Preliminary Master Logic Diagram for ITER Operation

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Abstract

This paper describes the work performed to develop a Master Logic Diagram (MLD) for the operations phase of the International Thermonuclear Experimental Reactor (ITER). The MLD is a probabilistic risk assessment tool used to identify the broad set of potential initiating events that could lead to an offsite radioactive or toxic chemical release from the facility under study. The MLD described here is complementary to the failure modes and effects analyses (FMEAs) that have been performed for ITER's major plant systems in the engineering evaluation of the facility design. While the FMEAs are a bottom-up or 'component level' approach, the MLD is a top-down or 'facility level' approach to identifying the broad spectrum of potential events. Strengths of the MLD are that it analyzes the entire plant, depicts completeness in the accident initiator process, provides an independent method for identification, and can also identify potential system interactions. MLDs have been used successfully as a hazard analysis tool. This paper describes the process used for the ITER MLD to treat the variety of radiological and toxicological source terms present in the ITER design. One subtree of the nineteen page MLD is shown to illustrate the levels of the diagram.

1 MLD Construction

The MLD construction began in mid-1997. The analysts began by recognizing two main differences between ITER and a fission reactor. The first difference is that in ITER the source terms are distributed in the reactor vessel, the fueling system, the fuel cleanup and purification system, and fuel storage system, rather than being contained in two locations (i.e., fission core and spent fuel pool). The second difference is that there are several types of radiological source terms for the ITER machine, and each of these potential source terms have varying conditions that could make release possible. Some source terms are easily mobilized and released, such as tritium and activated dust from the plasma facing components (PFCs). Other source terms (such as activated structural materials) are not releasable until volatilization occurs. The variety of ITER source terms are listed in Table 1.
The differences between ITER and fission reactors caused the ITER MLD to vary from the traditional fission plant diagram. Another variation is that the ITER MLD also treats the non-radiological inventories of beryllium dust and cryogens.

The MLD construction process began with a review of past fusion MLDs, to build upon any past work. Madrid et al. developed portions of an MLD for a hypothetical fusion power plant. While ITER is not a power plant, that work was used to initiate the development of the MLD for ITER. Two important issues for MLD construction are knowledge of the plant and the determination of critical safety functions for the plant. Plant knowledge was drawn from the Detail Design Report (DDR) and the system Detailed Design Descriptions. The safety functions for ITER have been defined in the DDR and are listed in Table 2.

Table 1. ITER Hazardous Material Inventories

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tokamak dust</td>
<td>This dust consists of submicron to micron size aerosol particles such as Be, C, and W PFCs. Other particles are from in-vessel components and may contain elements of structural materials (e.g., Mn, Fe, Cr, Cu), insulation and diagnostics.</td>
</tr>
<tr>
<td>Tritium in tokamak dust</td>
<td>This tritium comes from the plasma, recombines with electrons, and is probably in elemental form. The tritium is assumed to be oxidized as a safety conservatism. The tritium bonds with tokamak dust.</td>
</tr>
<tr>
<td>Activated corrosion products</td>
<td>Water coolant can be corrosive at high temperatures and pressures. Corrosion products from the stainless steel pipe walls become neutron activated, resulting in activated oxides of Cr, Mn, Fe, Co, Cu, and other isotopes.</td>
</tr>
<tr>
<td>Tritium</td>
<td>Elemental tritium fuel is in the fuel cycle system and in the auxiliary buildings. It is usually considered to be oxidized for safety analysis.</td>
</tr>
<tr>
<td>Tritium on/in PFCs</td>
<td>This tritium is on the surface of PFCs and deeply bound in the PFCs. Special conditions of heating are required to mobilize the deeply bound tritium. The tritium is assumed to be oxidized as a safety conservatism.</td>
</tr>
<tr>
<td>Plasma vaporized material</td>
<td>During a plasma disruption, the plasma radiates very large quantities of heat and also some plasma ions bombard the vacuum vessel PFCs. With increasing heat flux, some PFC material is vaporized.</td>
</tr>
</tbody>
</table>
Table 1. ITER Hazardous Material Inventories (continued)

Oxidation driven material
This material is from the PFCs and structural materials. In the presence of steam or air and at elevated material temperatures (over 500°C), oxidation will occur and mobilize the material.

Neutron multiplier
The Blanket Test Modules will use beryllium to multiply the neutron flux for more efficient tritium breeding. The multiplier will become activated, and Be is chemically toxic when in aerosol form.

Activated NBI cryogens
The neutral beam injectors will use liquid nitrogen as a coolant for its cryopumps. The nitrogen will be activated, making N-13 and C-14.

Liquid helium and nitrogen
The liquid helium and nitrogen contained in the cryoplant could potentially be released, and while not toxic chemicals, these are simple asphyxiants. In large releases, the cold ground-level cloud may reach the site boundary, creating a hazard.

Table 2. ITER Safety Functions

1. Reduce inventories
2. Provide confinement barriers
3. Ensure decay heat removal
4. Control hydrogen inventories and chemical reactions
5. Control effects of magnetic energy
6. Control effects of coolant energy
7. Monitor status of safety functions and safety related parameters
8. Provide support services to ensure safety functions

The safety functions are not listed in order of importance; they are equally important. For the ITER MLD, only safety functions 2 through 6 are included since these deal directly with the ITER process and safety systems. Safety function 1 can be viewed as an engineering control in the design process. While safety functions 7 and 8 are important for maintaining plant control, they are not necessary for identifying initiating events in an MLD. That is, loss of monitoring or support services does not directly lead to a radiological or toxicological release. Loss of safety function 7 or 8 typically leads to an orderly plant shutdown.
With the hazardous inventories and safety functions defined, and plant design information at hand, the MLD was completed. The diagram required seven levels to complete the logic. Figure 1 shows one branch expanded from level 1 down to level 7. The tree construction proceeded from a top event of no excessive off-site release of radioactive or chemically toxic material that could present a public hazard. For ITER, this was defined as a release in excess of normal effluents.  

The second level of the MLD defined the release pathway, either release from an auxiliary building or a release from the tokamak building. Using traditional MLD terms, the tokamak building is an indirect release due to the multiple confinement barriers provided for the inventories used in high energy processes (i.e., the plasma). Direct releases can occur from auxiliary buildings (e.g., radioactive waste handling facility, the tritium plant, the cryoplant) where because of the lower inventories there are generally fewer barriers than for the tokamak with its multiple inventories.

The third level deviates from traditional diagrams. This level defined the origin of the release; that is, which system releases the hazardous material. That level was considered necessary to account for the many systems in a fusion plant that contain radioactive materials and to allow the introduction of the concept of mobilization of radioactive species.

The fourth level listed the release species. This level was specified because of the combined nature of the inventories in the tokamak and in waste handling, and since there are temperature and oxidation restrictions on the mobilization and release of some species. These restrictions need to be delineated for source term assessment.

Level 5 identified the barriers to release, generally mobilization and physical barriers. Some of the inventories in the fusion reactor are readily mobile (gases and liquids), but some are bound in the solid structure and require significant heating and the presence of oxygen to be mobilized by volatilization. For the tokamak, the primary and secondary independent barriers (the vacuum vessel and cryostat) were challenged, requiring representation by an AND gate configuration.

Level 6 identified the safety functions for that branch of the diagram. The safety functions are those acts or functions that must be carried out to prevent offsite releases. Not all safety functions were called upon for each branch of the MLD since some functions do not apply in all branches.

The final level, level 7, identified events that can fail the safety functions. These events were labeled "failure events". These events can be initiating events (IEs) for ITER, but due to the presence of the AND gates at level 5, they must be combined to yield events with hazardous consequences. Failure events that exist on both sides of an AND gate are generally the most important events, since the single event occurrence leads to an offsite release.
2 MLD Results and Conclusions

The initial MLD was completed in September 1997 and spanned seventeen pages. It was reviewed by members of the ITER design team and other safety personnel. Comments were incorporated and the diagram has been expanded to clarify terms used and to include more treatment of plasma heating systems. The MLD results were compared to the FMEA results, and were reported in an ITER safety assessment report. The results agreed well. In some cases, the FMEAs gave more detailed IE information. In other cases, the MLD treated areas where no FMEAs had yet been performed. The MLD did not uncover any IEs not already identified by other approaches, but it does serve as a good graphical tool to present the initiators. The ITER MLD complemented the FMEA engineering evaluation of major ITER systems and provided a second means of demonstrating completeness in the selection of IEs. The MLD provides breadth in IE identification for ITER.

Disclaimer

This paper is an account of work assigned to the U. S. Home Team within the Agreement among the European Atomic Energy Community, the Government of Japan, the Government of the Russian Federation, and the Government of the United States of America on Cooperation in the Engineering Design Activities for the International Thermonuclear Experimental Reactor ("ITER EDA Agreement") under the auspices of the International Atomic Agency (IAEA). This paper has not been reviewed by the ITER Publications Office.

References

Figure 1. The ITER Interim Master Logic Diagram with the 'tritium in plasma facing components' branch fully expanded.

notes: PHTS - primary heat transport system, VV - vacuum vessel, CV- cryostat
FW- first wall PFC cooling, LOVA - loss of vacuum accident. For clarity, AND gates are darkened, OR gates are not.