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Atoms for Peace and Development

Basic Principles of Accident Management (Module 1b)

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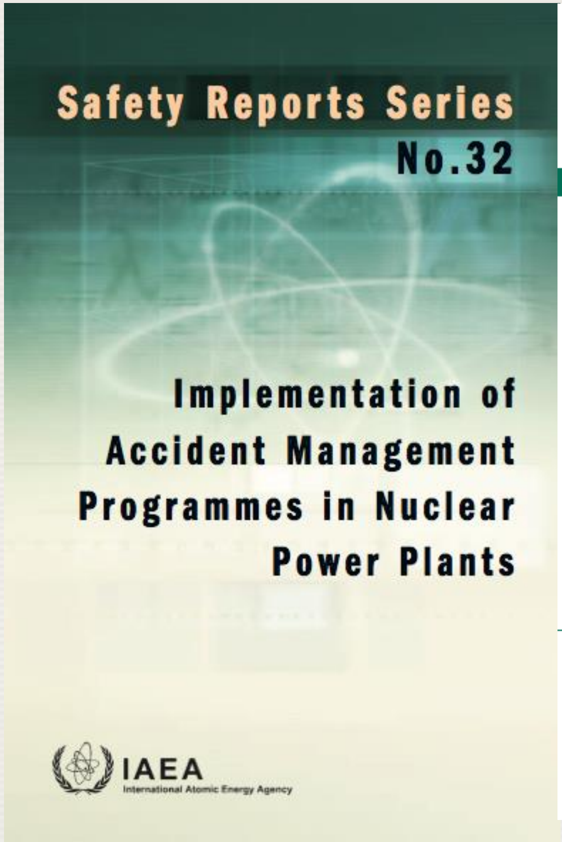
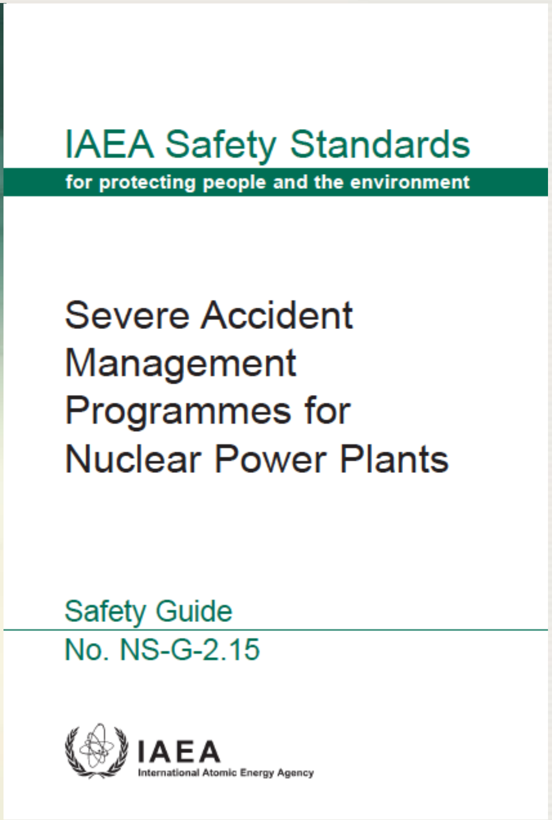
(ref. lecture by Mr. J. Gabor, JensenHughes, US, course 2015)

IAEA Training Workshop on Severe Accident Management Guideline Development using the IAEA SAMG-D Toolkit, 11-15 December 2017

Summary of Module 1b

- Introduction to Accident Management
    1. Principles of AM
    2. Basic Structure of the Development of AM
    3. Main Characteristics of AM, EOPs and SAMGs
    4. Preventative and Mitigative measures





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Principles of Accident Management

- Operating procedures exist for
  - **Normal** operation
  - **Anticipated** occurrences
    - Alarm Response procedures
  - **Accident** conditions
    - Emergency Operating Procedures (EOPs)
      - Design Basis Accident
      - Limited or no fuel damage
    - Severe Accident Management Guidelines (SAMGs)
      - Fuel damage

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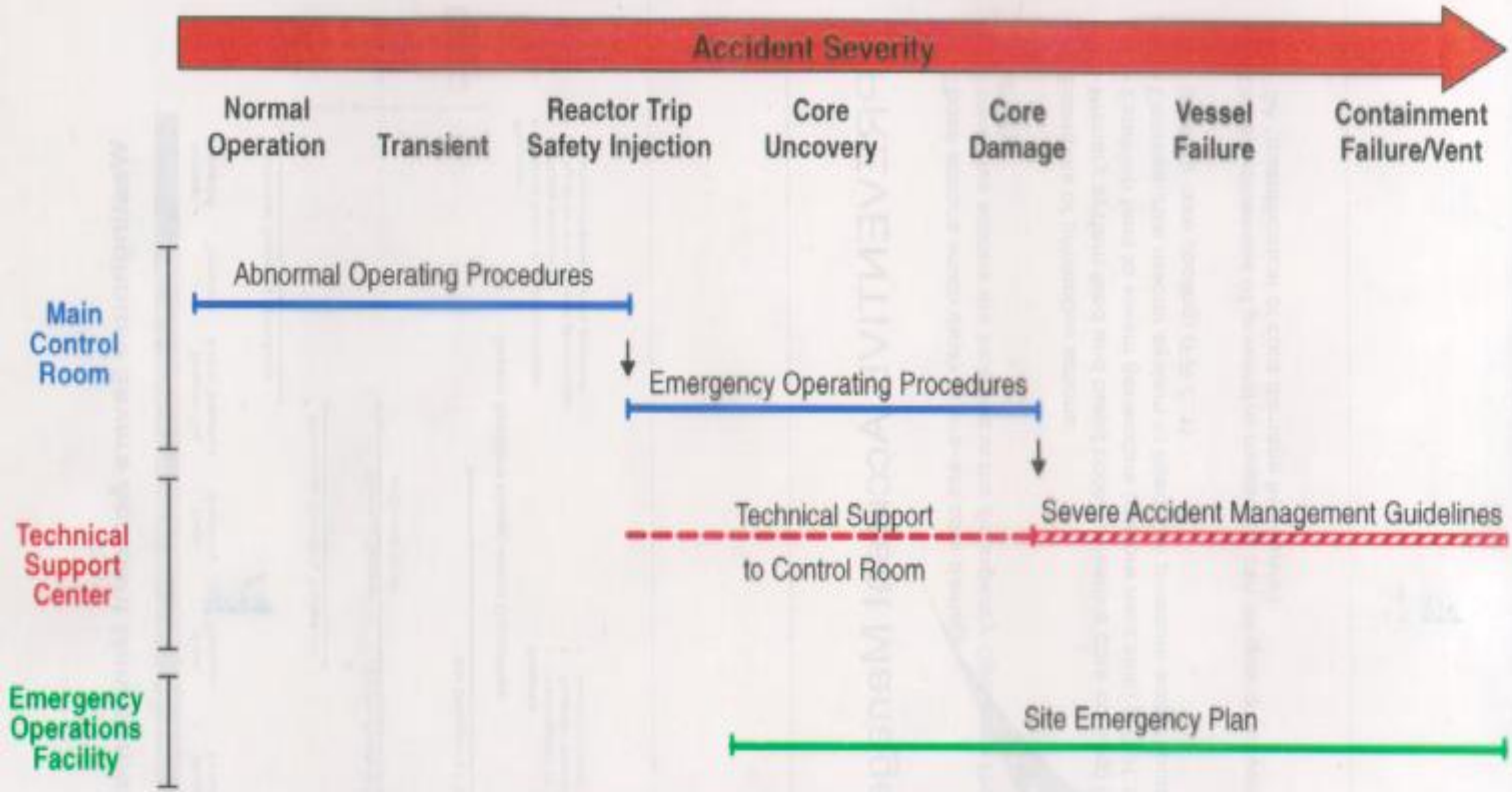
Westinghouse Severe Accident Management



Severe Accident Management Guidelines

Purpose

- Protect fission product boundaries
- Mitigate releases
- Mitigate severe accident phenomena
- Restore controlled stable condition

Features

- Implemented by TSC
- Separate from EOPs
- Symptom based

Definitions SAMG – from IAEA Glossary

- Accident Management is the taking of a set of actions during the evolution of an accident beyond the design basis:
  - To prevent the escalation of the event into a severe accident
  - To mitigate the consequences of a severe accident; and
  - To achieve a long term safe stable state

Definitions (cont'd)

- Mitigation can also be called Severe Accident Management
  - To terminate the progression of core damage once started,
  - To maintain the integrity of the containment as long as possible, and
  - To minimize releases of radioactive material.

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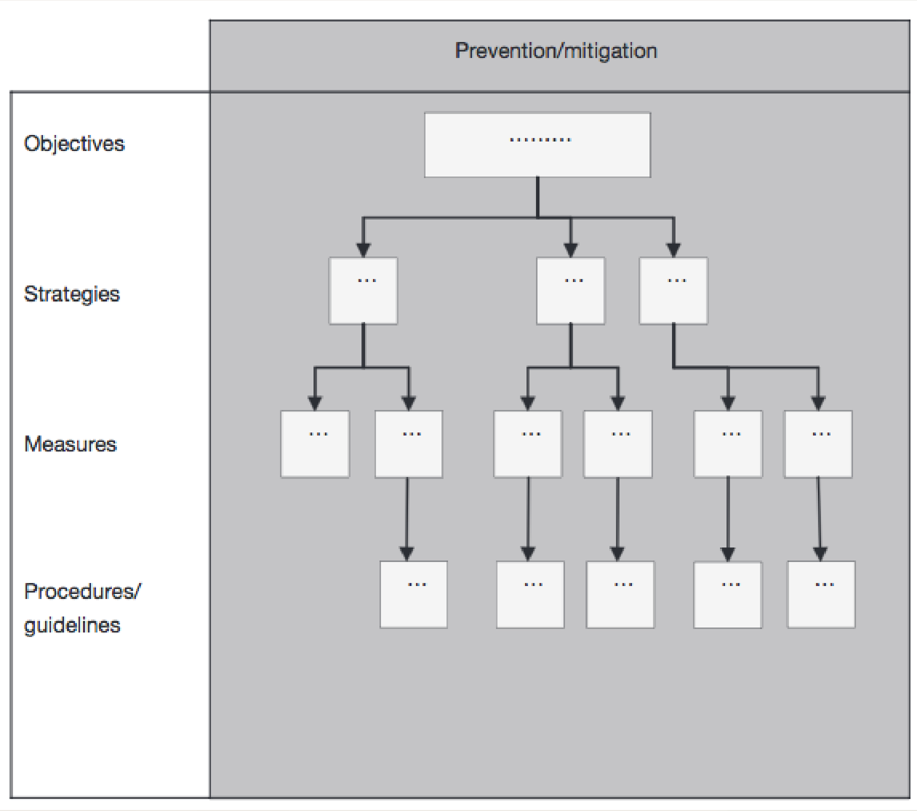
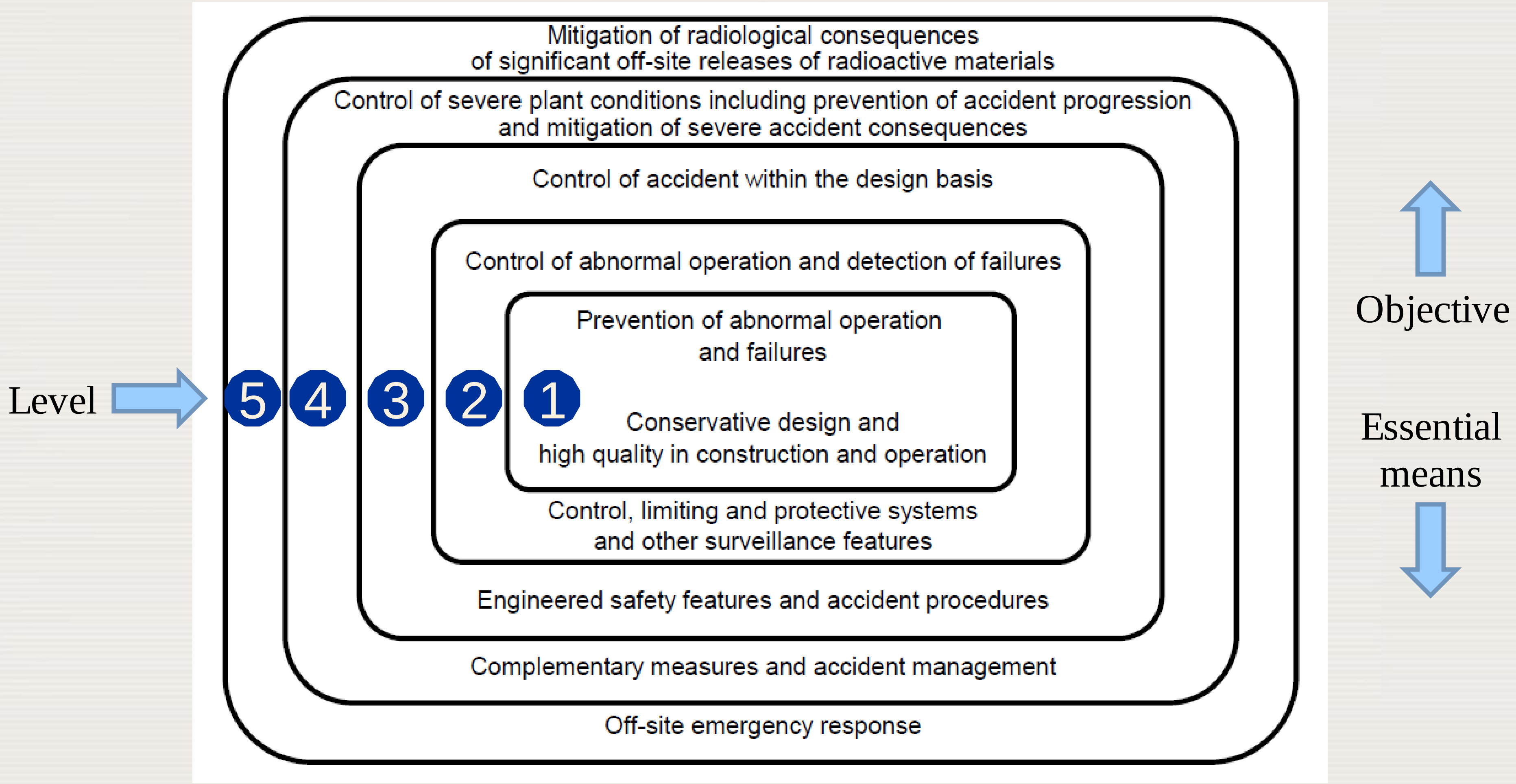
AM Program Development

- Structured top-down approach
  - Objectives
  - Strategies
  - Measures
  - Procedures/guidelines



Severe Accident Management Programmes for Nuclear Power Plants, Safety Guide, No. NS-G-2.15

Levels of Defense in Depth



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Defence in Depth in Nuclear Safety
INSAG-10, IAEA

Prevention and Mitigation

- As stated in the 4th level of Defense-in-Depth, both prevention and mitigation need to be addressed.
  - **Prevention** measures are directed to prevent core melt and bring the plant to a stable state.
  - **Mitigation** measures are directed to protect remaining fission product barriers and reduce any possible radioactive release.

Components of AM Program

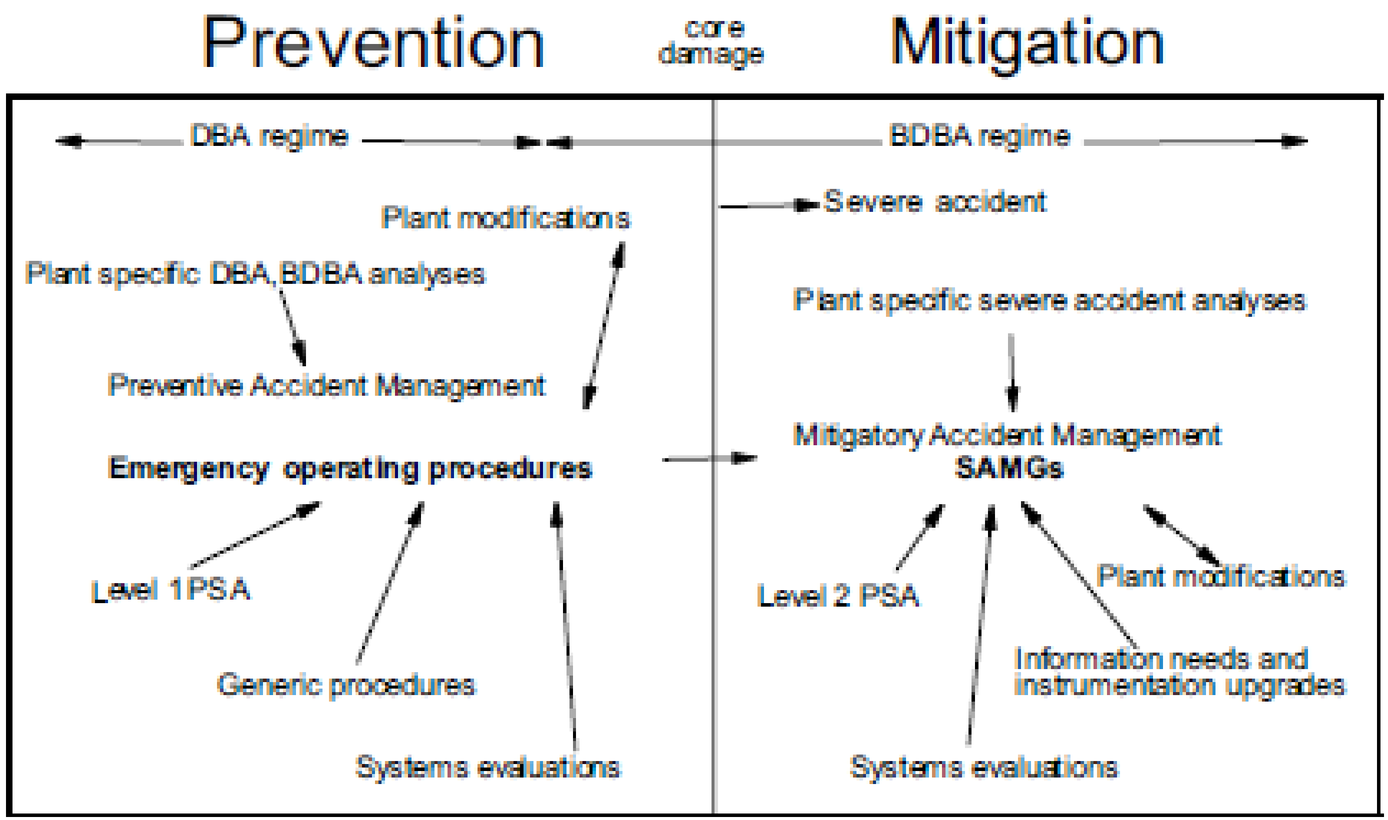

FIG. 1. Different components of an AMP[1] (DBA: design basis accident, BDBA: beyond design basis accident).

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Implementation of Accident Management Programmes in Nuclear Power Plants, Safety Reports Series, No. 32

Prevention and Mitigation

- Prevention
  - Usually in the form of procedures
  - Emergency Operating Procedures, ´EOPs`
  - Supported by Level 1 PSA
- Mitigation
  - Usually in the form of guidelines, ´SAMG`
  - Other names (e.g. GIAG (French - EdF), Operating Strategies for Severe Accident – OSSAs (Areva-Paris))
  - Supported by Level 2 PSA

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Preventive Measures

- Use engineered safety systems <u>and</u> other systems as feasible
- System <u>function</u> has priority over system protection, but try to stay within the system design basis
- Priority is with the <u>core</u> (sub-criticality, core cooling)
- Actions <u>not</u> limited to design basis (e.g. PWR feed and bleed: e.g. ECCS feed and SRV bleed)
- Actions may use <u>other</u> systems (e.g. fire water)

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Preventive Measures (cont'd)

- Actions are clear-cut, have been pre-analyzed, and their outcome is known before hand
- Therefore, procedures are prescriptive (= precise steps and sequence)
  - Example: if containmt pressure rises use containmt spray
- Decisions usually made by Main Control Room staff, possibly with support from Technical Support Centre
- Instruments are mostly reliable (as we are mostly inside the I&C design basis, *single* indication usually sufficient)

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Procedures

- Event-based
  - Event diagnosis required
- Symptom-based
  - Event diagnosis not needed
  - Actions taken to satisfy a set of ´critical safety functions`

Event Based procedures initially utilized, but industry has evolved to more symptom based (trigger: TMI accident)

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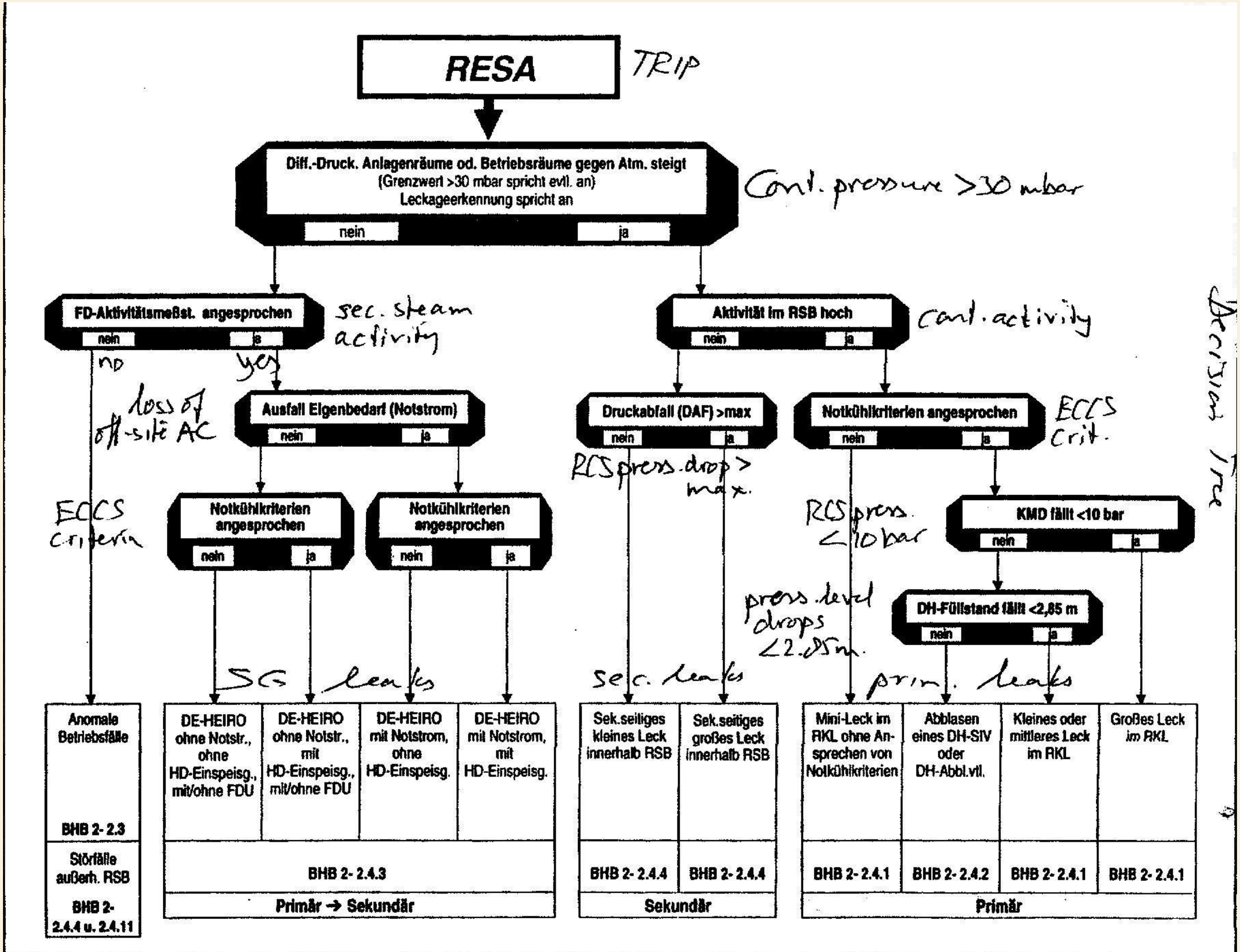
Example of EOP logic diagram (Areva)



Procedures (cont'd)

- Example of Critical Safety Functions (from W)
  1. Subcriticality
  2. Core cooling
  3. Heat sink
  4. Primary boundary integrity
  5. Containment integrity
  6. Reactor coolant system inventory

Note: numbers give the priority of the CSFs

CSFs followed in parallel to event based procedures

Example from Combustion Engineering approach in EOP

- **SAFETY FUNCTION HIERARCHY:**

1. Reactivity control
2. Maintenance of vital auxiliaries (AC and DC power)
3. RCS inventory control
4. RCS pressure control
5. Core heat removal
6. RCS heat removal
7. Containment isolation
8. Containment temperature and pressure control
9. Containment combustible gas control

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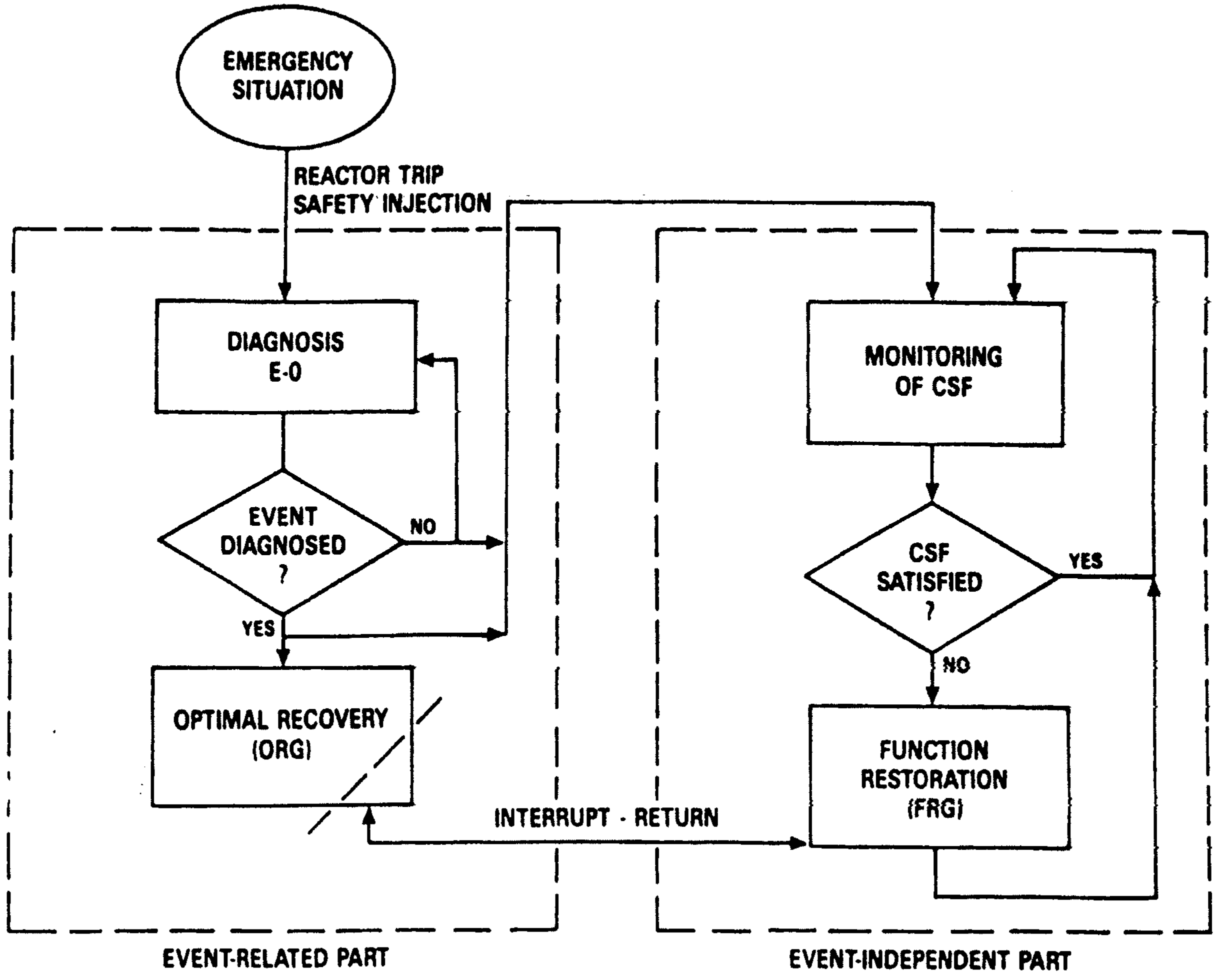
ERGs OPERATOR RESPONSE PATTERN



Advantages of Symptom Based Procedures

- Work for wide range of events
- No need to know initiating conditions
- Actions are appropriate, irrespective of initiating events
- Event procedures possible and encouraged, assuming a clear indication of the event (e.g. Small Break LOCA, Station Black Out)
  - Note: some approaches use *only* symptom based procedures

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Mitigative Measures

- Mitigative measures use *all* systems available, not only dedicated ones
- System function has priority over system protection, i.e. damage to the system may be accepted
  - Example: RCP restart (PWR) at low pressure to sweep loop seal water through the core may damage RCPs
- Priority shifts to fission product barriers, not just the core (as in EOPs)
- Actions not as clear cut as the outcome is not as well known before hand – therefore: *guidance*
  - we are far beyond design basis, possibly core melt

Mitigative Measures (cont'd)

- Employs thought process to consider both positive *and* negative consequences of actions (in EOPs: no negative consequences)
  - Example: containment spray may de-inert containment atmosphere and create H2 combustion
- Benefit from insights in physics of severe accidents
  - As evolution of accident may deviate from anticipated course
- Decision making usually outside Control Room, with Emergency Response Organization (ERO)
  - May involve need for outside support

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Elements of Mitigation Measures

- In severe accident domain, guidance is preferred tool
- Once a strategy has been selected, clear instructions to the operators should be given (hence, guidelines are to be handled in the TSC rather than in the MCR)
- SAMG should cover all modes of operation
- There should be clear entry criteria
  - Note that also the organisation must be ready for entry into SAMG, e.g. the ERO (TSC) should be set up **&** be functional!!
- There should also be clear exit criteria
- Actions should have initiation, throttling, termination criteria

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From EOP to SAMG

- Entry:
  - Initiation or imminent (severe) core damage
  - Decision by MCR (e.g., on core exit T) or by Site Emergency Director (through overall assessment of situation)
- Examples:
  - Westinghouse: by exit of the EOPs FR-C.1, FR-S.1 or ECA 0.0: core exit T 650, 550 ºC, dependent on plant
  - EdF: core exit T 1100 º C *and* high containment radiation
  - CEOG: by Site Emergency Director decision
  - B&WOG: through Computational Aid (RCS p versus incore T)
  - BWROG: if containment flooding is required (~ flow to RPV is known not to be able to prevent vessel failure)
  - Some Areva SAMG: if two CSFs cannot be maintained

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From SAMG to long-term accident management (i.e. exit of SAMG) – example (W)

- Core temperature below certain limit AND stable or decreasing
- Site releases below site area emergency levels AND stable or decreasing
- Containment pressure below certain limit AND stable or decreasing
- Containment hydrogen below certain limit AND stable or decreasing

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Recall: Prevention by *Procedures*

Consequences of actions well understood, therefore procedures are:

- Step-by-step instructions
- To be followed word-for-word
- Required actions known before hand
- Fuel intact, safety systems intact, instruments functional

EOPs

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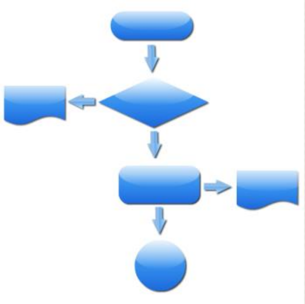
Recall: Mitigation by *Guidelines*

Severe accident analysis involves considerable uncertainty, therefore:

- No ´rigid` procedures but guidelines
- May still be structured (step-by-step)
- Deviation allowed; not word-for-word
- On-the-spot evaluation to select best actions from several alternatives
- Fuel damage likely, safety systems lost, instrumentation possibly not reliable



SAMGs

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Symptom Based: use *measurable* parameters

- Examples of acceptable symptoms include:
  - Core exit temperature
  - Primary system pressure
  - Steam generator level
  - Containment pressure
- Examples of unacceptable symptoms (as these can only be obtained from complex calculations)
  - Fuel clad temperature
  - Break size

Tools may exist for complex calculations, but maybe more risky to rely on

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Event Based

- EOPs and SAMGs both are typically symptom based
- Some events are easily diagnosed:
  - Large Break LOCA
  - Steam generator tube rupture (SGTR)
    - but can be difficult in 2-loop PWR
  - Station blackout (SBO)
  - Extended loss of AC power (ELAP)

Recall main SAMG Principles

- SAMG contain <u>mitigative</u> actions and apply at <u>imminent</u> or <u>after</u> core damage
- SAMG are guidelines, not procedures
- SAMG are symptom based
  - on measured parameters *only*
- Challenges to fission product barriers addressed in SAMG
- Actions may have both <u>positive</u> *and* <u>negative</u> consequences

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Recall main SAMG Principles (cont'd)

- Multiple strategies to be prioritized based on positive/negative weighting
- All means used to mitigate accident, including operating systems beyond their design basis
- Use multiple I&C indications, as individual indications may not be reliable

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Recall: Preventive Domain

- Goal is to prevent core damage
- Maintain critical safety functions
- Responsibility with control room
- Procedures used in the form of EOPs
- Define exits to SAMG

Recall: Mitigation Domain

- Goal is to protect fission product barriers and minimise releases
- Establish priorities between measures
- Responsibility (usually) with ERO
  - Make clear who ultimately has decision authority!
- Guidelines used in the form of SAMGs
- Define exits to long term AM

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Further lectures

- Severe accident phenomena (i.e. the physics of severe accidents)
- How they threaten fission product barriers
- How to find stategies to mitigate those threats
- How the strategies are transformed into the guidelines, the SAMG
- How the ERO functions in a severe accident
- Verification and validation of SAMG
- Training and exercises
- Maintenance of SAMG

Questions?