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Preliminary environmental radiation considerations for CFETR

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ABSTRACT

Since Chinese fusion engineering test reactor (CFETR) stepped into the engineering design phase, it was significant to discuss the environmental radiation issues considering both Chinese radiation safety regulations and lessons learned from international thermonuclear experimental reactor (ITER) being constructed in France. In this study, firstly, the legal and regulatory framework of nuclear safety in China and ITER licensing process lessons were reviewed. Secondly, public dose limit was proposed for CFETR. Thirdly, safety limit and radioactive source terms were discussed and proposed for CFETR. Fourthly, public radiation dose was estimated, tritium emission limit was proposed under normal operation from the perspectives of tritium emission limit for nuclear power plants (NPPs) in China and reverse value based on public dose limit. Finally, potential consequences of environmental radiation were discussed under accidental conditions. Nuclear emergency countermeasures including no evacuation criteria needed or not were proposed. The preliminary environmental radiation considerations were proposed for CFETR: 1) It had better invite the experts from Chinese national nuclear safety administration (NNSA) to participate in the engineering design, which can make the related persons understand the fusion safety characteristics as early as possible, so as to further speed the licensing process; 2) 0.1 mSv/a was proposed as the public dose limit of CFETR under normal operation; 3) The same ITER safety limit was proposed to be set for CFETR from the consideration of both comparable size of vacuum vessel (VV) and hydrogen/dust explosion; 4) A tritium emission limit of 5–33 g/a was proposed for CFETR; 5) The "no off-site emergency response" was suggested as one of the safety goals during the design of CFETR, however, "off-site emergency measures" were still proposed to be deployed during the operation of CFETR. It was expected the environmental radiation considerations could provide a reference to speed the construction of CFETR on the premise of environment friendly and public safety.

1. Introduction

As fusion energy is deemed the promising energy with the advantages of safety, low-carbon and virtually limitless energy, grand projects related with fusion energy have been approved by many national and local governments. An international thermonuclear experimental reactor (ITER) is under construction contributed by international collaboration of seven members after finishing the detailed engineering design [1]. Meanwhile, the concepts of Chinese fusion engineering test reactor (CFETR), the fusion nuclear science facility (FNSF) and fusion demonstration reactors (EU-DEMO, K-DEMO, Japanese DEMO) have been proposed [2–6]. Various degrees of concepts design are being performed. For CFETR, the engineering design phase has begun since 2017 after the concept design phase in 2011–2016 and will be hopefully completed around 2020, then to support the proposal for construction according to the recent roadmap.

Deuterium (D) and tritium (T) is regarded as the fuels for the above fusion reactors because D–T scenario requires the lowest fusion triple product to achieve energy self-sustaining among various fuels scenarios. However, D–T fusion system also brings special radiation issue due to the existence of tritium and neutrons produced by D–T nuclear reaction. For ITER, the maximum tritium inventory on site is 4 kg. In addition to tritium, massive quantity of radioactivity will be produced as a result of neutron activation [7]. The radioactive materials may threaten public safety by normal and accidental release [8,9]. Thus, research and discussion on environmental radiation is a significant topic in getting the license and designing a fusion system. Similar researches have been performed for ITER during the design phase [10–12]. It still need to discuss whether the related lessons of ITER could be applied to CFETR as there are still gaps between ITER and CFETR on the point of national conditions and design targets. For instance, ITER safety design should follow French Acts and regulations,

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while CFETR should follow Chinese laws and regulations. In addition, the specific activity of plasma faced materials (PFM) for CFETR is also different due to a higher neutron loading compared to ITER.

In this study, we attempted to propose environmental radiation considerations for CFETR based on both ITER lessons and Chinese native conditions. Several key points such as possible applicable regulations and standard, licensing process, public dose limit, safety limit, tritium emission limit, radiation dose and consequences were discussed and proposed for CFETR. It was expected to provide a reference to speed the construction of CFETR on the premise of environment friendly and public safety.

2. Nuclear safety law, regulation and standard framework in China

With the rapid development of nuclear energy in China, the nuclear safety legal and regulatory framework was established step by step. On September 1, 2017, the Nuclear Safety Law was approved by Standing Committee of the National People's Congress and issued in the form of the Presidential Order No.73. The Nuclear Safety Law was the top-level law in the field of nuclear safety. The Nuclear Safety Law provided the responsibility between government (supervision) and operator of nuclear installations (full responsibility for nuclear safety). Beyond the nuclear safety law, Law on Prevention and Control of Radioactive Pollution issued in the form of the Presidential Order No.6 became effective on October 1, 2003 [13].

Under the national laws, there were 7 administrative regulations approved by the State Council and issued in the form of the State Council Decree. They were "civil nuclear safety supervision and management regulation in China (issued in 1986)", "nuclear material control regulations of China (issued in 1987)", "nuclear emergency management regulation of nuclear power plants (No. 124 issued in 1993)", "radioisotopes and radiation safety and protection regulation (No. 449 issued in 2005)", "civil nuclear safety equipment supervision and management regulation (No. 500 issued in 2007)", "radioactive materials transportation safety management regulation (No. 562 issued in 2009)" and "radioactive waste safety management regulation (No. 612 issued in 2011)". Both of laws and administrative regulations have universally binding effects.

Under the national laws and administrative regulations, up to hundred department rules (HAF) and guidance documents (HAD) were approved and issued by various ministries. HAF and HAD were only binding on a designated person. Among the HAF and HAD files, HAF00X defined the general regulations. HAF001/01-1993 defined the application and issuance procedure of safety license of nuclear power plants (NPP), HAF001/03-2006 defined the same contents for the research reactors, and HAF002/01-1998 defined the emergency preparedness and response of operating unit of NPP. HAF10X was defined for NPP. HAF101-1991, HAF102-2004 and HAF103-2004 defined site safety, design safety and operational safety regulations of NPP, respectively. HAF20X was defined for research reactor. HAF201-1995 and HAF202-1995 defined the design safety and operational safety regulation of research reactors, respectively. HAF30X˜90X defined other safety regulations including radioactive waste management, radioactive materials control, etc. HAD defined more detailedly and applied the similar numbering rule as HAF.

Beneath the legal and regulatory framework, various national standards (GB) or industry standards (HJ) were also issued. Among the standards, GB18871-2002 (named basic standards for protection against ionizing radiation and for the safety of radiation sources) provided the general principles and values of radiation protection, e.g. dose limit, dose factor, etc. GB6249-2011 (named standards for environmental radiation protection of nuclear power plant) defined the dose limit of various operational states and tritium emission limit for NPP. The legal, regulatory framework and standards related with nuclear safety in China were shown in Fig. 1.

3. ITER licensing process lessons and Chinese condition

Nuclear safety license is that the national regulatory body approves the applicant to perform specific activities related to nuclear safety, e.g. siting, construction, commissioning, operation and decommissioning, etc.

As the first nuclear fusion facility, ITER belonged to basic nuclear installation (INB) was approved by the French nuclear safety authority (ASN) at last in 2012 to start the construction phase. For the application procedure, a first version of the package files including project, environment and preliminary safety report (RPrS) etc. were prepared and submitted to ASN for approval by ITER organization (IO) in January 2008 but refused by ASN in July 2008 because of incompleteness. A new version was sent in March 2010. The ASN started to evaluate the files and feedback to IO with the help of another expert association. In the ITER case, the radiation protection and nuclear safety institute (IRSN) analyzed the ITER files. However, the ASN is the licensing body and could also order a comparative study by another expert association. After discussing and updating again and again, the procedure entered the public debate and enquiry phase. The examination by IRSN lasted until the approval of ASN in June 2012, followed by a creation decree in November 2012. The licensing procedure since the first submitting files to ASN lasted almost 5 years [14].

In China, there are not yet so clear procedures or any experiences special for fusion facility. But for fission NPP, the application procedures have been defined by national nuclear safety administration (NNSA) in HAF001/01-1993. At the siting stage for a NPP, the applicant must submit the site safety analysis report to the NNSA. At the construction stage, the summited files include the NPP construction application, NPP preliminary safety analysis report and other relevant documents. During the application, public debate and enquiry phase is not needed in China. And the evaluations of the submitted files were performed by the experts in NNSA considering the suggestions from local government and relevant departments in the State Council. The construction licensing process of ITER and civil nuclear facility in China were shown in Fig. 2.

From the experiences of fission NPP construction licensing, it seems to need a shorter time (about 1 year or shorter) in China compared with ITER (5 years). However, this is mainly attributed to the fact that many reactors of the same types are approved currently here. However, a new reactor type like CFETR would formulate new challenges, for which a common understanding of both applicant and regulator has to be developed both in verification and validation of the standards. The preliminary licensing considerations have been discussed in the Annual Conference on Integrated Engineering Design of CFETR at Nov. 27-30, 2018. The dominant perception is that licensing of CFETR could not be released like fission NPP or Research Reactor as it may last a long time. A possible and effective approach is to invite the experts from NNSA to participate in the engineering design phase of CFETR and to understand the fusion characteristics, so as to further speed the licensing procedures of CFETR.

4. Public individual dose limit

4.1. Recommendations of ICRP, UNSCEAR and IAEA

Radiation protection researches have been performed for tens of years, and most of the results were summarized in the UNSCEAR and ICRP publications, which are also the original references to set the regulations about personal dose limits [15,16]. IAEA is an international organization proposed by the United Nations and also releases series of reports about public safety of nuclear energy. In the IAEA report, the public individual dose limit follows that of UNSCEAR and ICRP recommendations [17]. In the member state, the limitation is more serious considering a margin for multiple sources in a certain nuclear site and uncertainty. For a nuclear installation, the radioactive emission

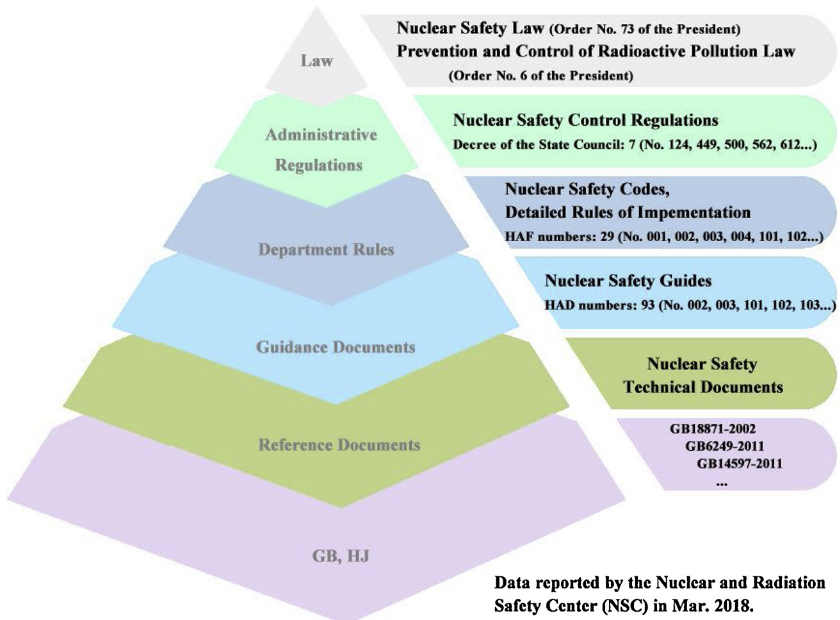

Fig. 1. Legal, regulatory framework and standards related with nuclear safety in China.

must obey the principle that the dose must be below the dose limit in its environment impact assessment (EIA) report for approval. The recommendations and compulsory applications of dose limit were summarized in Fig. 3.

4.2. Dose limit of ITER and China

Under normal operation of ITER, the public dose constraint value is 0.1 mSv/a. The value is the dose constraint that ITER imposed to itself to design its facility, like other operators do also but not systematically with the same value. While, in China, the limit is 0.25 mSv/a for a fission NPP site according to the Chinese standards for environmental radiation protection of NPP (GB 6249-2011).

ITER was managed as an INB like other fission nuclear reactors. Under abnormal condition, three types of events were defined as incident, accident and hypothetical accident. The corresponding public dose limits were defined as 0.1, 10 and 50 mSv/a, respectively [18]. The limits were also defined by ITER for its design (not from the French regulation). For fission NPP in China, the accident conditions were divided into infrequent accidents (frequency: 10^{-4}~10^{-2} per reactor year), limiting accidents (frequency: 10^{-6}~10^{-4} per reactor year) and severe accidents. Besides, postulated siting accident was also defined to determine the boundary of exclusion area and planning restricted area in the stage of site approval. For the dose constraint, the individual effective dose in the boundary of exclusion area within any 2 h or planning restricted area in the whole accident (30 days) must be lower than

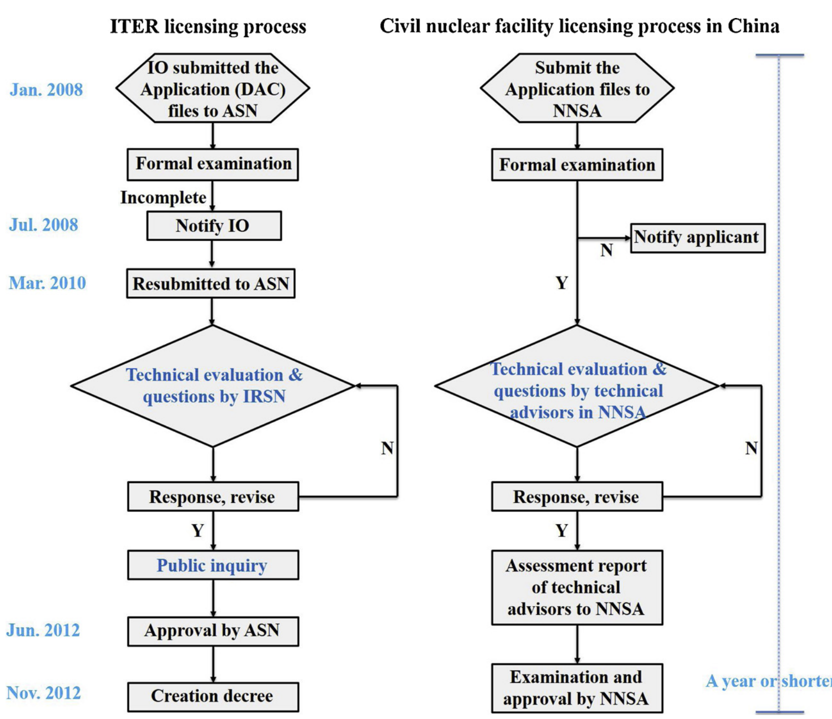

Fig. 2. Construction licensing process of ITER and civil nuclear facility in China.

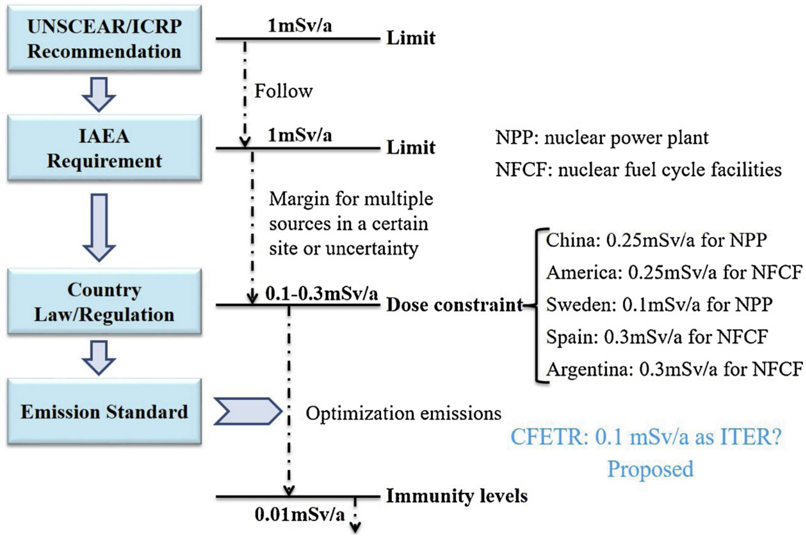

Fig. 3. General origins for radiation protection and normal public individual dose limit.

Table 1
Comparison of public dose constraint for ITER and NPP in China.

Type of plant situation			Public dose constraint	
Frequency	ITER	China (for fission)	ITER	NPP in China
$> 10^{-2}$	Normal	Normal	0.1 mSv/a	0.25 mSv/a
10^{-4}~10^{-2}	Incident	Infrequent accidents	0.1 mSv	5 mSv
10^{-6}~10^{-4}	Accident	Limiting accidents	10 mSv	100 mSv
$< 10^{-6}$	Hypothetical	Postulated siting accident	50 mSv	250 mSv

5 mSv, 100 mSv and 250 mSv for infrequent accidents, limiting accidents and postulated siting accident, respectively. Public dose limits of ITER and China were showed in Table 1, respectively.

From the comparison, it is clear the public dose limit of NPP and NFCF (nuclear fuel cycle facilities) in various countries lies in 0.1~0.3 mSv/a. The public dose limit of ITER was at a bare minimum. For CFETR in China, the phase I was defined as nuclear installation like ITER, and the phase II was defined as a demonstration reactor. Thus, for CFETR phase I, we proposed the same dose limit (0.1 mSv/a) as ITER. It would be more acceptable as this value is lower than the currently applied value of fission NPP (0.25 mSv/a) in China and also obtained from ITER's practice.

5. Safety limit and source terms

5.1. Safety limit

For a D–T fusion reactor, large amounts of tritium would be retained in the in-vessel materials. And huge amounts of dust could be produced as a result of the plasma-wall interactions [19]. In case of a postulated accident involving ingress of steam into the vacuum vessel (VV), hydrogen would be produced through chemical reaction with hot metal and dust. Under this condition, if the ingress of air into the VV also happen, reaction of air with hydrogen or dust might result in an explosion destroying the VV tightness. In light of the abovementioned issues, a safety limit of 1 kg tritium and 1000 kg dust was set as the maximum mobile inventory in the VV for ITER [20–22]. When the safety limit is approached, measures such as baking should be taken to allow the tritium to outgas from the materials and then pumped out of the VV. And at each in-VV maintenance the dust will be removed from the VV as much as possible and recovered in the hot cell facility for conditioning and storage. For ITER, the safety limit could be regarded as the total source terms of the reactor. When making safety analysis under accidental conditions, it is always assumed conservatively all of the tritium and dust could be mobilized. In addition, the same safety limit was also proposed for the EU-DEMO [23].

For CFETR, the safety limit has not been proposed clearly till now. Considering the comparable size to ITER and EU-DEMO, we proposed to set the same safety limit for CFETR to prevent the severe accident and ensure public safety. Beyond that, to control tritium inventory in VV was also benefit to the achievableness of tritium self-sufficiency.

5.2. Tritium

For ITER, beryllium will be used as the first wall and tungsten as the divertor during the D–T burning phase. The 1 kg limit of tritium could be reached in few thousand pulses and the retained tritium will be found in beryllium, tungsten materials and the cryopumps [24]. During accidents, the total mobilized tritium inventory inside the VV is 1 kg, and all of the tritium is assumed to be entirely oxidized to tritiated water (HTO). Some of the released tritium into the second confinement could be released into the environment with a certain release fraction.

For CFETR, all tungsten PFMs have been proposed. The 1 kg limit of tritium could be reached during the steady state operation scenario according to the research on the assumed all tungsten scenarios for ITER (few tens of thousands of pulses) [24]. Then, tritium removal would be performed using the cleaning techniques. The dynamic tritium amount in VV of CFETR was shown in Fig. 4.

Another significant tritium source term is tritium flow in tritium plant of CFETR. Tritium cycle amount in tritium plant is greatly depending on tritium processing time and tritium burn-up fraction. Early tritium cycle studies had assumed 24 h for fusion system referred to TSTA results at LANL in 1986 [25]. In recent studies, an ambitious goal for tritium recycle has been set as 1 h for ITER tritium plant design [26,27]. Due to the comparable but different tritium fuel cycle of CFETR, the state-of-the-art prediction for CFETR was 2–6 h [28].

$$\text{T Inventory} \propto \frac{1}{\textit{Cyclling Time} \times \textit{Burnup Fraction}}$$

Tritium burn-up fraction is the ratio of tritium burning rate to tritium fueling rate. According to design experiences of ITER, the tritium fueling rate can be affected by many factors to maintain the operation of a fusion reactor. A conservative 0.3% of burn-up fraction was regarded to be achievable in ITER under the condition 50:50 mix of DT. To be optimistic, tritium burn-up fraction could reach about 1% if only tritium fueling was used for replenishing the burnt tritium and particle transport loss and deuterium fueling for other fueling requirements, e.g.

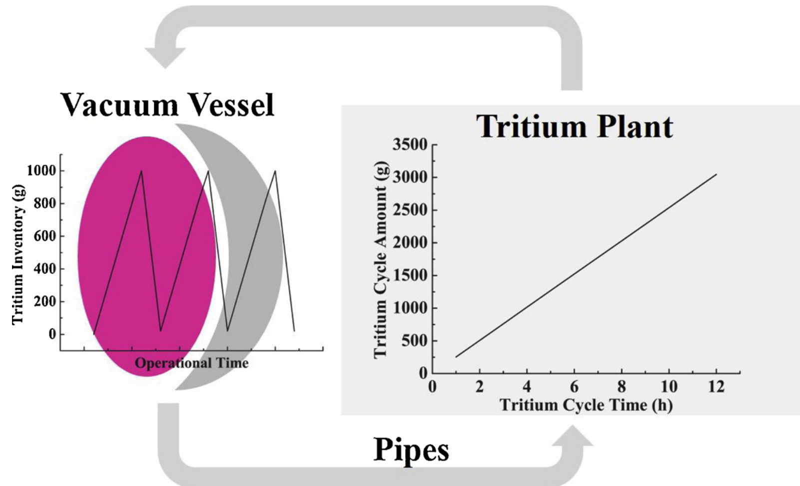

Fig. 4. Dynamic tritium cycle amount in the tritium cycle systems of CFETR.

triggering the edge localized mode (ELM) frequency for reducing the ELM energy loss, controlling the peak power load on the divertor plates [29,30]. Thus, the prediction of tritium burn-up fraction for CFETR was 1%. Steady state tritium cycle amount in tritium plant was estimated and showed in Fig. 4 as variation of tritium cycle time from 1 to 12 h.

5.3. Tungsten dust

For ITER, the activation analysis has been performed to get the source term based on the pulsed scenario (neutron fluence: 0.13 MWa/m^2). The total specific activity of tungsten dust at t = 0 s is 1.59×10^{11} Bq/g, and ^{187}W contributes 65% of the total activity, followed by ^{185}W [7].

For phase I of CFETR, the specific activity of tungsten dust at t = 0 s was 3.40×10^{11} Bq/g, in which ^{187}W contributes about 56% [31]. Thus, the tungsten activity of CFETR was slightly (2.1 times) higher than ITER. To make a further comparison, the activation analysis of fusion power plant such as ARIES-AT was referred to, and its tungsten dust specific activity at t = 0 s was 5.85×10^{11} Bq/g, which was 1.7 times higher than CFETR phase I [32]. As for the phase II of CFETR, the total specific activity of tungsten dust might lie in 3.40~5.85×10^{11} Bq/g.

In addition to tritium and tungsten dust, other types of radioactive materials (ACPs: activated corrosion products, activated gases) could also be possibly produced and enter the environment. For example, in case of an in-vessel loss of coolant accident (LOCA) ACPs as well as tritium poisoned coolant could enter the plasma chamber and provide additional source term inventory potentially being released. For CFETR, the ACPs mainly originates from water cooling loops as water would be used as the main coolant [33]. However, ACPs and activated gases could be considered as negligible comparatively due to its small quantity [34].

6. Normal operation

6.1. Radioactivity emission and public dose of ITER

In France, tritium emission limit has been defined in the regulation of the release of tritium from nuclear facilities. The usual limits of yearly total gaseous discharged activity are 5.0×10^{12} Bq for 2 nuclear reactors and 8.0×10^{12} Bq for 4 nuclear reactors [35]. For ITER, the limit of discharge radioactivity into the environment is about 2.2×10^{14} Bq (0.6 g) of tritium and 2.0×10^{9} Bq of other beta-gamma emitters. Besides, part of the rare gases (^{41}Ar) and ^{14}C (CO_2) will also be released under normal condition. Among all of the emissions, tritium in HTO form contributes about 96% of the total dose, followed by ^{14}C (less than 3%), ^{41}Ar (less than 1%), ^{187}W (less than 0.2%) [7]. Thus, the public dose during normal operation is largely due to emission of tritium under gaseous form.

For ITER, tritium emission is controlled below 2.5 g in years of heavy maintenance (changing the divertor) and 0.6 g for other years. When assuming the wind direction frequency as 1/16, wind speed as 5 m/s, release height as 58 m and atmospheric stability as D, the public individual dose due to 0.6 g/a T (HTO) release was evaluated and showed in Fig. 5. We calculated the maximum individual dose was about 2.93 μSv/a as a baseline (in ITER RPrS, 2.3 μSv/a), which was much lower than the dose limit (0.1 mSv/a) and even below the immunity level.

6.2. Emission limit discussions for CFETR

Tritium emission limit of ITER is 0.6 g/a under normal operation. Thus, many proposed the same level for CFETR in China. Objectively speaking, the emission limit of 0.6 g/a will bring great challenges to both tritium processing technology and safety confinement systems of CFETR due to a larger number of release paths and tritium handling quantity. In this work, we proposed to control tritium emission as 5~33 g/a for CFETR based on the two following perspectives.

Firstly, from the perspective of tritium emission limit of NPP in China, the maximum gaseous tritium emission is 4.5×10^{14} Bq/a for a heavy water reactor and 1.5×10^{13} Bq/a for a light water reactor

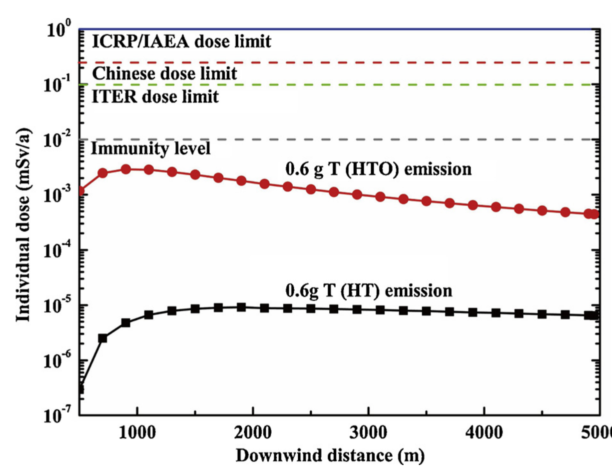

Fig. 5. Public individual dose due to tritium emission from fusion reactor for an operation year.

according to Chinese regulation (GB 6249-2011). For a site with several nuclear power reactors, the total emission amount can be extended to a value four times larger than the above one. That means the tritium emission for a heavy water reactor site is limited to 1.8×10^{15} Bq/a (5 g/a). Furtherly, the individual dose produced by tritium for fission reactor only contributes a minor fraction to the total dose. While the individual dose produced by tritium for fusion reactor contributes most to the total dose (see Sec. 6.1, tritium contributes 96%). Thus, the tritium emission for CFETR can be controlled at least 5 g/a.

Secondly, from the perspective of public dose limit proposed for CFETR (see Sec. 4.2, 0.1 mSv/a), the tritium emission can be reversed as 33 g/a according to the public individual dose results (maximum dose: 2.93 μSv/a) in Fig. 3. Thus, the tritium emission amount must be below this value.

Thus, considering the above reasons, the tritium emission limit was proposed to be in a range of 5˜33 g/a. Meanwhile, the tritium emission should also be minimized to as low as reasonably achievable (ALARA) if possible.

7. Accidental conditions

For the accident conditions, previous works gave systematic identification of accident sequences for the DEMO plant [36]. Series of postulated initiating events (PIEs) were summarized specially for DEMO which added the blankets compared to ITER. For CFETR, similar PIEs should be considered. This part attempted to discuss other perspectives. The first was the special tritium dynamic migration behavior and release discussions (to provide a general reference from dose limit to release limit for different types of accidents). The second was to discuss the hypothetical accidents which were usually regarded as very low probability events and not requested to be paid much attention.

7.1. Public dose and release limit discussions

The public individual early dose depends strongly on the release and environmental modes for the accidental conditions. In our previous study, the conservative condition has been determined as instantaneous release, site boundary, calm wind speed, F atmospheric stability and no rain. Under the conservative condition, the public individual early dose of CFETR phase I is 0.23 mSv, 20 mSv and 0.725 mSv due to 1 g tritium (HT), tritium (HTO) and tungsten dust release, respectively [34]. It is worth noting that tritium environmental migration behavior is complex and unique compared with other radionuclides [37]. For the HTO release, the individual early exposure dose is mainly contributed by the first dispersion in the air, followed by the reemission dispersion (deposited to the soil and then reemitted to the air). For the HT release, the individual early dose is mainly contributed by the reemission dispersion after the oxidation behavior of HT in soil [37–39]. Due to this characteristic, it wouldn't produce severe consequences from the point of early radiation for a HT release accident.

Through the above dose limit in Sec. 4.2 and dose factor (mSv/g), the tritium and dust release amount limit for various kinds of accidents could be determined as $0.23\ M_{T(HT)} + 20\ M_{T(HTO)} + 0.725\ M_{dust} \leq 5$, 100, 250 for infrequent accidents, limiting accidents and postulated siting accident, respectively.

7.2. Hypothetical accident and off-site emergency

In the current nuclear safety philosophy, not all types of nuclear accidents were considered during the design of fission NPP or fusion facilities. Engineered safety feature (ESF) wasn't required to protect the safety function not to be failed when the probability is too low. This is called "probability cut-off". In reality, the low-probability accidents could happen and bring catastrophic consequences, such as the Chernobyl and Fukushima nuclear accidents. As a consequence, 100% of the noble gases, up to ten percent level of the halogens, 4% of the solids in the core inventory of Chernobyl and Fukushima NPPs could be released into atmosphere environment [40–42].

Analogically, for fusion facility, tritium and dust could be released into atmosphere environment with a high fraction if both of confinements failed to work. The most possible release fraction of radioactivity under hypothetical accidents is about 1 kg tritium and 10˜100 kg dust, lessons learnt from the former fission accidents [9,43]. According to the released activity, the hypothetical accidents can be defined as level 6 accidents. The maximum public individual dose would be possible to reach 24˜60 Sv. In addition, it needs at least 34–52 years for local residents to wait for returning to their hometown after the accidents even no ingestion of local polluted food [9]. According to the nuclear emergency countermeasures consideration, evacuation and sheltering should be undertaken if individual dose of 50 mSv/7d and 10 mSv/2d could be averted [44]. Apparently, the nuclear emergency countermeasures still should play a significant role for public safety. Another perspective is that the safety objectives should be considered to eliminate the need for off-site emergency response including evacuation of the public for future Gen-IV reactor design [45]. For EU-DEMO, one of the safety objectives is to apply a safety approach that limits the hazards from accidents such that in any event there is no need for public evacuation on technical grounds which corresponds to the "no-evacuation criterion" commonly applied to fusion facilities [46].

For CFETR, we proposed to set "no off-site emergency response (including no-evacuation criterion)" as one of the safety objectives during the designs. However, "off-site emergency measures" should also be deployed during the operations unless the total source terms were controlled as low as the emergency risk could be eliminated essentially. Both were to ensure the public safety. In addition, to alleviate the radioactive consequences, we proposed to add an artificial rainfall system around the fusion site as one of nuclear emergency measures. Because of the high wet deposition behavior of tritium (HTO), the rain could wash most of the tritium from air into the soil once the hypothetical accident happens. At last, most of the early public dose can be averted.

8. Conclusions

Research and discussion on environmental radiation is a significant topic in designing a fusion system. CFETR is the first fusion device hopefully built in China according to recent roadmap. The radiation safety issues should be discussed before its construction. The present work is to provide environmental radiation considerations based on ITER experiences and Chinese native conditions to provide a guide reference. The main conclusions are drawn as follows.

1)A new reactor type like CFETR would formulate new challenges to get the license compared to the current NPP in China, and a common understanding of both applicant and regulator has to be developed both in verification and validation of the standards. A possible approach is to invite the experts from NNSA to participate in the engineering design phase of CFETR earlier and to make them understand the fusion characteristics, further to speed the licensing procedures of CFETR.

2)The public dose limit of NPP, INB, NFCF in various countries lies 0.1˜0.3 mSv/a. The public dose limit of ITER was at a bare minimum. For CFETR in China, the same dose limit was proposed as ITER (0.1 mSv/a).

3)Considering the comparable size with ITER and EU-DEMO, the same safety limit for CFETR was proposed to set and prevent the severe accident and ensure public safety. Under this condition, the practical radioactivity source terms and potential released radioactivity of CFETR is just several times higher than ITER although operating a higher dpa of PFM.

4) A tritium emission limit of 5˜33 g/a was proposed for CFETR in China from the perspectives of tritium emission limit for NPP in China and reverse value based on public dose limit. Definitely, the tritium emission should also be minimized to ALARA criterion if possible.

5) "No off-site emergency response" was proposed as one of the safety goals during the design of CFETR, however, "off-site emergency measures" were still proposed to be deployed during the operations unless the total source terms were controlled as low as the emergency risk could be eliminated essentially.

With the preliminary considerations, it was attempted to propose some environmental safety concerns and possible boundary/limit for CFETR to ensure safety in the early stage. Lots of work was still needed to validate its appropriateness in future.

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