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Preliminary Concepts for Safety Index Monitoring System during Severe Accidents

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1. Introduction

The Fukushima accident has started a new era in nuclear industry and now the industry is looking forward for the methodologies to mitigate the Beyond Design Basis Accidents (BDBA). BDBA's marked by loss of residual heat removal, and coupled events such as loss of electric power and loss or degradation of critical instrumentation are difficult to mitigate due to the loss of information on critical parameters [1]. It has been suggested that the severe accident management guidelines (SAMGs) could only be much more useful if the monitoring of critical parameters is somehow made available to the operator. A desired capability of the monitoring system is to predict the gross behavior of the essential NPP subsystems under BDBA conditions, especially before substantial core damage occurs [2].

International Nuclear Energy Research Initiative (INERI) project has been started to address this area of nuclear safety with the intention to develop an accident monitoring and diagnostics tool which could guide the emergency procedures at plant to limit the accident progression in a prolonged Station-blackout (SBO). It is therefore, necessary that while giving a signal regarding plant safety (Safety Index: SI) the processing unit should also be able to diagnose the pattern of accident progression. As a part of INERI team, we have started our research to identify the requirements, methodologies and resources for the development of a Safety Index Monitoring during Severe Accidents (SIMSA) system.

In this paper, we are going to present the preliminary concepts regarding the SIMSA system.

2. Materials and Methods

TMI and Fukushima accidents were exacerbated due to by an unclear chain of commands, because the operators were not aware of the plant state due to the lack of information on safety parameters. Nowadays, the problem of partial loss of power to instrumentation has been almost solved due to the redundancy in the designs of I&C system. However, in case of prolonged SBO, there is a need to have instrumentation and communication systems that can give information regarding the critical parameters related to plant safety. At a broader level, for a complete accident management and emergency planning the areas to be focused are transitional procedures, onsite and offsite interactions, design and equipment and, and human and organizational factors [1]. In INERI project we are mainly concerned safety critical functions which include working of components like emergency diesel generators, motor-operated valves, motor-driven pumps, turbine-driven pumps, air-operated valves, and others. It also includes working of sensors and actuators to monitor and maintain safety critical functions and parameters such as temperature, water level, radiation level, etc. at proper locations under severe accidents [3, 4].

In order to avoid operator's mistakes that may aggravate the accident, we need a system that can keep the track of ongoing activities and predict the state of plant at some late stage to guide the operator. Having reviewed reactor accidents, specially Fukushima, we found that a system that could serve for severe accident management should have the following capabilities; 1) monitoring of parameters important to represent the safety state of the plant at post-accident stage, 2) Representation of safety state by a single metric, 3) To predict the future state of the plant and 4) capability to work in SBO.

In the next section we are going to present the conceptual framework of our modular system which is SIMSA.

3. Framework for SIMSA System

We have developed a modular approach to fulfill the requirements set in the previous section for severe accident management system. Our system for Safety Index Monitoring during Severe Accidents (SIMSA) comprised of three main modules.

1. Monitoring
2. Index generation
3. Prediction

For instance KAERI is working on monitoring module and KHU is taking care of other two modules. The sub-modules of SIMSA system are shown in figure 1. Each module is briefly described in following sub-sections.

3.1 Monitoring module

In order to analyze accident progression, we need to monitor signals from reactor core (core exit temperature, radioactivity concentration, gamma spectrum etc.), sump water level, containment (pressure, hydrogen concentration etc.) when the Emergency/Standby safety systems are operating. We may also have to monitor the working state of Emergency/standby systems (valve, flow rate, vibration). Monitoring is comprised of two modules where one consists of externally powered sensors and I&C unit and other deals with self-powered I&C which is suggested to cope with the situation happened at Fukushima.

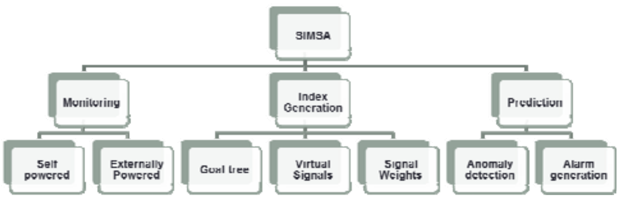

Figure 1: Modules and sub-modules of SIMSA system.

3.2 Index generation module

The objective of this module in SIMSA is to represent the state of the plant by a metric (Safety Index). This will be accomplished by the sub-modules for the construction of Goal Tree, Virtual signals and signal weights.

3.2.1 Goal Tree

Goal tree is regarded as a methodology to integrate the monitored signals on the basis of functional logic in success domain. The top goal has not been decided yet, however would be to represent the minimum condition that the plant state is under control in a post-accident situation. By applying After applying suitable weights from the 'signal weights' module to each signal the top goal can be represented by numerically in percentage as 'Safety Index'. The logic for functional tree must be developed in such a way that the top goal can be defined even with the minimum number of available signals for critical parameters.

The idea has partially been drawn from the plant health index calculation for power plants and process industry [5]. However, with regard to post-accident monitoring and safety management, we have introduced two more modules to address specific problems.

3.2.2 Virtual signals

It is quite conceivable that during severe accident majority of signals are lost due to SBO or instrumentations' degradation/ failure. To handle such conditions SIMSA will provide virtual signals from pre-stored accident simulation data and will compensate for the lost signals. We are working on the generation of accident simulation database by using MELCORE and MAAP codes.

3.2.3 Signal Weights

During the calculation of safety index each signal must be given proper weight according to its relative importance. We may expect accident/ scenario dependent weighting factors. Also we have to define weights for the cases where we have a small number of signals from sensors. Since, this area is quite new in safety investigations; we have to strongly rely on simulation data for the generation of accident scenarios and calculation of accident dependent weights from virtual signals. A methodology to assign weights to each parameter in LOCA and non-LOCA accident scenarios is one of the goals of INERI project.

Also, a good deal of research is being devoted in the area of optimal sensor installation with respect to design and location of installation for severe accidents to handle loss of signals problem as well.

3.3 Prediction Module

SIMSA system will have the capability to be able to identify the accident progression patterns on the basis of information collected from monitoring and index generation module. The anomaly detection module will calculate the differences between the safe accident patterns and the run-time signals utilizing statistical learning algorithms. The size of anomalies will be analyzed on the basis of pre-defined statistical bands in alarm generation module and if the size of anomaly is greater than the acceptable difference the system will generate an alarm so that the operator can make suitable action.

4. Conclusions

INERI project has been devoted to develop a system to guide safety management during severe accidents. We have presented a preliminary concept of a SIMSA system that would serve as tool for intelligent safety management during severe accidents. We hope that with the active collaboration of INERI team, soon, we will be able to see practical SIMSA system.

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