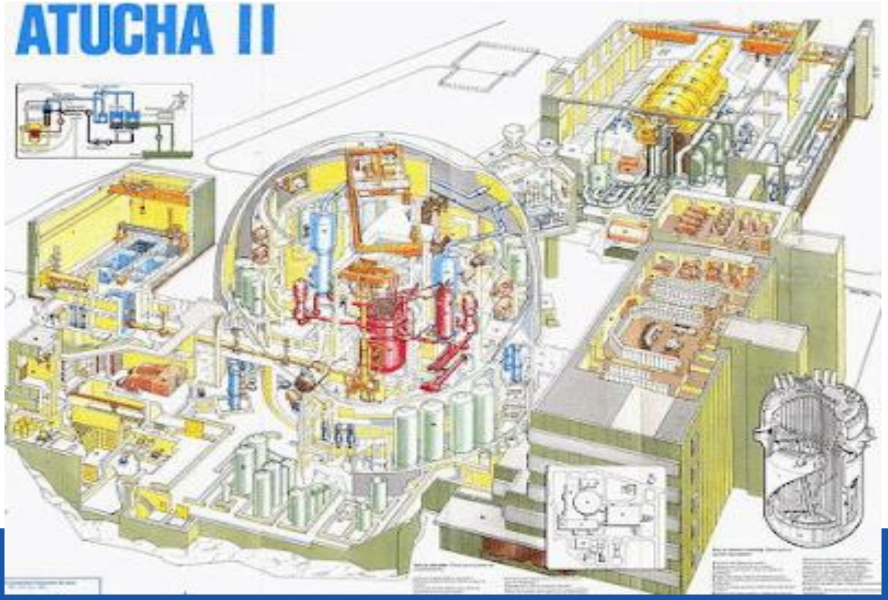
The final SA must reflect the final plant design. DSA is also used for evaluating design changes, supporting decision-making processes, revealing new issues, etc.

- **Regulatory Applications**
  - Audit calculations
  - Evaluation of emergency operating procedures
  - Review of significant events and incidents
  - Evaluation of emergency operating procedures
  - Unresolved Safety Issues Evaluation

COMPLEXITY OF THE SYSTEM







Methodology of DSA

A complex analysis of a power plant requires often a set of inputs and model. These models are called Evaluation models.

- EVALUATION MODELS of a nuclear power plant is developed in order to perform Deterministic Safety Analysis.
- An Evaluation Model (EM) is the calculation framework for evaluating the behaviour of a plant during a postulated transient or Design Basis Accident (DBA)

Methodology of DSA

An EM may include one or more computer codes, other calculational aids (analytical tools, calculational procedures), special models, and all other information necessary for application of the calculational framework to a specific event, such as:

- Procedures for treating the input and output information.
- Specification of those portions of the analysis not included in the computer codes for which alternative approaches are used.

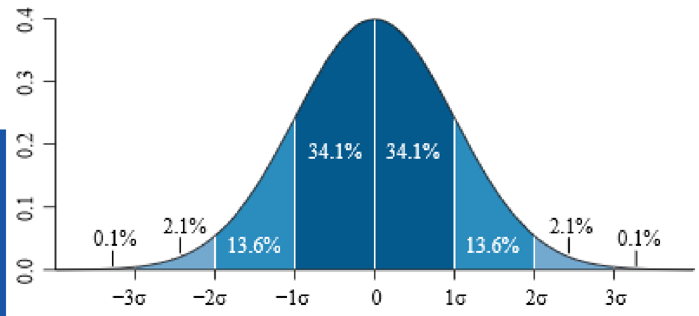
Input Data Preparation

- The construction of the input data to perform Safety Analysis must be subject of an adequate Quality Assurance program.
- All sources of data must be referenced and documented.
- The whole process must be recorded and archived to allow independent checking.

Input Data Preparation (conservative)

- Input data to a conservative DSA:
  - Conservative initial values of the plant variables.
  - Conservative boundary conditions through the transient (e.g., systems and operator performances).
  - Conservative physical models in the code.
- Different degrees of conservatism:
  - Most variables are set to "high" values (taking account of their probability distribution functions). E.g.,: average value plus "two sigma", or 95.4 percentile…
  - Some variables can be set to extremely high values. E.g.: values established in Appendix K to 10 CFR 50, for LOCA analysis.

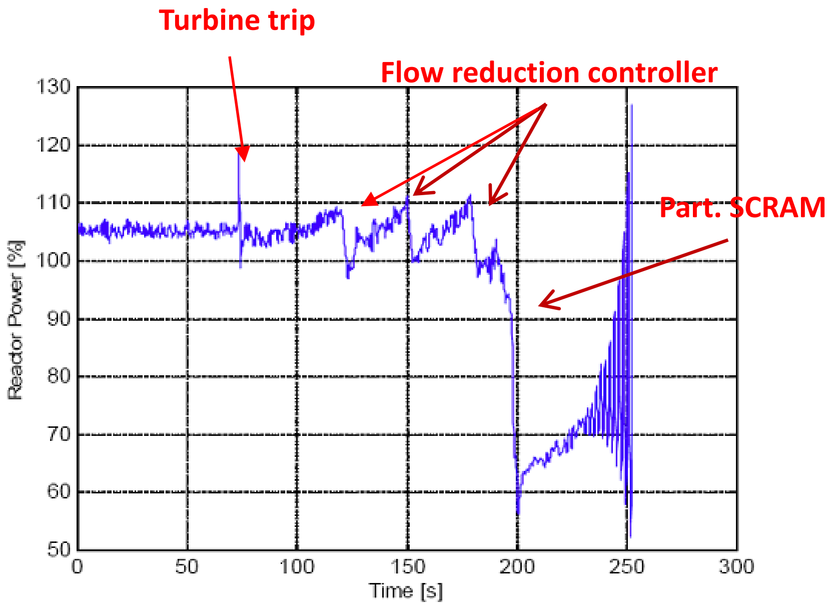
Normal distribution where each band has a width of 1 standard deviation



Conservative input Data Preparation (DB)

Conservative assumptions made for DB analysis:

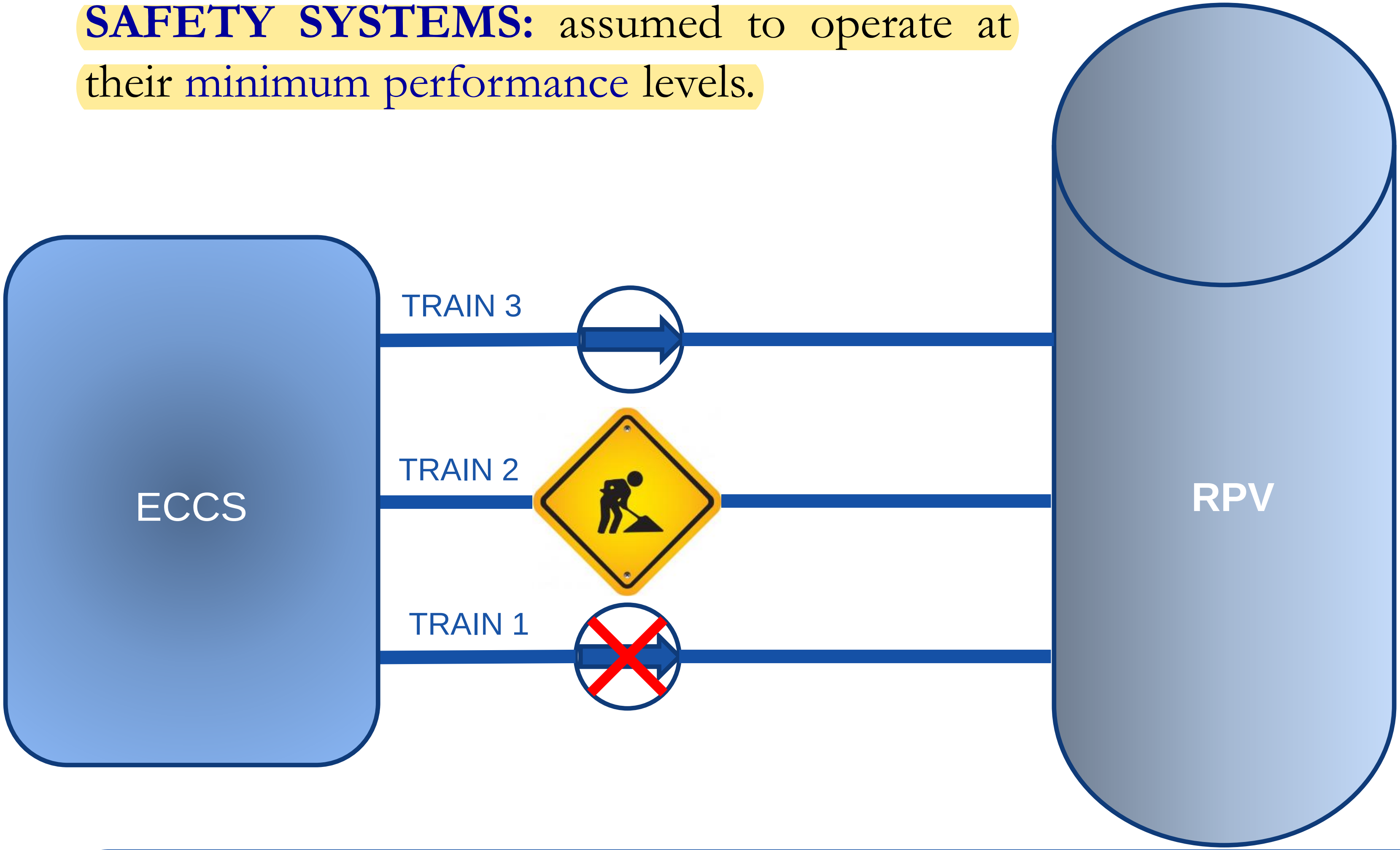
- **TIME:** Initiating event occurs at an unfavourable time.
- **BEHAVIOUR OF THE CONTROL SYSTEM:** It operates only if their functioning would aggravate the effects of the initiating event. No credit for mitigation.



- **SAFETY SYSTEMS:** All plant systems and equipment not designed as safety class, should be assumed to fail causing the most severe effects for the PIE **<u>if their operation does not have a aggravating the effects of the PIE</u>**
- **SINGLE FAILURE:** Worst single failure assumed in the operation of the safety groups required for the initiating event. For redundant systems it is often assumed running of minimum number of trains.

Conservative input Data Preparation (DB)

SAFETY SYSTEMS: assumed to operate at their minimum performance levels.



Conservative input Data Preparation (DB)

- **AVAILABELITY of SYTEMS**: Structures, systems or components that do not have PROVEN full operability during the accident should be assumed UNAVAILABLE.
- **HUMAN BEHAIVOUR:** Actions of the plant staff to prevent or mitigate the accident are only modelled when it is shown that there is sufficient time to perform them, and that procedures and training are adequate or have a negative effect on the outcome of the accident.

Conservative input Data Preparation (DB) - chain of the events

DB analysis should include any failures which could occur as a consequence of the IE, including:

- If the IE is part of an electrical distribution system, all the equipment powered from that part will be unavailable.
- If the IE is an "energetic event" (failure of pressurised system), failure of the equipment that could be affected.
- Fire, floods or external events: failure of the equipment neither designed nor protected against the effects.

Conservative input Data Preparation (AOO)

AOOs: operational processes deviating from normal operation that have the potential to challenge the safety of the reactor. According to design provisions, AOOs do not cause any significant damage to items important to safety, nor lead to accident conditions.

- Loss of feedwater flow,
- turbine trip,
- loss of off-site power

Conservative input Data Preparation (AOO)

- For AOOs, the deterministic SA should include many of the conservative assumption of the DBA analysis, especially those related to the systems for maintaining critical safety functions.

- *But it's not necessary to assume unavailability of all non-safety systems and equipment or no credit to mitigation by control systems, unless the PIE impose it.*

Input Data Preparation (best-estimate)

- Input data to a best-estimate DSA:
  - Plant and model parameters and variables that will participate in the uncertainty analysis: set to realistic values. But the input is not a single value, rather a probability density function (pdf).
  - Variables and parameters that will not intervene in the uncertainty analysis will be set to conservative values.
- Both conservative and BE analysis need to know the probability distribution of the uncertain variables and parameters. But the knowledge must be finer for the BE approach, coarser for the conservative one.

Methodology of DSA

A Methodology includes several types of calculations using different tools in evaluation models :

- Thermo-hydraulic, simulating the behavior of the coolant in the plant.
- Reactor dynamic, simulating the fission processes in the reactor core.
- Structural, simulating the behavior of structures against the loads, stresses,…
- Radiological.

All these types of calculations are "deterministic"(no probability involved, conservative assumptions <u>not for best-estimate methodologies</u>).

Methodology of DSA

- Thermo-hydraulic calculations:
  - Performed with fluid-dynamic based codes
  - Simulating coolant behaviour in primary and secondary systems, the containment…
- Reactor dynamic calculations:
  - Performed with reactor dynamic codes
  - Simulating fission process in the core
- Structural calculations
- Radiological calculations

Methodology of DSA

EM DEVELOPMENT AND ASSESSMENT PROCESS:

EMDAP basic principles according to REGULATORY GUIDE 1.203, "Transient and Accident Analysis Methods of USNRC:

- Determine requirements for the EM: i.e., Mathematical models, components, phenomena, physical processes, etc., needed to evaluate the event behavior relative to adequate figures-of-merit (FOM).
- Develop an assessment base consistent with the above-mentioned requirements: experimental data. Sometimes performance of new experiments is required.
- Develop the EM: the calculational tools are selected or developed. For a particular plant and event, it is necessary to select proper code options, boundary conditions and the temporal and spatial relationship among the component devices.

Methodology of DSA

- Assess the adequacy of the EM: by comparing requirements and capabilities. Some of this assessment is best made during the early phase of code development, to minimize posterior corrective actions. It is important to assure that the calculational devices are used within the range of their assessment.
- Follow an appropriate Quality Assurance protocol during the EMDAP.
- Provide comprehensive, accurate, up-to-date documentation.

Requirements of DSA - General

To achieve the appropriate level of confidence, the safety analysis shall:

- Be performed by qualified analysts in accordance with an approved QA process;
- Apply a systematic analysis method;
- Use verified data;
- Use justified assumptions;
- Use verified and validated models and computer codes;
- Build in a degree of conservatism; and
- Be subjected to a review process

Requirements of DSA - Analysis Method

The analysis method shall include the following elements:

- Identifying the scenarios to be analysed as required to attain the analysis objectives;
- Identifying the applicable acceptance criteria, safety requirements, and limits;
- Identifying the important phenomena of the analysed event;
- Selecting the computational methods or computer, models, and correlations that have been validated for the intended codes applications;

Requirements of DSA - Analysis Method (contd.)

- Defining boundary and initial conditions;
- Conducting calculations, including sensitivity cases, to predict the event transient, starting from the initial steady state up to the pre-defined end-state;
- Accounting for uncertainties in the analysis data and models;
- Verifying calculation results for physical and logical consistency;
- Processing and documenting the results of calculations to demonstrate conformance with the acceptance criteria.

Requirements of DSA - Analysis Data

The safety analysis shall be based on complete and accurate design and operational information.

The boundary and initial conditions used as the analysis input data shall:

- Reflect accurately the NPP configuration;
- Account for the effects of aging of systems, structures and components;
- Account for various permissible operating modes;
- Be supported by experimental data, where operational data is not available.

Significant uncertainties in analysis data, including those associated with nuclear power plant performance, operational measurements, and modelling parameters, shall be identified.

Requirements of DSA - Analysis Assumptions

Assumptions made to simplify the analysis, as well as assumptions concerning the operating mode of the nuclear power plant, the availability and performance of the systems, and operator actions, shall be identified and justified.

The analysis of AOO and DBA shall:

- Apply the single-failure criterion to all safety systems and their support systems;
- Account for consequential failures that may occur as a result of the initiating event;
- Credit actions of systems only when the systems are qualified for the accident conditions, or when their actions could have a detrimental effect on the consequences of the analysed accident;

Requirements of DSA - Analysis Assumptions (contd.)

- Account for the possibility of the equipment being taken out of service for maintenance; and
- Credit operator actions only when there are
  - unambiguous indications of the need for such actions,
  - adequate procedures and sufficient time to perform the required actions,
  - environmental conditions that do not prohibit such actions.

For the analysis of BDBA, it is acceptable to use a more realistic analysis methodology consisting of assumptions which reflect the likely plant configuration, and the expected response of plant systems and operators in the analysed accident.

Requirements of DSA - Computer Codes

- Computer codes used in the safety analysis shall be developed, validated, and used in accordance with a quality assurance program that meets the requirements

BEPU - DSA example

Requirements for LOCA Analysis

Input Data Preparation (best-estimate)

- Input data to a best-estimate DSA:
  - Identify the plant and model parameters and variables that will participate in the uncertainty analysis:
    - set to realistic values. (The input is not a single value, rather a probability density function (pdf).
  - Variables and parameters that will not intervene in the uncertainty analysis (UA) will be set to conservative values.
- In BE analysis, we need to know the probability distribution of the uncertain variables and parameters in detail.

LWR LOCA BE Analysis Requirements

The goal is to obtain a best estimate prediction of the vital system variables such as:

- Pressure in the reactor vessel
- Pressure in the containment,
- Maximum fuel temperature
- Maximum cladding temperature

The first step in any LOCA analysis involves establishing the initial T/H conditions.

LWR LOCA BE Analysis Requirements

The BE modeling requirements for initial steady-state calculations in both BWRs and PWRs are:

- Complete geometrical simulation of the reactor system with realistic modeling of all the important flow paths, material masses, and system components.
- Steady-state or unperturbed transient modeling of mass, momentum and energy distribution for the coolant, including flow velocities and temperature, for single-phase and two-phase flow in all reactor components.
- Single-phase pressure drop in pipes, bends, fuel bundles, area changes, and in all special reactor components.
- Single-phase heat convection for water and steam and boiling heat transfer.

LWR LOCA BE Analysis Requirements

- Two-phase density (or void fraction) and velocity distribution in the boiling channels, including subcooled boiling voids.
- Two-phase pressure drop in boiling channels and in other reactor components such as pipes, separators, etc.
- Steady-state heat conduction and temperature distribution in solids.
- Heat conduction in the gap between fuel and cladding.
- Realistic modeling of the characteristics of specific system components such as pumps, steam separators, jet pumps, etc.
- Reliable approximation of the thermodynamic and transport properties of the reactor materials such as fuel, cladding, vessel, piping and the coolant (liquid and vapor).

BWR LOCA BE Modelling Requirements

- Time dependent distributions of mass, momentum and energy for the coolant material in all system components.
- Time dependent velocities and local flow densities in all one-dimensional and Multidimensional components including the following items:
  - One-dimensional flow through fuel channels (BWR), pipes, valves, pumps, etc.
  - Multidimensional flow through downcomer, lower plenum, upper plenum, bypass, and steam dome.
  - Flow through pumps in forward and reverse directions, with proper pressure loss coefficients.
  - Flow through steam separators and reverse directions, with proper loss coefficients. And dryers in forward
- Critical flow calculation at the break and at any internal junction that may experience very steep pressure gradients.

BWR LOCA BE Modelling Requirements

- Interfacial exchanges of mass, momentum and energy between vapor and liquid, including the effects of various two-phase flow patterns.
- Circulation pump characteristics.
- Safety and relief valve component modeling capability.
- Transient heat conduction and temperature distribution for fuel cladding, and other solid structures.
- Single-phase heat transfer to vapor and liquid in different flow geometries.
- Gap heat conductance.
- Boiling heat transfer including nucleate, transition, and film boiling at all pressures.

BWR LOCA BE Modelling Requirements

- Critical heat flux (or dryout) prediction relevant to BWR fuel geometries.
- Non-equilibrium temperature distribution between vapor and liquid with individual heat transfer between either phase and the channel walls.
- Liquid entrainment in vapor and de-entrainment.
- Countercurrent flow and CCFL effects at the side entry orifice and at the upper tie plate geometries.
- Radiation heat transfer between any fuel rod and other rods, surrounding steam and droplets, and the channel walls.
- Minimum film boiling temperature and rewet heat transfer.

BWR LOCA BE Modelling Requirements

- Power calculation with time-dependent neutron kinetics model, including at lease six groups of delayed neutrons.
- Decay heat of fission products with contribution from transuranic elements.
- Realistic trips with appropriate delay actions and parameter dependencies.
- Control system models with universal simulation capabilities.
- Containment simulation capability, including dry and wet wells, heat transfer, pool boiling, and condensation on the walls.