REDUCTION OF RADIOLOGICAL ACCIDENT CONSEQUENCES

Title	**Main Progress Performed in AMP Optimization**
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Defence in Depth (DiD) concept

REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

Level of defence Approach 1		Objective	Essential design means	Essential operational means	Level of defence Approach 2	
Level 1		Prevention of abnormal operation and failures	Robust design and high quality in construction of normal operation systems, including monitoring and control systems	Operational limits and conditions and normal operating procedures	Level 1	
Level 2		Control of abnormal operation and detection of failures	Limitation and protection systems and other surveillance features	Abnormal operating procedures and/or emergency operating procedures	Level 2	
Level 3	3a	Control of design basis accidents	Safety systems	Emergency operating procedures	Level 3	
Level 3	3b	Control of design extension conditions to prevent core melting	Safety features for design extension conditions without significant fuel degradation	Emergency operating procedures	4a	Level 4
Level 4		Control of design extension conditions to mitigate the consequences of severe accidents	Safety features for design extension conditions with core melting[2] Technical support centre	Severe accident management guidelines	4b	Level 4
Level 5		Mitigation of radiological consequences of significant releases of radioactive substance	On-site and off-site emergency response facilities	On-site and off-site emergency plans and procedures	Level 5	

Accident Management

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- Automated response in a design accident was not able to prevent accident progression
- In this case, AM provides a strategy to use all still available equipment of the NPP to either prevent core damage or at least to prevent releases of radioactive materials
- Equipment may range from still available safety systems, to systems for normal operation, to non-standard equipment available on site like fire brigade trucks and systems foreseen for such events, like mobile pumps

EOPs / SAMGs / EDMGs – Hardened Core

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- Emergency Operating Procedures (EOPs) are applied to manage Design Bases Accidents (DBA), as well as to manage design extension conditions up to core damage (DEC A)
- EOPs are part of **preventive** accident management – main goal is to prevent core damage
- In case the EOPs are not successful and core damage cannot be avoided, focus changes to prevent containment failure (DEC B conditions)
- => Switch from EOPs to Severe Accident Mitigation Guidelines SAMGs

EOPs / SAMGs / EDMGs

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- Transition from EOPs to SAMGs usually based on criteria indicating core damage or imminent core damage

- Usually based on Core Exit Temperature, examples:
  - CET > 650°C (Belgium, Korea, Finland, …)
  - CET > 1100°C (Pressure depended, France, Hungary …)

- Once SAMGs are entered, accident management changes from **preventive** to **mitigative**

Difference between “Procedure” and “Guideline”

- Procedure: clear set of sequential instructions to address a plant condition, operators are expected to follow instructions step-by-step

- Guideline: does not necessarily provide set of instructions, rather a suggested strategy to respond to unpredictable and dynamic situations

Emergency Operating Procedures

- Two approaches – event based (older approach)
  - Accident can be clearly identified by operator, procedure indicates optimal recovery strategy
- Symptom based approach (current approach)
  - The operator identifies the status of the plant by working through critical safety functions (CSF) (e.g. subcriticallity, core cooling, heat sink, …)
  - Each critical safety function may be satisfied or challenged
  - Based on the status of the CSFs a suitable EOP is identified.
- EOPs should have clear entry condition and exit condition and shows procedure as flow-chart and text

Advances AMP in the R2CA Project

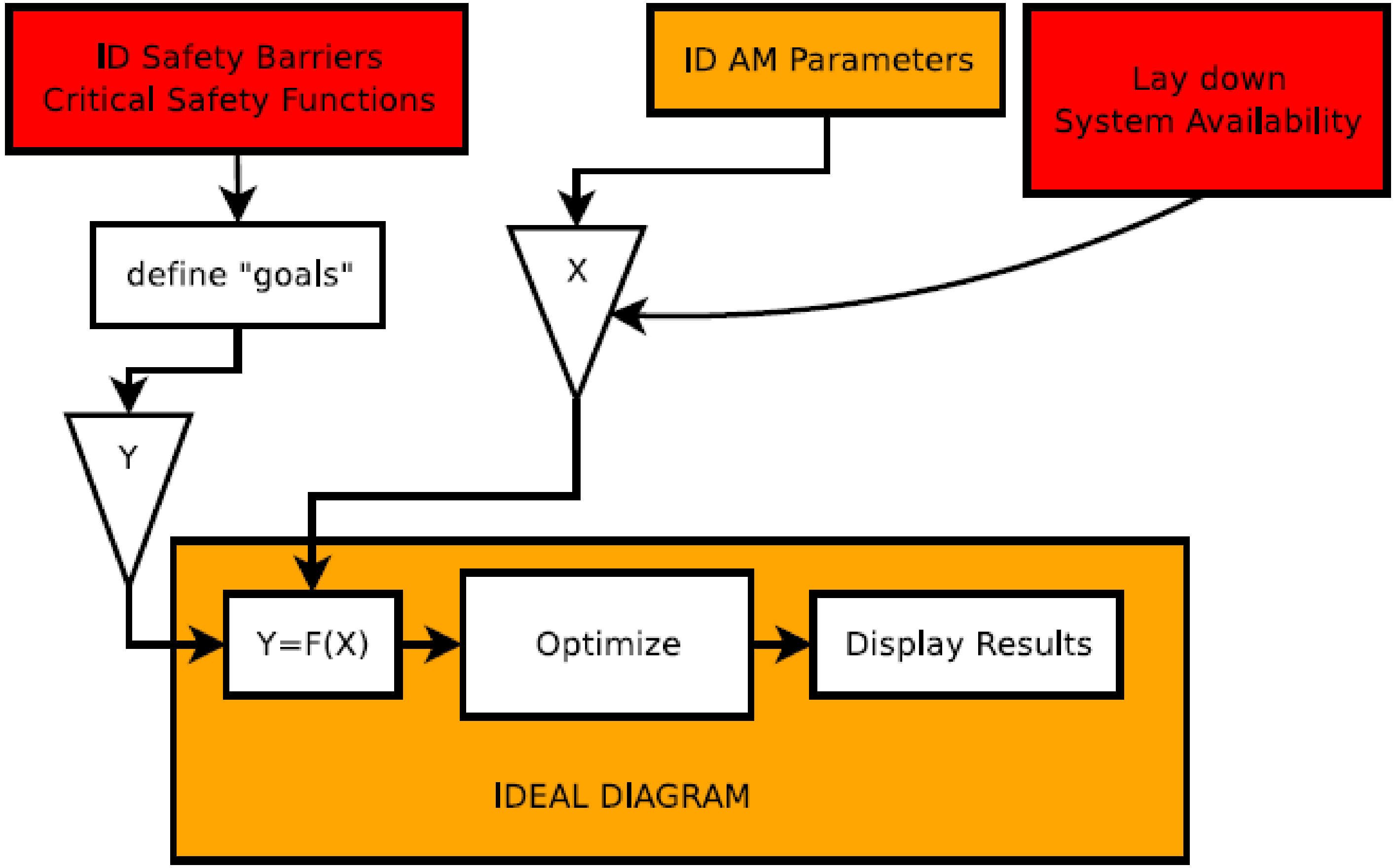
REDUCTION OF RADIOLOGICAL CONSEQUENCES OF DESIGN BASIS & DESIGN EXTENSION ACCIDENTS

- Questionnaire and literature research on innovative AMP approaches
- Key results – instrumentation to detect radioactivity in the main steam lines – possibility to have automated engineered safety features dealing with SGTR and PRISE
- Key results – passive emergency heat removal system for steam generator – possibility of heat removal via intact steam generators also in case of SBO
- Key results – Optimization of Operator Actions during

AM Optimization in case of SGTR Scenario

- Scenario – Steam Generator Tube Rupture at Generic PWR
- Four loop PWR, general safety concept 4x50%, Thermal power 3750 MW
- DEC – A Scenario: SGTR plus SRV in affected loop stuck open, all trains of LPIS unavailable
- AM Strategy: Cool down primary system by SS depressurization of unaffected loops with rate of 100 K/h, disconnect HPIS trains, depressurize further by opening PORV, reconnect make-up/let-down system
- Overall goal – reduce releases to the environment

Advances AM – Procedure to optimize AM



Based on four steps

1.) Safety Barriers/ Critical Safety Functions
2.) Identify AM Parameters
3.) Fix system availability
4.) Optimization and "Ideal Diagram"

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Step one – dependent parameters

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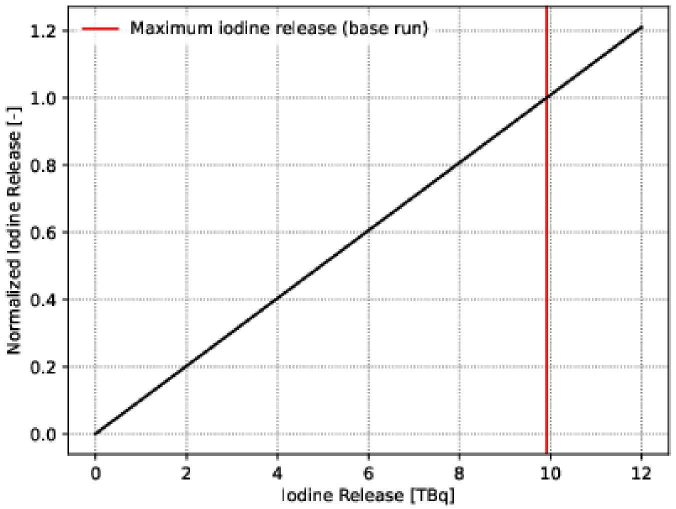

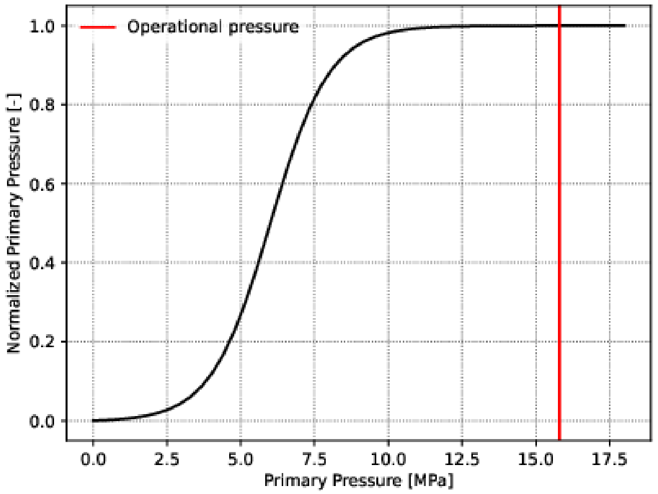

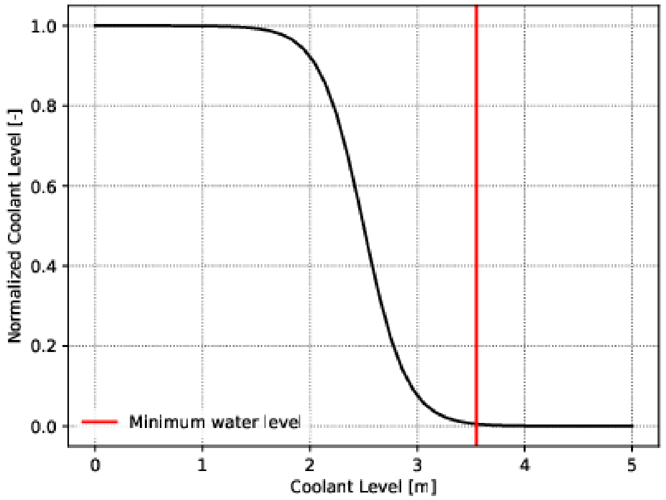

Parameter	
Maximum Iodine Release	
Primary Pressure	
Coolant level	

Step two – independent parameters

Set of independent parameters:

1.) Time of switch off of HPIS train 1

2.) Time of switch off of HPIS train 2

3.) Time of opening the pressurizer relief- and safety valve

Step three – the optimization

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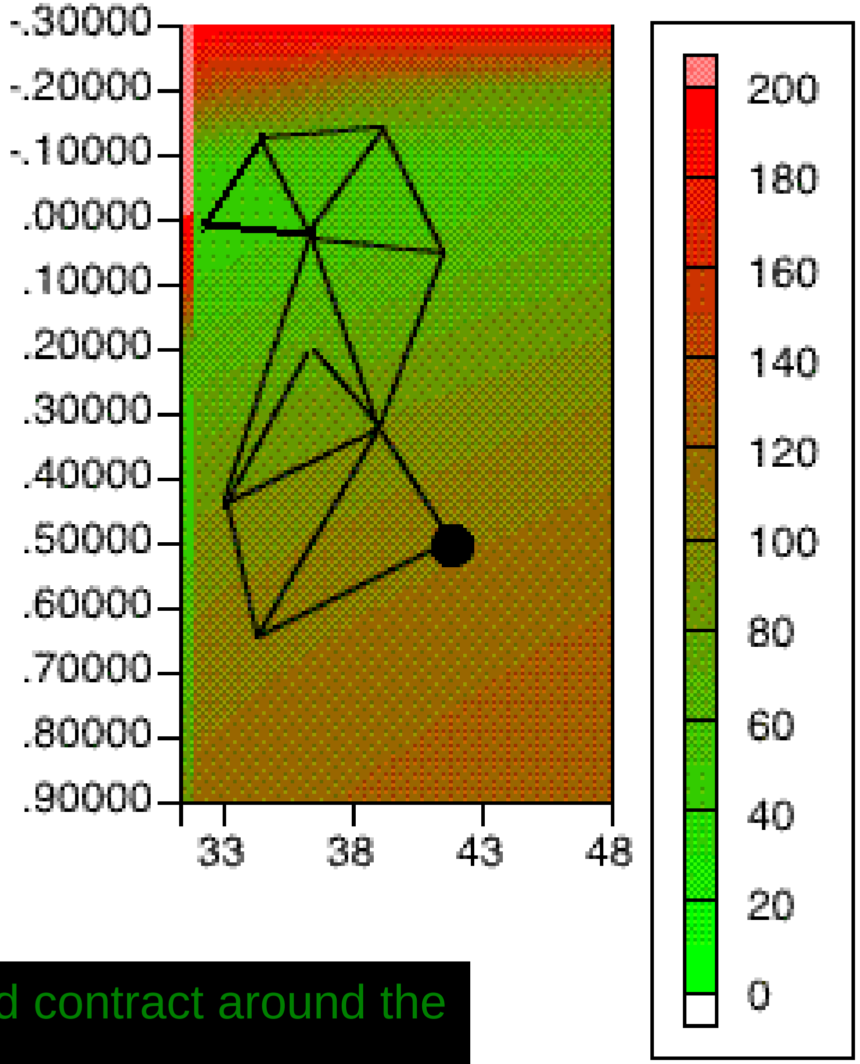
Example:

Finding a minimum of a function depending on two (arbitrary) parameters.

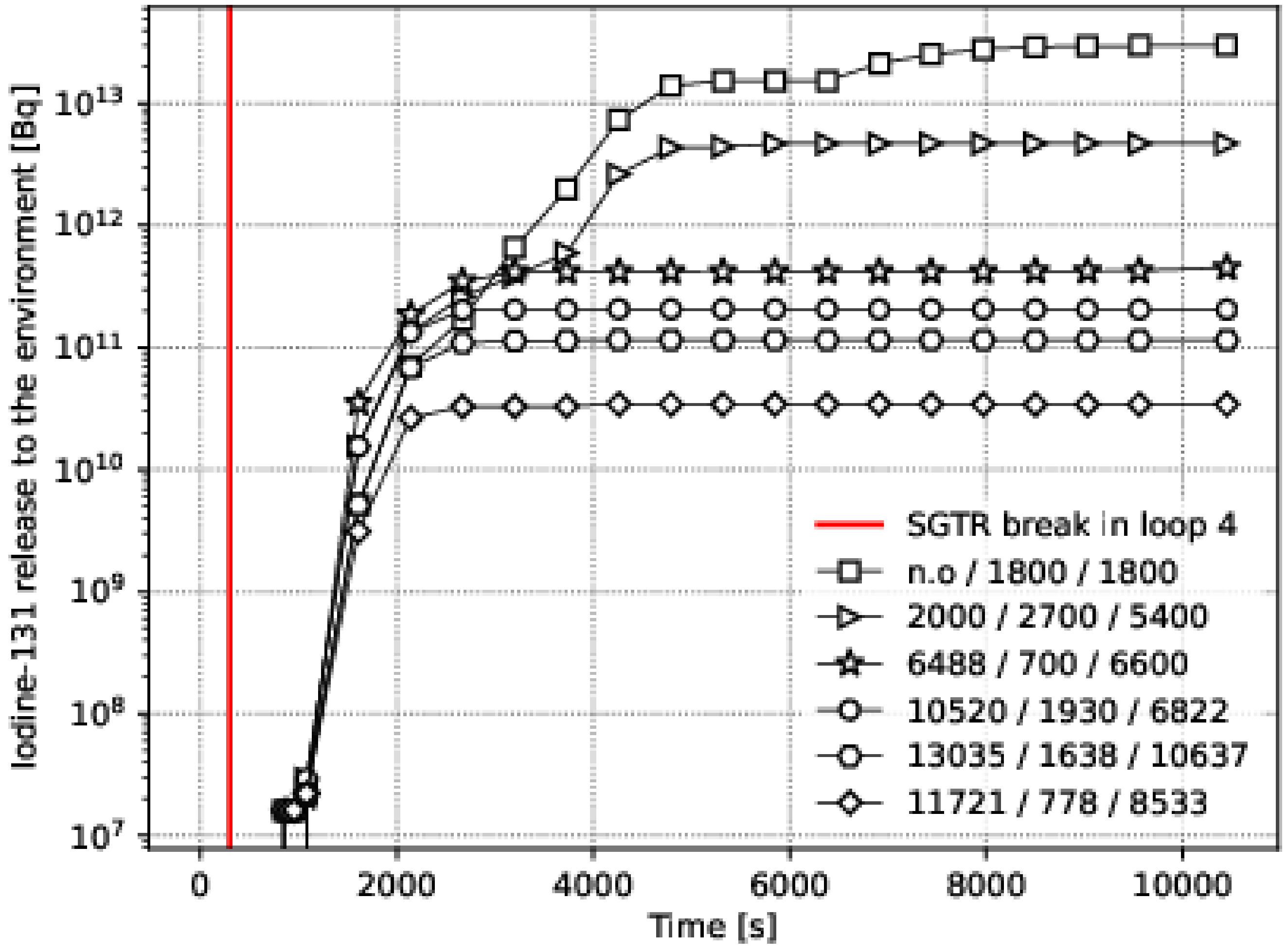
First one constructs a simplex (the simplest geometrical object in two dimensions with an area, a triangle). The initial simplex is the one with the marked point. The function is evaluated on each point

The highest point is moved through the opposing site to build a new triangle conserving the area. This step is repeated with the new triangle



The method can expand towards and contract around the minimum

Step three – results:



Results:
Switch off three trains HPIS early, keep one running

Open PORV at later stage

Reduction of Iodine releases of orders of magnitude!

Procedure to optimize AM

- Optimal timing can hardly be reached during accident
- However, knowledge about optimal timing beneficial during design of procedure
- Knowledge about the importance of timing for specific procedure or strategy

Summary

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- Safety Systems and part of EOPs manage DBAs
- In conditions more severe, e.g. because of multiple failures, EOPs lead operator through Design Extension Conditions A (DEC A)
- If not successful and core damage is imminent, Design Extension Conditions B, (DEC B), operator changes to SAMGs

- Strategy for DEC A – try to make as much water available to cool down the reactor core
- Strategy for DEC B – try to make as much water available to remove heat from containment – keep SGs secondary side covered

Thank you!

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