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Key Laboratory of Neutronics and Radiation Safety, CAS

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Tritium Environmental Assessment for Fusion Reactor Using TAS3.0

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2. Application to CFETR
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4. Summary
Tritium environmental migration behavior

Diagram showing the migration of tritium (HT/HTO) from a fusion reactor through various environmental processes:

- **Wind direction/velocity**
- **Mixing layer**
- **Rain/snow/fog**
- **Wet deposition (HTO)**
- **Atmospheric dispersion**
- **Inhalation and skin absorption, ingestion, drinking water**
- **HTO absorption in air by plant leaf**
- **HTO conversion to OBT in plant leaf**
- **HTO/OBT transfer to other organs**
- **HTO uptake by plant roots**
- **HTO transport into deeper soil**
- **Dry deposition (HT/HTO)**
- **HTO reemission**
- **Fusion reactor**
- **Stack**

The diagram illustrates the complex pathways through which tritium can migrate in the environment, including atmospheric dispersion, deposition, and uptake by various organisms.
Tritium environmental migration model

1. HT/HTO release
   - ADM
   - HT in air
   - HTO in air
   - HT in soil
   - Oxi.
   - HTO in soil
   - Inf.

2. HT in air
   - HTO in air
   - Plant HTO
     - Leafy veg.
     - Fruit veg.
     - Root crops
     - Grain
     - Pasture

3. Plant OBT-2
   - Animals HTO
     - Milk cow
     - Beef cow
     - Pigs
     - Chicken
     - Laying hen

4. Animals OBT
   - Milk cow
   - Beef cow
   - Pigs
   - Chicken
   - Laying hen

5. Metabolism
   - Human
     - Dose
     - Ing.
     - Inh.
   - Milk
   - Beef
   - Pork
   - Chi.
   - Eggs

ADM correction

HT/HTO release
Tritium atmospheric dispersion modeling

- **Routine release**
  - Gaussian plume model
  - Gaussian average sector plume model

- **Accidental release**
  - Gaussian puff model

### Gaussian Dispersion Model Used

- **Release source**
  - Building wake effects
  - Mixed source
  - Effective release height
  - Molar percentage of HT and HTO source term

- **Diffusion parameters**
  - Diffusion parameters select from regulations in China (HJ/T2.2—93)
  - Diffusion parameters of downwind is equal to crosswind for gaussian puff model
  - The modified Pasquill stability classification method (GB/T13201-91)

- **Source deposition**
  - Dry deposition
  - Wet deposition

- **Wind velocity**
  - Wind velocity in any height
  - Calm wind
  - Mixed layer
Tritium in soil

- **HTO source**
  - HTO in air
    - Deposition & absorption
  - HTO deposition
    - Dry deposition: under surface
    - Wet deposition: rain, snow, fog
  - HTO in soil
    - Infiltration, re-emission, absorption

- **HT source**
  - HT dry deposition
    - Deposition velocity under surface (soil, plants, snow)
  - HT loss from surface soil layer
    - Re-emission, Infiltration, oxidation
  - HTO re-emission & absorption
    - HTO amounts in soil, area source (virtual point source), re-emission rate
    - Plants absorption HTO from soil and air

Diagram:
- HTO in air
  - Surface layer (0-5cm)
  - Second layer (5-10cm)
  - Bottom layer (10-15cm)
  - Infiltration

- HTO in soil
  - Surface layer (0-5cm)
  - Second layer (5-10cm)
  - Bottom layer (10-15cm)
  - Infiltration

- Microorganisms in soil
Tritium in biology

**Plants**
- Plant species
- HTO dynamic absorption
- OBT formation, transfer, accumulation
- Results: HTO & OBT concentration in plants

**Animals**
- Animal species
- Inhalation & skin-absorption (HT/HTO)
- Ingestion (pasture, grain)
- Results: HTO & OBT concentration in animals and products (dynamic)

**Human**
- Different groups: adult, child and infant
- Complex recipes
- Inhalation & skin-absorption & Ingestion
- Results: HTO & OBT concentration in humans and dose assessment (dynamic)
TAS: Tritium Analysis Program for Fusion System
(Current Version is TAS3.0)

- **Main Functions**
  - Tritium self-sufficiency analysis
    - TBR, Min T supply, consumption & breeding
  - Tritium distribution and release
    - Retention & release amounts
  - Tritium safety analysis
    - Public dose & health effects

- **Testing & Applications**
  - **Testing**: TriMo, IAEA-EMRAS benchmark, . . .
  - **Applications**: FDS-II, FDS-III, DFLL-TBM, CFETR, Fusion reactor
Basic functions of TAS3.0 environmental module

- Calculating HT/HTO/OBT steady state/dynamic concentration in air/soil/plant/animal/human.
- Assessing the dose to workers/public and tritium metabolism in body.

(Plotting two-dimensional contour map, three-dimensional concentration map.)
Verification with ACUTRI based on Canadian HT release experiment on CRNL

Dose through inhalation and skin absorption with reemission

**Tips:** D. Galeriu, P. Davis, W. Raskob, et al. given that order of magnitude differences remained in dispersion modeling about air concentration. Moreover, the different models predicted very different contributions of the various food items to the total dose.

Verification with UFOTRI based on ITER benchmark

A series of tests have proved the TAS environmental migration module to be a good tool to evaluate tritium environment impact.

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# Source terms and main input parameters

<table>
<thead>
<tr>
<th>Source Terms</th>
<th>Types</th>
<th>T amounts</th>
</tr>
</thead>
</table>
| Plant States | Normal | 0.6g (HT)/a  
0.06g (HTO)/a |
|              | Infrequent Accident | 50g (HT)  
5g (HTO) |
|              | Limiting Accident | 1000g (HT)  
100g (HTO) |
|              | Postulated siting accident | 2433g (HTO) |

<table>
<thead>
<tr>
<th>Main Input parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack release height</td>
<td>58m</td>
</tr>
<tr>
<td><strong>Wind speed (h=58m)</strong></td>
<td>5m/s</td>
</tr>
<tr>
<td>Stability class</td>
<td>D(neutral)</td>
</tr>
<tr>
<td><strong>HT deposition velocity</strong></td>
<td>0.0005m/s</td>
</tr>
<tr>
<td><strong>HTO deposition velocity</strong></td>
<td>0.018m/s</td>
</tr>
<tr>
<td>Reemission ratio</td>
<td>0.6</td>
</tr>
<tr>
<td>Oxidation rate in air</td>
<td>0.5%/d</td>
</tr>
<tr>
<td>Oxidation rate in soil</td>
<td>5.8%/min</td>
</tr>
<tr>
<td><strong>Exclusion area limit</strong></td>
<td>500m</td>
</tr>
<tr>
<td>Evaluation height</td>
<td>1.5m</td>
</tr>
<tr>
<td>Terrain</td>
<td>0.3</td>
</tr>
<tr>
<td>Age</td>
<td>Adult of China</td>
</tr>
</tbody>
</table>
Sensitivity analysis of key input parameters

- **Wind speed/atmospheric stability**
  Different wind speeds in each atmospheric stability

<table>
<thead>
<tr>
<th>Atmospheric stability</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed(m/s)</td>
<td>0~3</td>
<td>0~5</td>
<td>≥2</td>
<td>≥3</td>
<td>0~5</td>
<td>0~3</td>
</tr>
</tbody>
</table>

The maximum public dose (1g HTO release) vs. wind speed in different atmospheric stability

- **Ages/release height**

The maximum public dose (1g HTO release) vs. release height in different ages

**Results:**
- Extreme parameters should have 
  **ground release, child group,**
  **calms in B atmospheric stability**
  for public dose (>500m)
Evaluation of public dose and tritium release term

The maximum public dose of tritium release under extreme parameters conditions

<table>
<thead>
<tr>
<th>Release height</th>
<th>Dose types</th>
<th>Normal</th>
<th>Infrequent accident</th>
<th>Limiting accident</th>
<th>Postulated siting accident</th>
</tr>
</thead>
<tbody>
<tr>
<td>58m</td>
<td>Max inhalation dose/mSv</td>
<td>0.0128</td>
<td>1.12</td>
<td>22.39</td>
<td>544.75</td>
</tr>
<tr>
<td>10m</td>
<td>Max inhalation dose/mSv</td>
<td>0.0128</td>
<td>1.24</td>
<td>24.73</td>
<td>601.68</td>
</tr>
<tr>
<td>Dose limit/mSv</td>
<td></td>
<td>0.25</td>
<td>5</td>
<td>100</td>
<td>250</td>
</tr>
<tr>
<td>Max. release amount (reevaluate)</td>
<td></td>
<td>0.183g HTO</td>
<td>20.2g HTO</td>
<td>404.4g HTO</td>
<td>1011g HTO</td>
</tr>
</tbody>
</table>

Results

- The maximum public dose is higher than the dose limit for the postulated siting accident, while below the dose limit for other operational events based on extreme parameters.

- Tritium release amount should be below the reevaluated values above mentioned, because dose limit in regulation is defined for all radioactive effluents.
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## Unit gram release source terms

### Tritium (1g)

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Activity (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^3$H (HT, HTO, Tritiated dust)</td>
<td>3.56E+14</td>
</tr>
</tbody>
</table>

### Tungsten Dust (1g)

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Activity (Bq)</th>
<th>Isotope</th>
<th>Activity (Bq)</th>
<th>Isotope</th>
<th>Activity (Bq)</th>
<th>Isotope</th>
<th>Activity (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{187}$W</td>
<td>1.04E+11</td>
<td>$^{188}$Re</td>
<td>1.19E+09</td>
<td>$^{184}$Ta</td>
<td>4.33E+07</td>
<td>$^{58}$Co</td>
<td>1.14E+06</td>
</tr>
<tr>
<td>$^{185}$W</td>
<td>3.72E+10</td>
<td>$^{182}$Ta</td>
<td>1.67E+08</td>
<td>$^{179}$Ta</td>
<td>2.74E+07</td>
<td>$^{60}$Co</td>
<td>1.27E+06</td>
</tr>
<tr>
<td>$^{181}$W</td>
<td>1.43E+10</td>
<td>$^{186}$Ta</td>
<td>6.40E+07</td>
<td>$^{184}$Re</td>
<td>1.99E+07</td>
<td>$^{54}$Mn</td>
<td>2.57E+05</td>
</tr>
<tr>
<td>$^{186}$Re</td>
<td>1.97E+09</td>
<td>$^{183}$Ta</td>
<td>6.40E+07</td>
<td>$^{109m}$Ag</td>
<td>3.72E+05</td>
<td>$^3$H*</td>
<td>1.78E+10</td>
</tr>
</tbody>
</table>

### Activated corrosion products (1g)

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Activity (Bq)</th>
<th>Isotope</th>
<th>Activity (Bq)</th>
<th>Isotope</th>
<th>Activity (Bq)</th>
<th>Isotope</th>
<th>Activity (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{55}$Fe</td>
<td>2.09E+09</td>
<td>$^{60}$Co</td>
<td>1.43E+08</td>
<td>$^{58}$Co</td>
<td>1.09E+08</td>
<td>$^{57}$Co</td>
<td>6.32E+07</td>
</tr>
<tr>
<td>$^{56}$Mn</td>
<td>1.46E+09</td>
<td>$^{51}$Cr</td>
<td>1.14E+08</td>
<td>$^{54}$Mn</td>
<td>1.02E+08</td>
<td>$^{57}$Ni</td>
<td>4.61E+07</td>
</tr>
</tbody>
</table>

### Activated gases (1g)

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Activity (Bq)</th>
<th>Isotope</th>
<th>Activity (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{14}$C (CO$_2$)</td>
<td>2.31E+15</td>
<td>$^{41}$Ar</td>
<td>6.34E+22</td>
</tr>
</tbody>
</table>

*Specific activity of Tritium dust release from fusion reactor ($1.78 \times 10^{10}$ Bq/g, assumed 50g T in 1000kg dust) referred to tungsten dust proposed by C. Grisolia.
Results:

- For 1g T accidental release, the early dose of 1g tritiated dust release is several times larger than that of 1g HTO release, about hundred to thousand times larger than that of 1g HT release.
- For 1g dust (including tritiated dust) release, the dose of $^{187}$W release contributes most to the total dust dose (89%).
Public dose due to various release source types

Results:
- Dose of 1g HTO release is much larger than other types release, about tens times larger than 1g dust release (or 1g HT release), a thousand times larger than 1g ACPs release.
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Summary

- **TAS environmental migration module**
  - The tritium environment assessment module of TAS has been developed to assess the HT/HTO/OBT concentration in air, soil, plants and animals as well as workers and public dose under routine condition and accident events (dynamic).

- **Preliminary analysis of public dose from CFETR tritium release**
  - **CFETR**: The maximum public dose is below the dose limit for the operational events, while larger than the dose limit for postulated siting accident based on extreme parameters.

- **Public dose due to unit fusion radioactivity release**
  - Dose of 1g HTO release is much larger than other types release, About several tens times larger than 1g dust release (or 1g HT release), a thousand times larger than 1g ACPs release.
Thanks for Your Attention!

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