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A PSA for External Events Endangering Water Intake from the River Danube at NPP Paks

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Background

- Hungarian nuclear safety regulations list the most important (internal &) external hazards that shall be addressed in PSA:
  - accidents in nearby industrial facilities,
  - effects of other man-made activities,
  - external natural hazards.
- Level 1 External Events PSA for Paks NPP – 2012
- PSA models for extreme wind, snow and frost
- Available hazard analyses did not enable to decide if blockage of the water intake filters could be screened out or not -> additional hazard assessment was proposed
- Hazard assessment resulted in a frequency $>10^{-7}$/a, so a detailed risk assessment had to be performed

Objectives

- quantify core damage risk induced by external events endangering water intake and to identify the main risk contributors,
- identify plant vulnerabilities and report safety concern,
- provide support to the formulation of a detailed operational and transient mitigation strategy to follow during a loss of ultimate heat sink event due to Danube contamination,
- scope: full power (& low power and shut down states of a typical refueling outage)

Major Analysis Steps

1. hazard assessment
2. analysis of plant response and fragility
3. PSA model development:
    a. event sequence delineation
    b. fault tree analysis
    c. human reliability analysis
    d. input data assessment
4. risk quantification and interpretation of results

Hazard assessment and plant response analysis proved to be the most significant challenges (due to scarcity of data, lack of knowledge and appropriate supporting background analyzes)

Hazard Assessment

- loss of ultimate heat sink due to Danube contamination was the subject of hazard assessment
- focused on loss of the essential service water system (ESWS) due to filter clogging (to some extent condenser and raw cooling water systems for non-safety systems)
- in order to identify and evaluate possible endangering events (experts on water management, environmental sciences and biology):
  (1) an exhaustive list of external hazards was developed with the associated endangering events,
  (2) dangerous substances were described in terms of chemical, physical and biological characteristics,
  (3) those events were selected that needed detailed PSA modeling and risk quantification.
- frequency of the screened-in external events was determined by a combined use of statistical data analysis and expert judgment
- time to recovery from loss of ESWS was also assessed

Hazard Assessment

Possible endangering events:

- road, rail transport and transport by inland waterways
- industrial and other man-made activity
- natural phenomena
- activities related to plant operation

Some endangering event can induce the same consequences:

- crude oil or other oil by-products floating under water surface get into the Danube, the cooling water channel and the water intake facility
- large scale fish devastation in the Danube, dead fish gets into the cooling water channel and the water intake facility
- grains with blockage potential get into the Danube, the cooling water channel and the water intake facility
- river vegetation with blockage potential gets into the Danube, the cooling water channel and the water intake facility

Consequence Events	Inducing Activity or Phenomena
Fuel or other oil by-products, floating on surface if in contact with water, get into the Danube, the cooling water channel and the water intake facility	• road transport • rail transport • transport by inland waterways • industrial and other man-made activity • activities related to plant operation
Crude oil or other oil by-products, floating under surface if in contact with water, get into the Danube, the cooling water channel and the water intake facility	• road transport • rail transport • transport by inland waterways • industrial and other man-made activity
Large scale fish devastation in the Danube, dead fish gets into the cooling water channel and the water intake facility	• road transport • rail transport • transport by inland waterways • industrial and other man-made activity
Decease of biological organisms settled in cooling water systems	• road transport • rail transport • transport by inland waterways • industrial and other man-made activity
Grains with blockage potential get into the Danube, the cooling water channel and the water intake facility	• transport by inland waterways • industrial and other man-made activity • natural phenomena • activities related to plant operation
River vegetation with blockage potential gets into the Danube, the cooling water channel and the water intake facility	• natural phenomena
Accumulation of biological organisms with blockage potential in the cooling water systems	• natural phenomena

Hazard Assessment

Type of Danube Contamination	Frequency of Loss of ESWS [1/a]	Average Time to Recovery [day]
Crude oil or oil by-products floating under water surface	$7.52\ 10^{-6}$	**3**
Toxic substances (large scale fish devastation on the Danube)	$2.50\ 10^{-5}$	**2**
Grains that may cause filter clogging	$1.00\ 10^{-5}$	**0.5**
River vegetation that may cause filter clogging	$1.00\ 10^{-5}$	**3**
Total	**$5.25\ 10^{-5}$**	**-**

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Plant Response Analysis

- all water intake filters would be blocked shortly after one another -> all 4 units requires shut down -> LOOP (recovery in short time)
- plant operating personnel initiates ESWS recovery
- condenser and raw cooling water system for non-safety systems are assumed unavailable (due to filter blocking or LOOP)
- the following water resources are available at the site for transient mitigation:
  - demineralized water supply (6*960 m^3 for the four units);
  - water in the discharge water channel (4*2000 m^3 for the four units);
  - virtually unlimited supply of water from the well station.

Plant Response Analysis

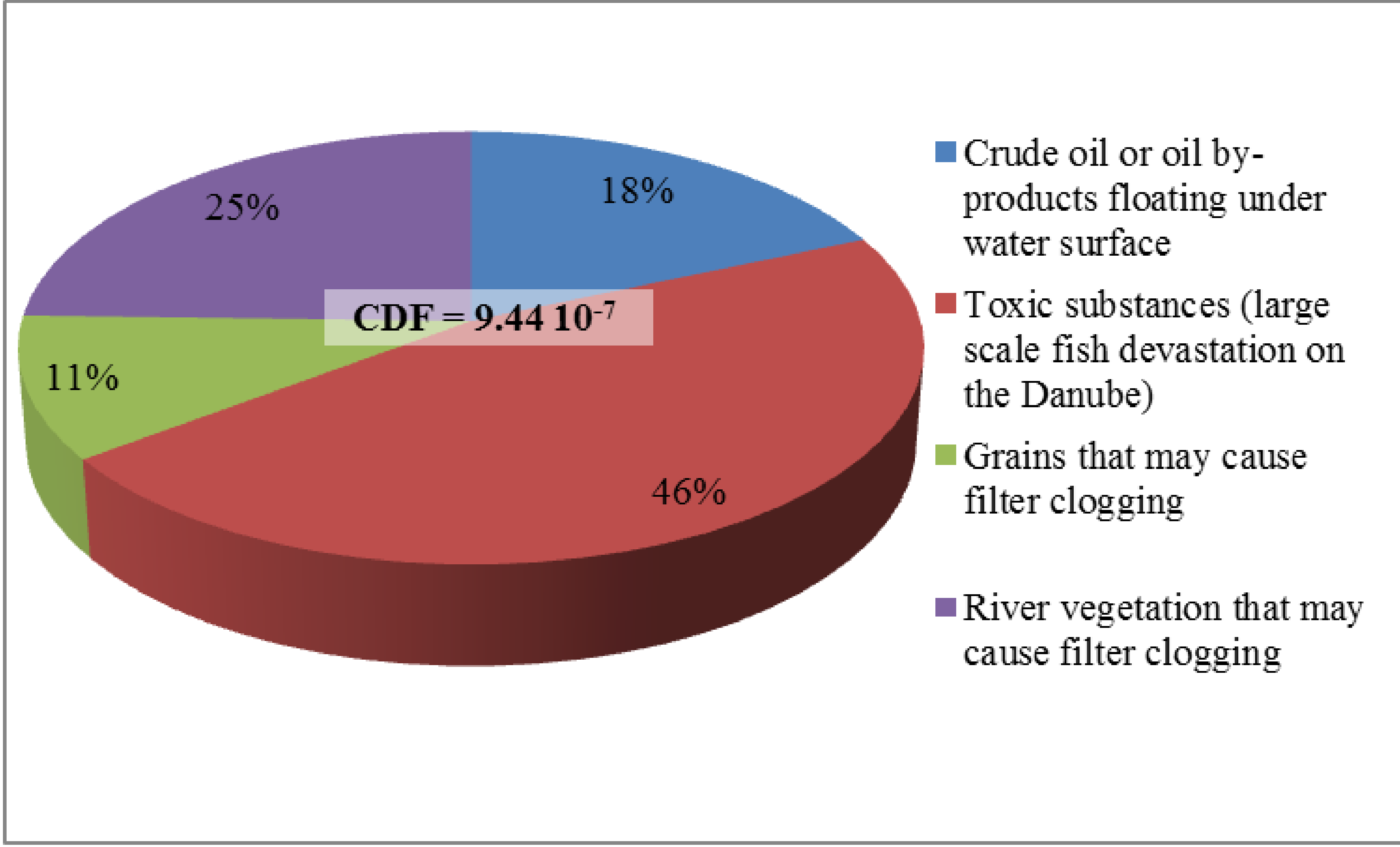
- cross connection between the fire water system and the ESWS has been implemented recently (characteristics of the different fire water subsystems were analyzed and evaluated)
- emergency and auxiliary emergency feed water systems can ensure residual heat removal (until the demineralized water sources are used up 110 hours) – if recovery of off-site power
- the fire water system can be connected directly to the condensers too (enough capacity)
  24 hours of operation of the EFWS or AEFWS is required in open heat removal mode to reduce pressure and temperature in the condenser to enable injection of fire water

PSA Model Development

- An event tree has been developed for each contamination type
- All headers relate to a mitigating actions or system operations:
  - recovery from loss of off-site power;
  - decay heat removal by means of EFWS or AEFWS;
  - recovery from loss of ultimate heat sink (primarily: ESWS);
  - decay heat removal with the fire water system.
- The fire water system had not been modeled in the original PSA -> reliability analysis.
- 3 human actions were identified and newly introduced:
  - the operators ensure cooling water for the diesel generators by the diesel driven fire water pump station;
  - the operators provide water supply to the steam generators from the well station;
  - recovery from loss of ESWS.

Results and Findings – CDF

Type of Danube Contamination	Frequency of Loss of ESWS [1/a]	Average Time to Recovery [day]	Core Damage Frequency [1/a]	Risk Contribution [%]
Crude oil or oil by-products floating under water surface	$7.52\ 10^{-6}$	3	$1.74\ 10^{-7}$	**18.4**
Toxic substances (large scale fish devastation on the Danube)	$2.50\ 10^{-5}$	2	$4.37\ 10^{-7}$	**46.3**
Grains that may cause filter clogging	$1.00\ 10^{-5}$	0.5	$1.01\ 10^{-7}$	**10.7**
River vegetation that may cause filter clogging	$1.00\ 10^{-5}$	3	$2.32\ 10^{-7}$	**24.6**
Total	$\mathbf{5.25\ 10^{-5}}$	**-**	$\mathbf{9.44\ 10^{-7}}$	**100**



Distribution of Core Damage Risk over Contamination Types

Results and Findings – CDF

Results and Findings – Safety Enhancement Proposals

- develop and implement a Danube contamination detection and alarm system to ensure preparedness
- various follow-on analyses and actions to enable a more accurate assessment of loss of ultimate heat sink potential and of consequences from endangering events
- set-up an operational and transient mitigation strategy and the corresponding sequences of actions to apply in case of Danube contamination
- installation of independent, constantly available diesel generators to ensure power supply to the well station pumps (a most effective measure for safety enhancement)

Conclusions

- The EEPSA for the Paks NPP, Hungary has recently been extended with an analysis of events that can lead to loss of ultimate heat sink due to river Danube contamination.
- The scope of level 1 PSA for the plant has been broadened by determining core damage risk attributable to the additional accident sequences developed in this analysis.
- Although the frequency of core damage due to river contamination was found moderate, the findings and insights from the analysis were used to develop proposals for follow-on actions that are seen necessary to ensure that the core damage risk from these kinds of events can be kept sufficiently low.

Thank you for your attention!

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