Vital Area Identification Software VIP for the Physical Protection of Nuclear Power Plants

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1. Introduction

There are two major factors to be considered for the physical protection of nuclear power plants. They are a design basis threat (DBT) and the vital area identification (VAI) [1]. The DBT has been considered as "the maximum credible threat." The vital area is defined as "an area inside a protected area containing equipment, systems or devices, or nuclear materials, the sabotage of which could directly or indirectly lead to unacceptable radiological consequences."

For the VAI of nuclear power plants, a software VIP (Vital area Identification Package based on PSA method) is being developed. The VIP is based on the current probabilistic safety assessment (PSA) techniques. The PSA method, including internal as well as external events, is known as the most complete and consistent method for identifying various accident sequences that might result in a core melt and radioactive material release to the environment. Thus, the VIP employs a fault tree analysis method in the PSA and utilizes the PSA results.

2. Vital Area Identification

The PSA-based VAI is performed by evaluating the location fault tree (LFT) that is developed based on the PSA results [2,3]. Location minimal cut sets (MCSs) and location minimal path sets (MPSs) are calculated by solving the core melt LFT and its dual LFT, respectively. The MCSs and MPSs are candidates for vital areas. In order to select the vital areas to be protected, a subjective expert judgment is performed on the candidate sets.

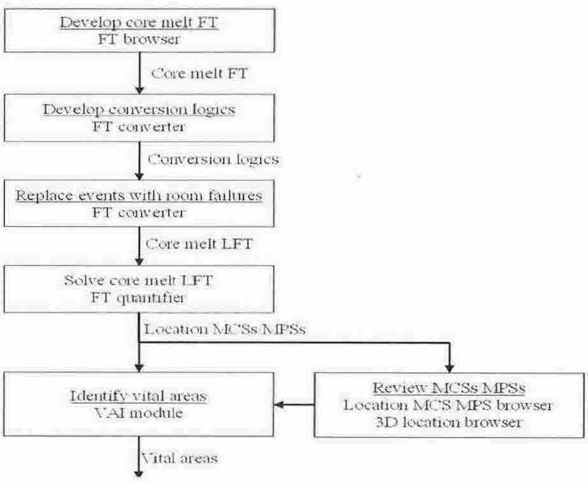

Fig. 1. Overall VAI procedure and main modules of VIP

As shown in Fig. 1, the vital area identification is performed as follows:

1. Develop a core melt FT by combining all the accident sequences in the PSA results.
2. Develop conversion logics from basic events to room failures.
3. Build a core melt LFT by combining the core melt FT and the conversion logics where the basic events in the core melt FT are replaced with room failures.
4. Identify candidate sets of vital areas by solving the core melt LFT and its dual LFT for the location MCSs and MPSs, respectively.
5. Identify the vital areas by performing expert judgments on the location MCSs or MPSs.

The identification of the candidate sets of the vital areas is accomplished in two stages.

First, the core melt LFT is solved to obtain the location MCSs, each of which identifies a combination of room failures that could cause a core melt. Once a complete set of the location MCS is identified, each set should be reexamined in order to be qualified for the final set of vital areas. The current paper proposes to use a structural importance measure and subjective expert judgments for prioritizing the location MCSs.

Next, the dual LFT is solved to identify the location MPSs. The dual LFT is obtained by taking the Boolean complement of the core melt LFT. Each MPS identifies a set of areas that contain the minimal combination of rooms to be protected in order to avoid a core melt. The successful protection of all the rooms in any location MPS guarantees no core melt and thus no radioactive material release. Thus, each MPS is a candidate for the set of vital areas that contains the structures, systems, and components (SSCs) to be protected against sabotage. By the subjective expert judgments to consider the attributes of the rooms in a MPS, one desirable location MPS is selected and its rooms become vital areas.

3. Vital Area Identification Software VIP

3.1 VAI Procedure and Main Modules of VIP

The whole VAI procedure and the VIP main modules are depicted in Fig. 1. The VIP has 6 main modules such as an FT browser, location MCS/MPS browser, 3-dimensional location browser, FT converter, FT quantifier, and a VAI module. Intended function, input, and output of main modules are also shown in Fig. 1.

3.2 FT Browser

The main functions of the FT browser are to edit the core melt fault tree and the conversion logics, convert the core melt fault tree to the core melt LFT according to the conversion logics, and provide a user interface to quantify the core melt LFT.

Conversion logics that connect the basic events or the initiating events to the room failures should be developed through failure mode and an effect analysis (FMEA) of the room failures. The conversion logics have relations between the basic events and room failures such as one-to-one, multi-to-one, one-to-multi, multi-to-multi mapping.

If a room has piping for a mitigating system, its failure causes component failures of the mitigating system. Similarly, the destruction of a room that has an air conditioning system, electrical power supply cables, or signal cables/lines could cause component failures of the mitigating systems. In these cases, the room failures should be located in the core melt LFT by supplying appropriate conversion logics.

3.3 FT converter

The core melt fault tree is converted into the core melt LFT by the FT converter. As illustrated in Fig. 2, all the basic events of the core melt fault tree are replaced with room failures following the conversion logics by the FT converter.

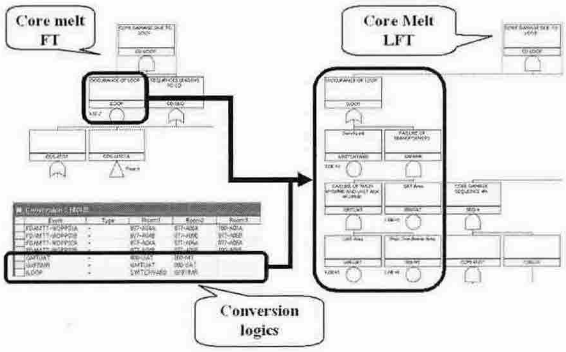

Fig. 2. Replacement of a basic event with location room failures

This conversion could be performed manually or automatically by the PSA software. Most fault tree quantifiers [4,5] could perform the conversion operation by taking the core melt fault tree and the conversion logics. During the automatic conversion, duplicated room failures under the same gate are internally reduced into one room failure in order to simplify the LFT.

3.3 FT quantifier

The FTREX [5] is employed as a default quantification engine to convert the core melt fault tree to the core melt LFT and generate the location MCSs or MPSs.

3.4 Vital area identification

The prioritization on the location MCSs or MPSs could be implemented by ranking some attributes by the experts from related areas such as security, plant operation, regulation, and safety. In the expert judgments, several attributes could be considered. They may include, for example, easiness to access a room, easiness to recognize a room, easiness to destroy a room, and the defensibility of a room.

For the prioritization of the room failures in the location MCSs, a structural importance measure [6] of the room failures could be calculated. Furthermore, one more attribute of the physical separation of rooms in the same location MCS could be included into an expert judgment. When considering the physical separation of the rooms in the same location MCS, the propagation of the explosion damage through broken doors might be accounted for if two rooms are adjacent to each other.

4. Conclusion

The VIP is believed to be very useful for the physical protection of nuclear power plants. The method in the present paper is consistent and the most complete for identifying the vital areas to be protected since it is based on well-proven PSA technology.

Acknowledgement

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