Safety of the Nuclear Fusion Facilities

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A B S T R A C T

Nuclear fusion can be basically the source of unlimited and environmentally safe energy on the earth. Creating fusion reactions on the earth (in hot nuclear fusion plants) at high pressure and temperatures is one of the proper options for human being to transform the resulted thermal energy to the electrical energy. Plants, especially compared to different common types of nuclear plants (fission type) have advantages including full fuel, easy and low-cost fuel cycle, high safety, not producing the nuclear waste with strong radioactivity and high life and not producing the harmful radiation for human being and environment. Fusion facilities should be designed, built, operated and disabled in a way that it guarantees staff, public and environmental protection and safety becomes an integrated part of design and exploiting the facilities.

INTRODUCTION

In thermal nuclear fusion plants, the reason of the radiation, creating nuclear wastes, codes, nuclear standards and rules should be considered in design, building, operating, repairing and maintain and disabling the facilities in addition to the standard and industrial codes, regulations and standards, so that the staff, society and environment can be protected against the possible dangers and harms. So, the present article provides some information about the safety strategies, safety necessities and environmental principles, designing principles, systems related to safety performance and the systems involved in or the hidden cases of nuclear fusion facilities.

1. Safety policy:

The nuclear fusion facilities should be designed, built, operated and disabled in a way that the protection of staff, society and environment is guaranteed; so the safety strategies should 1) protect the society in a way that the risk for the health and safety of the person due to operating the fusion facilities is not more than the risks due to other public facilities for the society which people are naturally exposed to, 2) protect the staff in a way that the risk of fusion facilities is not more than the comparable industrial facilities, 3) reducing the dangers for the staff and society to the minimum level, 4) avoiding the need for off-site drain, 5) reducing the wastes, especially high radioactive wastes in fusion facilities.

2. Safety requirements:

In order to obtain safety in fusion facilities, an integrated part of design and operation of the facilities is required. Safety strategies include two types of performance that are society safety and staff performance safety.

Fusion facilities have to be designed in a way that the certainty about staff performance and society is always provided for the basic design. Safety performance of the society for fusion facilities includes locking up the dangerous materials (Beryllium and Vanadium) and radioactive materials (such as active by products and Tritium) and the staff safety performance involves controlling the operation dangers including radioactive and dangerous materials.

Some of the hidden safety issues which should be considered during designing process for reducing the safety performance challenges of the society (locking up the radioactive or dangerous materials) include certainty about the thermal transfer after extinguishing, possibility of controlled reduction of plasma energy.
controlling the controlling energy, controlling the chemical, controlling magnetic energy and limiting the liquid
distribution and airborne into the environment.

In addition, the obstacles for locking up the radioactive and dangerous materials should be enough, resistant
and certain in designing the fusion facilities so that they prevent radioactive and dangerous distribution of
materials during the normal or abnormal operation. It is more required in multi-layer obstacles; destruction of a
layer should not lead to the destruction of other layers even if the evaluation instructions are allowed to violate
it. The redundancy and variety principles should be observed in all the strategies of locking up even not tested
elements of an obstacle.

3. Safety and environmental principles:

   Principles of redundancy, variety, independence, simplicity and monitoring should be applied in designing. The
   process of designing for fusion facilities should include the concept of defense in depth including the multi-
   layer protection for facing the distribution of radioactive and dangerous distribution. Protection level should be
   fitted with the danger for the staff, society and environment.

   The concept of defense in depth which can be applied in fusion facilities should include the selecting the
   materials and other designing process for reducing the amount of dangerous and radiologic materials,
   conservative designing, continuity of physical obstacles, providing the multi-function devices for being certain
   about the safety performance of the society using the basic designing indexes, facilities and official strategies
   and operating to reduce the expected operational events and abnormal condition and for controlling the
   consequences, implementing an official quality guarantee plan, organizing and creating safety culture, using the
   emergency programs needed for reducing the effect of radioactive and dangerous materials` distribution for the
   staff, society and redundancy defense.

4. Designing basis:

   Designing the fusion facilities should be done considering the necessary defense levels for facing the
   internal challenges (the possibility of $10^{-6}$ events per year) and the designing actions should be provided to be
   sure about the performance of the key safety tasks and goals. Designing principles in external challenges should
   include considering the natural events (earthquake, flooding and sever winds), environmental effects and
dynamic effects (breaking the pipe, pipe vibration and jet injection).

   Heat transform more than the fusion power, losing the cooling systems, losing the gap, chemical reactions
   (Hydrogen explosion), jet injection (motor production collection) and natural events (earthquake, flood, sever
   winds and alike) based on the designing are the hidden events of the designing principles for fusion facilities of
deuterium-tritium.

   Safety performance of the constructs and systems are the components of radioactive materials (such as
   tritium, active dust, corrosive productions) and poisonous (such as beryllium and vanadium dust) and the
general designing principles include designing for reliability and defense in depth.

   Constructs, systems and the related components should be designed to be resistant against the static loads
   (facilities weights), pressure (internal and external), thermal, electromagnetic, vertical movement event/break
   and close and neighboring systems.

Fig. 1: Tritium confine diagram (DOE6004: 33).

   Codes and standards should be applied in limits of mechanical designing, construct designing, resistance
   against the safety, Neutronic and thermo-hydraulic designing, electric design, control system design and precise
devices, radioactive protection and shielding, protection against the fire, testing and repairing, cool design, magnetic system design, designing gap system and safety.

5. **Systems related to safety performance:**

The systems related to the safety performance include the confine system, ALARA designing requirement, protection against the radiation and controlling the access of radioactive dangers, non-radioactive dangers of the staff.

**Table 1: Combinational loads (DOE6004: 6)**

<table>
<thead>
<tr>
<th>Plant Condition</th>
<th>Static</th>
<th>Thermal</th>
<th>Electro-magnetic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Norm.</td>
<td>Trans.</td>
<td>Norm.</td>
</tr>
<tr>
<td>Normal Operation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Design Basis</td>
<td>X</td>
<td>Y</td>
<td>X</td>
</tr>
<tr>
<td>Accident</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Initiates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Coolant Leak</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2. In-vessel Leak</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3. Out-of-vessel Leak</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>4. Loss of Pumping</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5. Loss of Fuel</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>6. Loss of Fuel</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>7. Vacuum Leak</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>8. Increase in Fusion Pressure</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>9. Vacuum Leak</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>External Initiates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Natural Phenomena</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2. Fire</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

- **Confine systems:**

Main and public function of safety is to confine the radioactive material (such as tritium, activated dust, corrosive productions and activating ones) and dangerous materials (such as beryllium and vanadium dust). Systems which provide the first obstacle of the confine limit (sometimes called primary confinements) include the vacuum source and external sources (including the separating isotope and fuel saving) which provide the tritium confinement. Main systems which (generally called secondary confinement and third confinement) provide the second and third obstacles include the cold clock, chambers/ glass chambers out of the source, pipe systems or fusion building.

The vacuum store is usually the primary confinement for poisonous and radioactive materials inside the store which is a circle shaped enclosure which is usually made of the metal and its volume is more than the plasma. The main function of the cold clock is to provide the vacuum limit for thermal insulation of the super conductive windings around the vacuum store from the external environment of the building.

- **ALARA Designing Consideration:**

Designing the fusion facilities should have the features of 1) selecting the materials which reduce the activation of the components and constructs and remove the need for land burying 2) designs which facilitate the destruction, separation and movement of the polluted facilities, 3) equipment designs which reduce the dangerous materials’ accumulation , 4) using the modular confinement with elastic ability, 5) using the direct liquid transform systems, 6) holding the cleaning components of output air in or near the independent limits, 7) piping systems with the complete drain capability with the stores, for reducing the radiation on staff while repairing and maintaining and disabling activities and distribution to the environment.
• Protection against radiation and controlling access from hazardous radioactives:
  Discharging (radiation) in controlled limits should be under the ALARA regulation in designing the equipment, official controls and facilities and the main methods which have the physical features of confinements, airing, protection against the radiation and tele-operating and official controls including the policy are used as secondary methods.

Access controls:
Access control of the staff should be set for each radiologic limit based on the proper control level with the real or hidden risk. In order to do this, signs and stops, inputs and control devices, voice controls and significant image of both, entrance lock and official controls should be used.

Shielding:
Shielding should be designed based on the designing goals 10CFR 835, selecting the design, arrangement and materials should be based on considering the factors including the reduction of doze heat, galvanic effect or hidden corrosion, weight, need to move the protection, thermal radioactive potential, thermal resistance and activation potential improved in the least amount. For example, for movement of the activated facilities, protecting the staff in touch with the repairs and protecting the sensitive equipment should be taken into account. Building the modular and movability of the protection should be considered, too.
Openings should be at the highest portion of a wall and should not be directly in touch with the source or any limit or space which may have to occupation potential and be ordered after each other so that the staff cannot be against the closed door to be prevented from the radiation.

• Non-radioactive hazards for the staff:
Non-radioactive for staff in the huge fusion facilities includes the high voltage electricity systems, liquid helium, laser systems, big electromagnetic fields, microwaves and high radio frequency, round devices and big vacuum chambers. The regulation ( such as OSHA standards in 1926 and 29 CFR 1910 ), provide controlling requirement of the industrial dangers for the staff in these areas including the choking, electrocution, radiation of cool materials, vacuum and round machines. Fusion facilities should be designed in a way that they limit the staff expose to the static electromagnetic environments during the daily routines.

6. Systems involved with potential safety issues:
Due to the great effect of designing issues in fusion on the hidden dangers for staff and environment, just two performance of confinement of the dangerous radioactive materials (public performance) and controlling the operation dangers (staff performance) are determined at this time for performance in all fusion facilities. In addition, hidden safety cases including the reliability of transformation after heating, possibility of fast extinguishing of the plasma, controlling the cooling energy (under-pressure water and cold clocks), controlling the chemical energy, magnetic energy (stored magnetic field energy) and limiting the liquid and airborne in the environment should be considered during the designing process for reducing the general safety performance of the dangerous material or radioactive confinements.

Conclusion:
Considering the safety necessities and requirements, the principles of redundancy, diversity, independence, simplicity and controllability/experiment and concept of the defense in depth including the multi-layers of protection for facing the radioactive distribution based on the ALARA regulation, should be considered in a fusion plant.

REFERENCES