Technical Specification for Radiation Maps
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Abstract

The scope, the input assumptions and the required output from a task to produce radiation maps are defined.

1 Background and Objectives

The radiation maps application allows users to view radiation maps throughout the tokamak complex. This will permit designers, safety engineers and non-nuclear specialists to quickly access vital information in a user friendly manner.

The scope of this contract is to conduct a series of radiation transport calculation to provide the data to be included in the Radiation Maps Application database and to take the set towards completion. A number of radiation transport calculations had been undertaken prior to this contract for different regimes of tokamak operation. A review of this data indicated that the data is incomplete or obsolete.

The aims of the work described in this contract are to replace or obtain the data which is not already covered. Any new data generated needs to fit within the radiation maps framework so that it is compatible with the existing radiation maps application. [1]

Radiation maps are required for biological dose rates, neutron and $\gamma$-ray fluxes during operations, shut down and cask transfer.

The proposed cut-offs for dose rate, gamma flux and neutron flux data are:

- Dose rate cut-off: 0.1 $\mu$Sv/hr
- Neutron flux (at any energy bin) cut-off: 0.05 n/cm$^2$/s
- $\gamma$-ray flux above 1 MeV cut-off: 2 $\gamma$/cm$^2$/s

The dose rate of 0.1 $\mu$Sv/hr has been chosen as below this level there is very little issue with operator dose. The neutron flux cut-off was based on the approximate neutron flux at an energy between 3-14 MeV that would give a dose rate of 0.1 $\mu$Sv/hr [1]. The gamma flux cut-off was based on the approximate gamma flux at an energy of around 4 MeV that would give a dose rate of 0.1 $\mu$Sv/hr [1].

A result which is one order of magnitude less than the cut-off with a statistical uncertainty of less than 10% will be adequate to demonstrate that, for the given area and operational scenario, the results are below the suggested cut-offs.

2 Scope of Work

The contractor will produce radiation maps for the following:

1. During plasma operation in the tokamak complex
2. $10^6$ seconds after plasma operation in the tokamak complex
3. During transfer of the divertor cassette
4. During transfer of blanket module
5. During transfer of upper port diagnostic plug

and
6. Will issue a final report

There will be a possibility to extend the contract to include the provision of radiation maps for the following:

1. For plasma operation inside the bio-shield
2. $10^6$ seconds after plasma operation inside the bio-shield
This will depend on the status of calculations which are expected to be conducted in parallel with this contract. A decision will be made by ITER two months before the expected completion date of this contract based on the status of other analyses.

3 Work Description

3.1 Calculation 1: Plasma operation in the tokamak complex

The tokamak complex during plasma operation is subject to the highest dose rates and gamma fluxes and is the only geographic/operational scenario in which neutron flux is required.

3.1.1 Contractor’s responsibilities

The contractor will provide the results for the radiation fields of interest, everywhere in the tokamak complex, that are above the cut-offs specified in Section 1, to a spatial resolution of 50 cm x 50 cm x 50 cm and with an uncertainty of less than 10%.

Explicitly the fields of interest are:
- Biological effective dose rate from gammas
- Dose rate in silicon from neutrons Gamma flux above 1 MeV
- Neutron flux at the five energy bins plus total neutron flux

3.1.2 Source terms

Gamma sources
The important gamma source locations are predominantly where water, used in the ITER cooling systems, has been activated by the neutron flux it has seen inside the bio-shield and has then been transported outside the bio-shield.

The important locations of the cooling water pipework are
- The lower pipe chase (B2)
- Vertical shaft 17 (running from B1 to L2)
- The upper pipe chase (L3)
- The heat exchangers (L4)

The radioisotope of greatest concern is $^{16}$N which has the following characteristics:

$^{16}$N Half-life 7.13 seconds $\beta^-$ 100% $E_\gamma$ 6.13 MeV (69%), 7.12 MeV (5%)

The $^{16}$N will be decaying as it is transported around the circuit however it is conservative not to take this into account and this approach has been taken in previous work [3]. The concentration of $^{16}$N at the divertor outlet and blanket module outlet has also been calculated previously [4] giving values of 1.25E+10 atoms/cm$^3$ and 8.54E+10 atoms/cm$^3$ respectively. A review of these values is required for the cooling water system design as specified at the start of the contract. The methodology of defining the source strength will be the same as that followed in [3].

Neutron sources
A neutron source for plasma operation has previously been modelled [5]. The neutron flux and energy spectrum was generated using the 1-D Sn code ANSIN with the nuclear data library.
Fusion217 (175 neutron groups and 42 photon groups) produced from FENDL2 with the TRANSX code. The geometry was based on 1D radial data. The neutron flux and energy spectrum was calculated at several points. In the previous 3D analysis [5] for results outside the bio-shield, the neutron current at the inner surface of the cryostat was used (reproduced in Figure 1).

**Figure 1 – Neutron current on the inner surface of cryostat (reproduced from [5])**

Because the 1D calculation did not capture streaming the actual neutron current could be significantly higher than that shown in Figure 1. It is required that the methodology described in [5], in which the argument has been made that this current (Alite41base in Figure 1) should be multiplied by 5.87, be used. However, it should be noted that [5] is only in draft format and there is some questions of the pedigree of this value. The contractor will review the neutron source assumptions and determine if they remain an accurate but conservative estimate, then a neutron source of equivalent spectrum and strength as [5] will be used.

Outside the bio-shield the most important locations for the neutron source are in the areas surrounding the bio-shield penetrations in the upper and lower pipe chases. The contractor will determine if it is necessary to add a realistic representation of the cryostat and specify a surface source across the entire inner surface based upon a preliminary assessment of the precision of the calculations.

**3.1.3 Model geometry**
The intention is that a single tokamak complex model will be used for the gamma transportation calculation. However if the radiation transport throughout the tritium and diagnostic buildings is proving difficult then three models may be used as follows:

1. Tokamak building only
2. Half of tokamak building and diagnostic building
3. Half of tokamak building and tritium building

3.2 Calculation 2: $10^6$ seconds after plasma operation in the tokamak complex

$10^6$ seconds after plasma operation there is potential for maintenance activities being carried out and calculation of operational associated worker doses is thus required.

3.2.1 Contractor’s responsibilities

The contractor will provide the results for the radiation fields of interest, everywhere in the tokamak complex, that are above the cut-offs specified in Section 2, to a spatial resolution of 50 cm x 50 cm x 50 cm and with an uncertainty of less than 10%.

Explicitly the fields of interest are:

- Biological effective dose rate from gammas
- Gamma flux above 1 MeV

It is noted that in the tritium and diagnostic buildings it is unlikely that the dose rate and flux will be above the proposed cut-offs. The contractor will determine if this is the case.

3.2.2 Source terms

The important gamma source locations fall into three main categories:

- Pipework which has had activated water running through it, as delayed neutrons from $^{17}$N will have activated the steel.
- The cryostat which has been activated from the neutron flux during plasma operation.
- Activated corrosion products which have settled in specific parts of the cooling system creating local hot spots.

The contractor will determine if it is necessary to construct a model which is able to simulate gamma photons from all sources simultaneously, as it is still unknown at this stage if one is dominant and in any case there is significant merit in having the whole picture for the buildings in one calculation or if separate calculations can be conducted and the results combined in one set of radiation maps.

For the activated pipework the important locations are:

- The lower pipechase (B2)
- Vertical shaft 17 (running from B1 to L2)
- The upper pipechase (L3)
- The heat exchangers (L4)

The calculation of the strength and spectrum of the gamma rays emanating from the activated pipework was undertaken in [6]. In [7] the spectrum for the lower pipechase was used to
generate 3D maps for the B2 level. The contractor will use the calculations in [6] and methodology in [7] as the basis for the spectrum for all activated pipework.

The previous calculations for the activated cryostat [7] assumed a source spectrum of $^{60}$Co with a source strength corresponding to that which would give a contact dose rate of 100 µSv/hr. The contractor will review this assumption and if necessary neutron activation calculations using FISPACT (or similar, to be accepted by the ITER Organization in advance) should be performed in order to generate a more realistic source term.

The activated corrosion product source term is not currently available. The activated corrosion products could make a significant contribution to the local dose rates. This aspect of the calculation will be put on hold if the necessary input data is not available from ITER within two months of the start of the contract.

### 3.3 Calculation 3: Transfer of the divertor cassette

The transfer of the divertor cassette occurs at the B1 level of the tokamak building. The divertor cassette will have seen a large neutron flux and be activated. From previous analysis [9] this results in local dose rates of the order of 1 Sv/hr. The casks pass close to sensitive electronics and therefore having a good understanding of the 3D radiation distribution is important. Cask transfer on the B1 level also affects the B2 level below and the L1 level above. Cask transfer in the tokamak building also affects the adjacent tritium and diagnostic buildings.

#### 3.3.1 Contractor’s Responsibilities

The contractor will provide the results for the radiation fields of interest, everywhere in the tokamak complex at the B2, B1 and L1 levels, that are above the cut-offs specified in Section 2, to a spatial resolution of 50 cm x 50 cm x 50 cm and with an uncertainty of less than 10%.

Explicitly the fields of interest are:

- Biological effective dose rate from gammas
- Gamma flux above 1 MeV

The contractor will determine if the tritium and diagnostic buildings truncated models may be appropriate as a function of the position of the cask.

#### 3.3.2 Source terms

The source term is the activated divertor cassette. This will be provided by ITER.

The contractor will carry out an investigation into transfer path and dwell time to determine if it may be appropriate to smear the source out over the entire path rather than conducting multiple discrete positions as has previously been implemented. Calculations will be conducted according to the conclusion of this study.

### 3.4 Calculation 4: Transfer of blanket module
The transfer of the blanket module occurs at the L1 level of the tokamak building. The blanket module will have seen a large neutron flux and be highly activated. Previous analysis for the divertor cassette transfer [9] has shown local dose rates of the order of 1 Sv/hr, it is expected the blanket module will have similar dose rates.

The casks containing the blanket modules pass close to sensitive electronics and therefore having a good understanding of the 3D radiation distribution is important. Cask transfer on the L1 level also affects the B1 level below and the L2 level above. Cask transfer in the tokamak building also affects the adjacent tritium and diagnostic buildings.

3.4.1 **Contractor’s responsibilities**

The contractor will provide the results for the radiation fields of interest, everywhere in the tokamak complex at the B1, L1 and L2 levels, that are above the cut-offs specified in Section 2, to a spatial resolution of 50 cm x 50 cm x 50 cm and with an uncertainty of less than 10%.

Explicitly the fields of interest are:
- Biological effective dose rate from gammas
- Gamma flux above 1 MeV

3.4.2 **Source terms**

The source term is the activated blanket module. This will be provided by ITER.

3.5 **Calculation 5: Transfer of upper port diagnostic**

The transfer of the upper port diagnostic (UPD) occurs at the L2 level of the tokamak building. The UPD will have seen a large neutron flux and be highly activated. Previous analysis for the divertor cassette transfer [9] has shown local dose rates of the order of 1 Sv/hr, it is expected the UPD will be approximately of the same order.

3.5.1 **Contractor’s responsibility**

The aim is to provide the results for the radiation fields of interest, everywhere in the tokamak complex at the L1, L2 and L3 levels, that are above the cut-offs specified in Section 2, to a spatial resolution of 50 cm x 50 cm x 50 cm and with an uncertainty of less than 10%.

Explicitly the fields of interest are:
- Biological dose rate from gammas
- Gamma flux above 1 MeV

It is recognised that for the tritium and diagnostic buildings truncated models may be appropriate depending on the position of the cask.
3.5.2 **Source terms**

The source term is the activated UPD. The contractor will determine the activation of the port plug at the end of ITER life-time.

4 **Responsibilities**

**ITER:**

ITER will provide the needed information and access to the adequate ITER files for executing this work when needed.

In particular ITER will make available any technical information, for example layout of plant, drawings, references needed for contractor to perform the work.

This will include a detailed CAD model of the cryopump for determination of materials etc. and a light model of the cryo-pump located in a port with housing details and contents of port cell and divertor water cooling pipes.

ITER will supply an up to date model of the tokamak complex (concrete and doors only)

ITER will provide definition of the chemical compositions of all materials.

**Contractor:**

The Contractor appoints a responsible person, the Contractor’s Responsible (C-R), who shall represent the Contractor for all matters related to the implementation of this Contract.

The contractor will provide results according to the scope of the work outlined above and will fulfil the implementation plan and conditions of present contract.

The contractor will appoint a responsible person who is permitted to use codes which are subject to export conditions.

5 **List of deliverables and due dates**

<table>
<thead>
<tr>
<th>Deliverable</th>
<th>Due date from $T_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Radiation Maps in ITER complex during plasma operation</td>
<td>2 month</td>
</tr>
<tr>
<td>2 Radiation Maps in ITER complex 10$^8$ seconds after plasma operation</td>
<td>3 month</td>
</tr>
<tr>
<td>3 Radiation Maps in ITER complex during transfer of the divertor cassette</td>
<td>5 month</td>
</tr>
<tr>
<td>4 Radiation Maps in ITER complex during transfer of blanket module</td>
<td>6 months</td>
</tr>
<tr>
<td>5 Radiation Maps in ITER complex during transfer of the upper port diagnostic plug</td>
<td>9 month</td>
</tr>
<tr>
<td>6 Final report</td>
<td>10 month</td>
</tr>
</tbody>
</table>

*Table 1: Due dates of deliverable after Kick-off meeting $T_0*

For each deliverable the contractor will deposit appropriately formatted data files into the radiation maps database. These files will include both the values of interest and the statistical
errors associated with the data. The contractor will also provide reports detailing the
calculations, the checking of the results and a summary of those results.

6 Acceptance Criteria

All deliverables describing the results of all analyses and incorporating changes to the draft
deliverables as requested by ITER (These changes will not constitute substantive changes
to the scope of this contract.)

7 Work Monitoring / Meeting Schedule

Upon entry into force of the contract and approximately 1 week after start the kick-off
meeting will be held to agree calculation techniques to be used and approximations to be
adopted, define terms of reference, identify any missing input data, and clarify task
specification.

The contractor must submit to ITER written monthly progress reports at monthly
meetings.

<table>
<thead>
<tr>
<th>Scope of meeting</th>
<th>Point of check/Deliverable</th>
<th>Place of meeting</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kick-off meeting</td>
<td>Confirm scope and schedule of the work</td>
<td>ITER site or video</td>
<td>One week after entry into force of the Contract</td>
</tr>
<tr>
<td>Closing contract meeting</td>
<td>Final meeting. Deliverable 6</td>
<td>ITER site or video</td>
<td>10 months after the Kick-off meeting</td>
</tr>
</tbody>
</table>

More meetings will be also organized if required by the Parties and/or considered to be
necessary for successful execution of the contract.

8 Quality Assurance (QA) requirement

The organisation conducting these activities should have an ITER approved QA Program or an ISO 9001
accredited quality system.

The general requirements are detailed in ITER document ITER Procurement Quality Requirements (22MFG4)

Neutronic analyses have to be performed following to the ITER QA requirements for analyses
and calculations: ITER_D_22MAL7 - Analyses and Calculations.

Prior to commencement of the task, a Quality Plan Quality Plan (22FMFW) must be submitted for IO
approval giving evidence of the above and describing the organisation for this task; the skill of workers
involved in the study; any anticipated sub-contractors; and giving details of who will be the independent
checker of the activities.

Deviations and Non-conformities will follow the procedure detailed in IO document MQP Deviations and
Non Conformities (22F53X).

Documentation developed as the result of this task shall be retained by the performer of the task or the DA
organization for a minimum of 5 years and then may be discarded at the direction of the IO. The use of
computer software to perform a safety basis task activity such as analysis and/or modelling, etc shall be
reviewed and approved by the IO prior to its use, it should fulfil IO document on Quality Assurance for
9 References / Terminology and Acronyms

MCNP - Monte-Carlo N-Particle transport Code
MCAM – CAD to MCNP translation tool developed by ASIPP, China

[4] Qi Yang, Dongchuan Ying, Yuefeng, Qui, Tongqiang Dang, Qin Zeng, Yican Wu Activation of the ITER cooling water, Ver 1.1, Dec. 10, 2010, ITER IDM 432LTA
[6] Dose rates in the tokamak building due to the $^{16}$N and $^{17}$N isotopes in ITER PHTS cooling water, G. Cambi and D. G. Cepraga, June 2011 DRAFT
[7] Radiation Maps Calculation for the Activated Pipework during Mode 1, C Holland, October 2011, 17206-TR-0004/ITER_D_654ARM v1.0
[8] Radiation Maps Calculation for the Activated Cryostat during Mode 1, C Holland, October 2011, 17206-TR-0005/ITER_D_675663 v1.0