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Evaluating the impact of extreme events

In the wake of the Nuclear Power Plant event in Japan in March of 2011, the atomic energy community sought to review their approach to comprehensive safety assessments of nuclear power plants (NPPs) with a specific focus on how to evaluate the robustness of the existing plant in terms of design features and procedures against the impact of extreme events.

International Atomic Energy Agency (IAEA) on an extra-budgetary project funded by the Norwegian government has been working to develop models with the purpose of evaluating the "Impact of Extreme Events on Nuclear Power Plants". They wanted to answer the following questions: What are the effects of combined hazards? What are all of the possible functional dependencies? Are there any obstacles for human interactions and issues in emergency procedures? And, what are the connections and interactions between plant buildings, compartments and components?

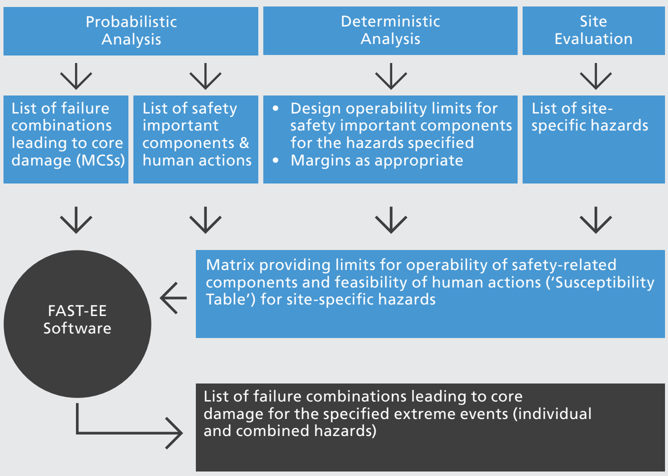
Lloyd's Register Energy has been working in cooperation with the IAEA to further develop the assessment approach. The result of this effort is a new method and software tool to assist in the evaluation of the impact of extreme events on NPPs. The method is Fault Sequence Analysis (FSA) and it utilises the output from Probabilistic Safety Analysis (PSA) – an approach that has been widely used in the nuclear industry for decades – along with design deterministic parameters namely, operability limits of the facilities Structures, Systems and Components (SSCs) to assess the results of hazardous events as well as combined extreme events. It is an iterative process described in the following steps:

1. Postulate one or more extreme events or hazards and their magnitude
2. Identify all the PSA components and human actions modelled in the Level-1 internal initiating events PSA [1] that are disabled by the extreme events or hazards.
3. Check to see whether the disabled components constitute critical paths leading to core damage. If they do not, increase the magnitude of the event or hazard and go to step 2. Otherwise go to step 4.
4. Verify the results and specify any incremental changes that can lead to core damage – also known as cliff-edges.

[1] A Level 1 internal initiating events PSA is a probability safety analysis that evaluates scenarios which could result in core damage.

The diagram in figure 1 shows how the new process effectively combines the results of the existing PSA and Deterministic Safety Analysis (DSA). The benefit of this method and the supporting software is that it allows for an efficient way to analyse a multitude of 'what-if'

Figure 1:



scenarios on the impact of different combined hazards at different magnitudes. These scenarios can include human interactions and long-term accident sequences.

To give an example scenario, consider two possible extreme events: an earthquake and a flood. The level of susceptibility of an electrical building is identified with quantifiable values of seismic measure of .4 Peak Ground Acceleration (pga) and flooding at 3m. The relationship between components and buildings is entered into the system. If the building containing critical generators can be compromised when flooding reaches 3m then the equipment inside the building is assumed to fail at that event. Likewise the equipment in the building will fail in the event of a .4 pga seismic event.

Sensitivities can be easily evaluated by increasing and decreasing the susceptibilities for components, buildings and initiating events. Thus it is possible to find the minimal combination of events that would lead to an unwanted consequence such as core damage. Once all of the scenarios are analysed, it is clear which safety functions, buildings and components need to be improved.

The Geosgen-Daeniken NPP located in the Solothum area in Switzerland served as a pilot plant for testing the IAEA's FSA method. As a result of pilot applications, NPP Goesgen is embarking on a seismic upgrade program to increase the seismic capacity of the reactor protection system.

The benefits of this new method are that it utilises the outcomes of the existing safety assessment studies (DSA and PSA) and is comprehensive in terms of addressing functional dependencies and the feasibility of human interactions under adverse conditions. The output of the tool is understandable by non-PSA specialists.

Two existing safety analysis methods

There are a number of methodologies that have been in place to evaluate complex systems such as a NPP. One is Deterministic Safety Analysis (DSA) where events are identified as the results of certain causes – like a cause and effect chain. It focuses on the engineering and physical parameters of the facility. A deterministic approach can be helpful in the initial design of a system, however the problem with DSA is that it does not handle how operators may respond in extreme events; nor is it able to account for probability of combined hazards. For example it cannot handle a situation where there is a fire and the city has turned off the water due to maintenance.

Another method, Probabilistic Safety Analysis (PSA) is suited for analysis of complex systems and has been widely adopted in the nuclear industry as a standard tool to evaluate NPPs. It characterises the risk by both severity and probability. This process involves obtaining detailed information on the facilities' structures, systems and components (SSCs), identifying initiating events (both external and internal) that could lead to plant damage and modelling the scenarios using fault tree analysis. The drawback is that the PSA method is limited to analysing one extreme event at a time. In a Level 1 PSA, the design and operation of the NPP are analysed to determine the sequences of events that can lead to core damage. A PSA that is updated to reflect changes to the design and operation of a NPP is called a "living PSA."

Figure 1 is from the IAEA papers: – "IAEA's Project to Develop an Approach for Systematic Peer Review of the Nuclear Facilities Protection against the Impact of Extreme Events – Fukushima" Nordic PSA Conference – Castle Meeting 2011, Stockholm, Sweden, 5-6 September 2011.I.Kuzmina , A.Lyubarskiy, M.El-Shanawany

– The Fault Sequence Analysis Method to Assist in Evaluation of the Impact of Extreme Events on NPPs presented at Nordic PSA Conference – Castle Meeting-2013, 10-12 April 2013, Stockholm, Sweden. I.Kuzmina , A.Lyubarskiy, P.Hughes, J.Kluegel, T.KozlikV. Serebrjakov

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Professor Mamdouh El-Shanawany is an international expert on nuclear safety. For the last 35 years, he has provided leadership, design, research & development, analysis, management and critical safety assessment, applications of Statutory regulatory requirements and policy development for the nuclear industry in the UK, Canada and Internationally. He is a member of the IAEA team which was awarded the Nobel Prize for Peace in 2005. He is currently Global Nuclear Technical Director at Lloyd's Register Energy and Professor of Nuclear Safety, Centre for Nuclear Engineering, at the Imperial College, London University.

Professor El-Shanawany was the Head of the Safety Assessment Section at the IAEA. The main responsibilities of the Safety Assessment Section are to strengthen Member States' capabilities (Regulatory Bodies, Designers and Operators) in effective safety assessment and safety enhancement of nuclear installations.
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