Safety Concept of Nuclear Cogeneration of Hydrogen and Electricity

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Outline

- JAEA concept of commercial nuclear hydrogen production
- Results of study on separation distance between NPP and industrial plant
- Conclusions
Background

- Currently > 95% of $\text{H}_2$ generated is extracted from fossil fuels, also > 95% of the primary energy needed is fossil-based
- Promising option for the future is
  - to generate $\text{H}_2$ by water splitting
  - to use nuclear primary energy for process heat and electricity production
- Several countries have done in the past or are doing comprehensive research on nuclear hydrogen production
Sulfur-iodine thermochemical cycle
GTHTR300C high temperature reactor

- Of 600 MW(th) generated per unit,
  - 168 MW to provide 900°C process heat
  - 432 MW to generate 202 MW(e)
Essential requirements

- Assurance of safety of NPP against postulated events occurring in the H\textsubscript{2} plant
- Construction / operation of H\textsubscript{2} system as conventional (non-nuclear) system
Safety against hydrogen-air gas cloud explosion

- Separation distance calculated with STAR-CD

<table>
<thead>
<tr>
<th>Amount of hydrogen released [kg]</th>
<th>Reference case</th>
</tr>
</thead>
<tbody>
<tr>
<td>~10, 25, 58, 97</td>
<td>97</td>
</tr>
<tr>
<td>Pressure [MPa]</td>
<td>4</td>
</tr>
<tr>
<td>Pipe diameter [mm]</td>
<td>20, 100</td>
</tr>
<tr>
<td>Height of release point [m]</td>
<td>0, 2.5, 5</td>
</tr>
<tr>
<td>Wind speed [m/s]</td>
<td>1 – 15</td>
</tr>
<tr>
<td>Horizontal angle of jet</td>
<td>0° – 90°</td>
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<tr>
<td>Atmospheric stability category</td>
<td>stable</td>
</tr>
</tbody>
</table>

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Safety against hydrogen-air gas cloud explosion

- Hydrogen mass of flammable cloud vs. moving distance

97 kg of $H_2$
5 s release time

More than half of the $H_2$ mass released remains below 4% concentration

Moving distance = projected distance on the ground
Safety against hydrogen-air gas cloud explosion

- Hydrogen concentration in air after 15 s

97 kg of $\text{H}_2$
5 s release time
Safety against hydrogen-air gas cloud explosion

- Variation of hydrogen mass released

![Graph showing variation of hydrogen mass released](image)
Safety against hydrogen-air gas cloud explosion

- Variation of release height

No hydrogen piping on the ground!
Safety against hydrogen-air gas cloud explosion

- Installation of protective wall
  - 2 m higher than release point
  - wall should be explosion-proof,
    e.g. > 12 cm of reinforced concrete acc. to Japan codes
Safety against hydrogen-air gas cloud explosion

- Variation of release angle (0° 22.5°)

Wall effectively reduces moving distance
Safety against toxic gas release

- Control room of GTHTR300C shall be safe against potential release of toxic materials
- If a gas concentration exceeds certain limit, ventilation system is shut down to isolate control room and recirculation air filter system is activated.
- There are various guidelines existing that define upper limits for gas concentrations.
- JAEA safety approach requires upper limits for toxic gases such that a 1h exposure time can be permitted
Safety against toxic gas release

- Assessment of separation distance against release of toxic materials done with heavy gas dispersion model SLAB
- Instantaneous release of total inventory as a gas is assumed
- Control room concentration depends on concentration at intake, exchange rate of ventilation system and leakage rate of CR

<table>
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<tr>
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<tbody>
<tr>
<td>Height of release point [m]</td>
<td>2.3 (for HI, I₂); 3.7 (for H₂SO₄, SO₃, SO₂)</td>
<td></td>
</tr>
<tr>
<td>Release mode</td>
<td>instantaneously as gas @ 0.1 MPa</td>
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<tr>
<td>Wind speed [m/s]</td>
<td>1</td>
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<tr>
<td>Atmospheric stability category</td>
<td>stable</td>
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</tr>
<tr>
<td>Distance to NPP control room [m]</td>
<td>250 (for HI section); 100 (for H₂SO₄ section)</td>
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<tr>
<td>Height of intake of control room ventilation [m]</td>
<td>22.3</td>
<td></td>
</tr>
<tr>
<td>Control room air exchange rate [h⁻¹]</td>
<td>0.06</td>
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<tr>
<td>Time for isolation of control room [s]</td>
<td>10</td>
<td></td>
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</tbody>
</table>
Safety against toxic gas release

- Simultaneous release of all toxics leads to evaluation indicator of 0.81 (value > 1 indicates unallowable exposure)
- Dominant hazardous chemicals are I$_2$ (75%) and SO$_3$ (15%)

Evaluation indicator = sum (over all gases) of ratios of calc. Concentration ovr toxic limit

Graph showing control room concentration over elapsed time [s] with concentrations of SO$_3$, SO$_2$, HI-I$_2$ vapor, and Sato 2014.
Conclusions

- JAEA conducted studies to assess separation distances for a 600 MW(th) HTGR connected to S-I H₂ production process with regard to hydrogen and toxic gas release.
- Computer simulations suggest a separation distance of 100 m be sufficient to pose no risk to the overall safety of NPP.
- Even for a 100 kg H₂ release, less than half of this mass will contribute to the flammable portion of the gas cloud.
- Despite moving distances > 100 m for H₂ releases larger than 25 kg, a protective barrier with 2 m above H₂ lines will reduce moving distance even of a 100 kg release to below 100 m.
Thank you for your kind attention

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