Fusion Engineering and Design xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Conceptual layout design of CFETR Hot Cell Facility

Zheng Gong [a,b,*], Minzhong Qi [b], Yong Cheng [b], Yuntao Song [a,b]

[a] University of Science and Technology of China, Hefei 230026, China
[b] Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, China

HIGHLIGHTS

- This article proposed a conceptual layout design for CFETR.
- The design principles are to support efficient maintenance to ensure the realization of high duty time.
- The preliminary maintenance process and logistics are described in detail.
- Life cycle management, maneuverability, risk and safety are in the consideration of design.

ARTICLE INFO

Article history:
Received 8 December 2014
Received in revised form 10 May 2015
Accepted 18 June 2015
Available online xxx

Keywords:
CFETR
Maintenance
Hot Cell
Layout
Conceptual design

ABSTRACT

CFETR (China Fusion Engineering Test Reactor) is new generation of Tokomak device beyond EAST in China. An overview of hot cell layout design for CFETR has been proposed by ASIPP&USTC. Hot Cell, as major auxiliary facility, not only plays a pivotal role in supporting maintenance to meet the requirements of high duty time 0.3–0.5 but also supports installation and decommissioning.

Almost all of the Tokomak devices are lateral handling internal components like ITER and JET, but CFETR maintain the blanket module from 4 vertical ports, which is quite a big challenge for the hot cell layout design. The activated in-vessel components and several diagnosis instruments will be repaired and refurbished in the Hot Cell Facility, so the appropriate layout is very important to the Hot Cell Facility to ensure the high duty time, it is divided into different parts equipped with a variety of RH equipment and diagnosis devices based on the functional requirements. The layout of the Hot Cell Facility should make maintenance process more efficient and reliable, and easy to service and rescue when a sudden events taking place, that is the capital importance issue considered in design.

1. General

CFETR (China Fusion Engineering Test Reactor) is next generation fusion experimental facility in China which is beyond the EAST and intervening between ITER and Fusion DEMO. The mainly purpose of CFETR is to test the related fusion technology and engineering in fusion power plant, especially long pulse or steady-state operation with envisioned duty cycle time at the range of 0.3–0.5 and exploring option for DEMO blanket & divertor with easy changeable in-vessel components by remote handling equipment [1–4] (Fig. 1).

As the lynchpin of the maintenance system, Hot Cell plays an important role in the campaign to guarantee the high duty time implementation. Many technical, economic, safety, managerial, logistic, organizational, legislative issues and other factors should be taken into account when planning maintenance activities such as remove, transport, inspection, repair, renewal, disassembly and refurbishment for the in-vessel components in the host to make the high duty time requirement of CFETR. Furthermore, layout's good and bad of design will directly influence the whole function of maintenance.

The CFETR maintenance system consists of Hot Cell Facility (HCF), Radwaste Treatment Facility (RTF) and Control & Access Facility (CAF) three main sub-systems which are located to south-east side of the CFETR Tokomak Building. In this paper, one layout design version of the Hot Cell Facility is established under the consideration of maintenance process combined with the components life cycle management and the efficient maintenance strategy.

2. Maintenance methodology

The realization of the high duty time is based on the reliability of host device, equipment and all in-vessel components, as a

* Corresponding author.
E-mail addresses: gongz@mail.ustc.edu.cn (Z. Gong), qiminzhong@ipp.ac.cn (M. Qi), chengyong@ipp.ac.cn (Y. Cheng), songyt@ipp.ac.cn (Y. Song).

http://dx.doi.org/10.1016/j.fusengdes.2015.06.088
0920-3796/

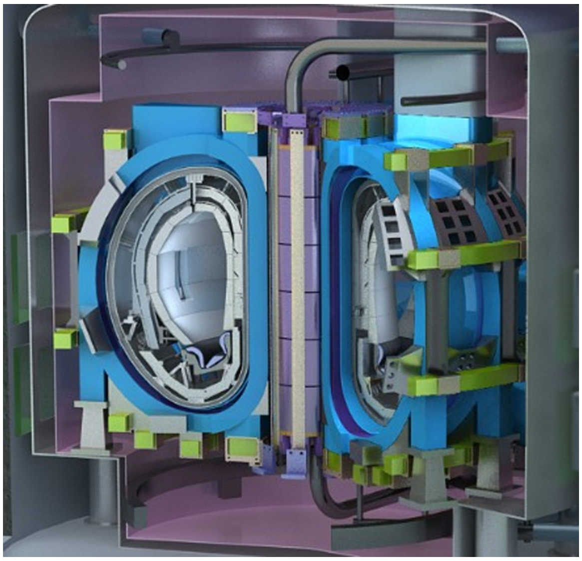

Fig. 1. Section view of CFETR host [1].

consequence, RCM (Reliability-centered maintenance) is introduced as the main maintenance methodology of CFETR to ensure the mission and goal of the maintenance.

RCM is an international general maintenance method, which is currently used in the aircraft and some other larger and complex equipment maintenance. For fusion device maintenance, one of the potential function of RCM is to determine the preventive maintenance requirements and also provide the system engineering approach to optimize the maintenance process and support to design the related maintenance equipment and system.

In order to meet the requirement of high duty time, the most important issue in the consideration of the layout design for HCF is how to make the maintenance process as efficient as possible to improve the availability, it can be expressed as:

$$A = \frac{\text{Uptime}}{\text{Uptime} + \text{Downtime}}$$

The availability of a year, for example, the denominator of the formula about 8760 h, the inherent availability from the perspective of design must meet the following formula:

$$A_{\text{inherent}} = \frac{\text{MTTF}}{\text{MTTF} + \text{MTTR}}$$

MTTF: Mean Time To Fail
MTTR: Mean Time To Replace

From the formula, if the average failure time (MTBF, mean time between failure) interval or the average time (MTTF, mean time to fail) before failure is greater than MTTR (MTTR, mean time to repair) and the average recovery time (MTTR, mean time to replace), the availability will be higher. Similarly, if the mean time to repair or mean time to recovery is very small, the availability will be higher too. If reliability decline decrescendo, we need to improve the maintainability, such as reducing MTTR can achieve the same availability.

Usually, for certain availability, reliability growth, the maintainability is not so important. So we can make a balance between reliability and maintainability, to achieve the same availability, but the two constraints must be synchronous improvement. If no human negligence occurred in system operation, the A_{inherent} is the biggest one we can get to support the high duty time.

From the dissection above, several maintenance strategy issues are taken in to the design requirements:

- Maintenance based on the functions protection.
- Each component of host is to maintain in their own cell or unit, maintenance area without crossing and overlapping for increasing the availability of CFETR host.
- Replacement and repairs implement in parallel.
- Replacement of reparation with change, preparing enough parts for turnover.
- Routing maintenance based on the process sequence, saving the intermediate costing.
- The travel distances minimizes during the transfer of the in-vessel components from/to the tokomak building and HCF.

3. Maintenance process in Hot Cell

Sequence and operation of maintenance for each components and equipment have been studied and generated by CFETR China National Integration Design Group. Each maintenance process will involve several main processes and specific technological dispose located at cubicle rooms in each sub-cell and unit inside Hot Cell Facility.

3.1. The overall of maintenance

In order to study the arrangement of hot cell layout, the design team draw up a preliminary maintenance process. The overall maintenance framework including several sections:

1. Removal and transport: the removal of In-vessel components from the host will be implemented by dedicated RH tools and transshipped by TB (Tokomak Building) cask to docking station after preliminary cleaning, transferred by intermediate cask to the respective maintenance area.
2. Maintenance: after enter the sub maintenance cell or units, the in-vessel components firstly will be placed in buffer storage area or the decay heat removal room, waiting to enter the next disassembly cubicle room, then the dismantling parts will be deep decontaminated and shipped by internal mover to next room, finally repaired and refurbished on the complex maintenance stand to check, inspection, discard and renew some parts of in-vessel components. All the new parts in spares room are standby for supporting maintenance, the failure parts storage area is also reserved in each sub-cell.
3. Post processing: all the activated and discarded parts will be specially disposed before decommissioning such as beryllium separation, tritium removal, and encapsulation for storage shipping and deep burial, these special process are all carried out in the radwaste facility.

Based on the maintenance process, a simplified maintenance workflow has been established shown as Fig. 2.

3.2. Maintenance process in sub-cell

3.2.1. For in-vessel components

After removing out of the vacuum vessel, the in-vessel components (IVC) will be preliminary cleaned in docking station and be packaged and kept in the decay heat removal room using HAVC (Heating, Ventilation Air Condition) to carry out decay heat removal process for a long time, the coolant is gas not water which is the coolant for decay heat in fission, due to the restrictions tritium water [5–7]. After that the transporter will remove it out of the decay heat removal room and deliver IVC into the sub maintenance cell to start maintenance process in sub cell: firstly, removing