The Particular Safety Aspects of the Combined HTTR/Steam Reforming Complex for Nuclear Hydrogen Production

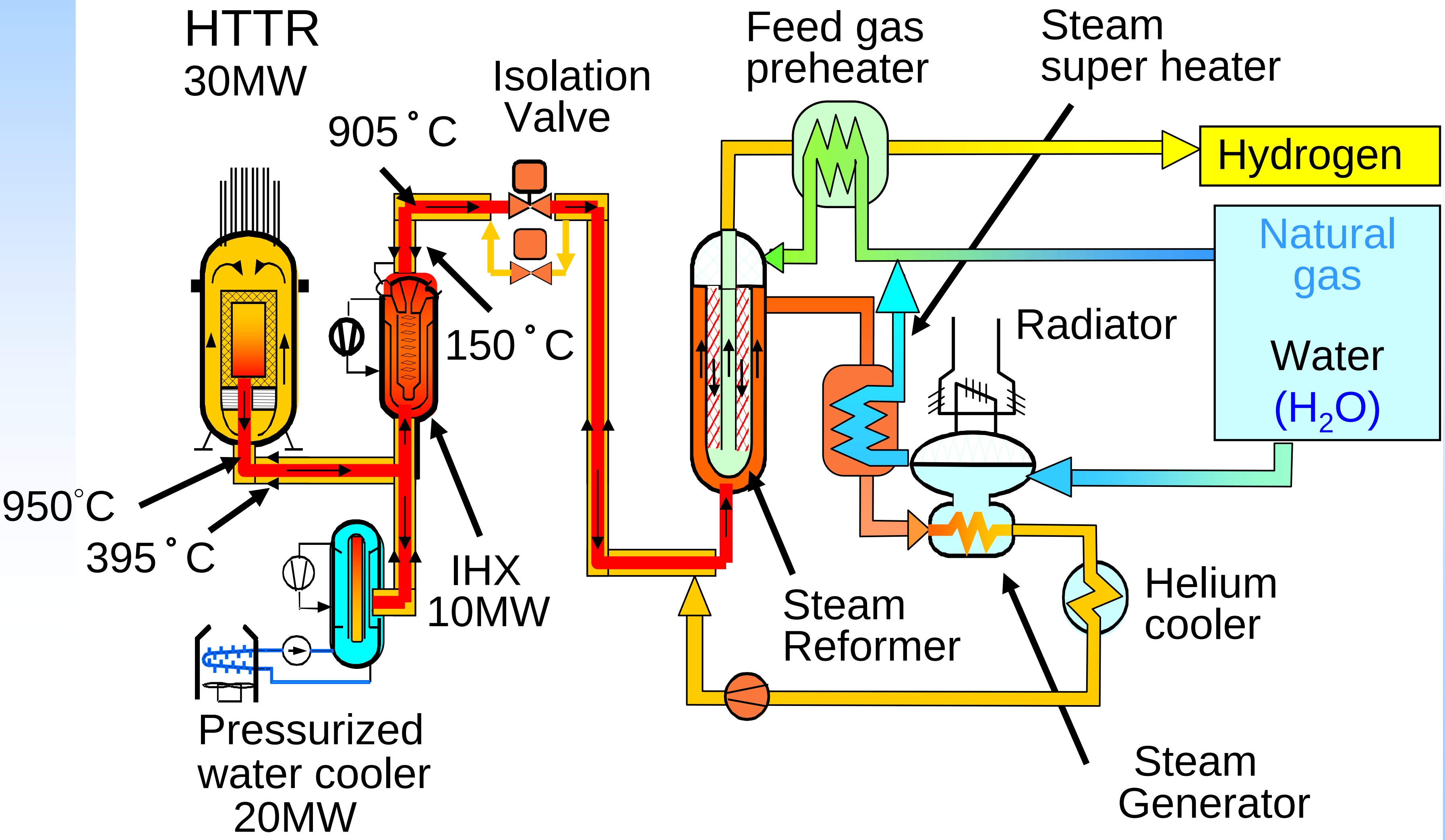
by

Karl VERFONDERN [1)] and Tetsuo NISHIHARA [2)]

[1)] Research Center Juelich, Germany

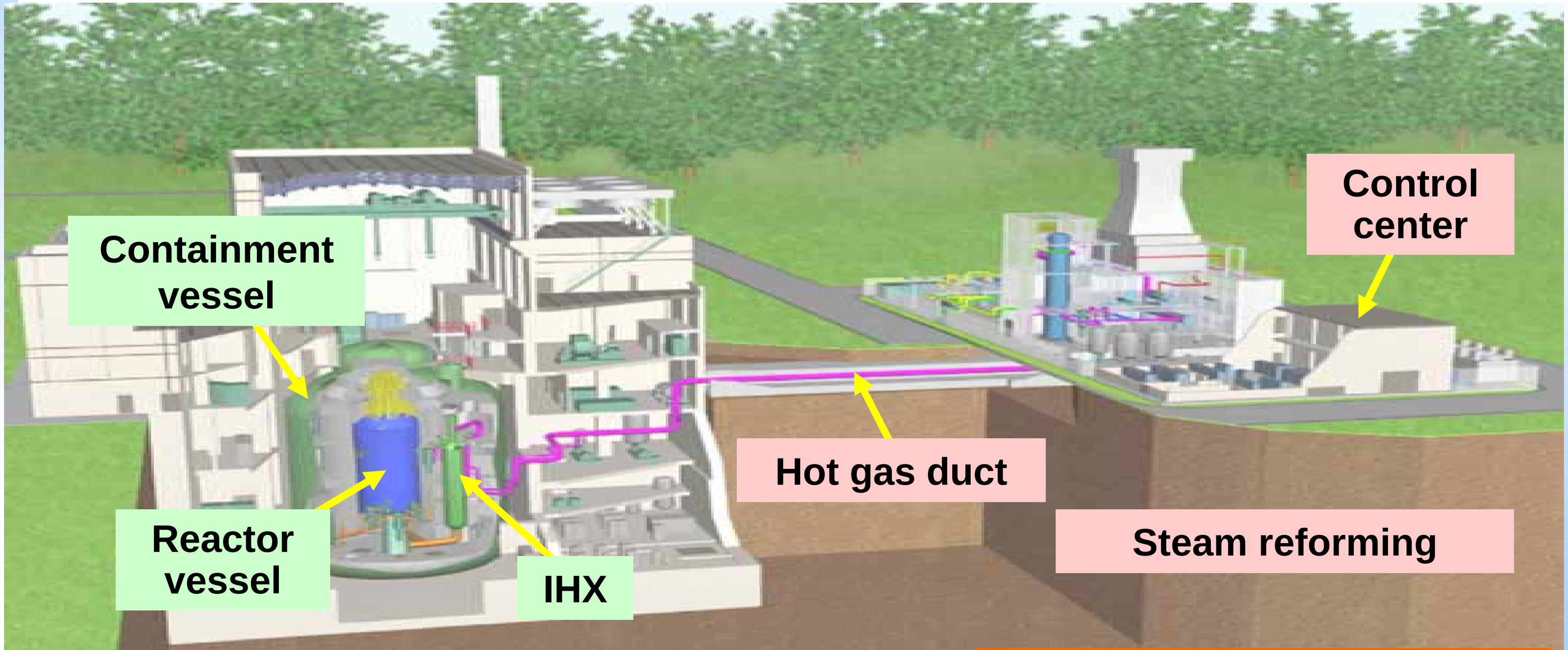
[2)] Japan Atomic Energy Research Institute, Oarai, Japan

Combined HTTR/Steam Reforming System



Combined HTTR/SR Complex

Reactor System | **Hydrogen Production system**

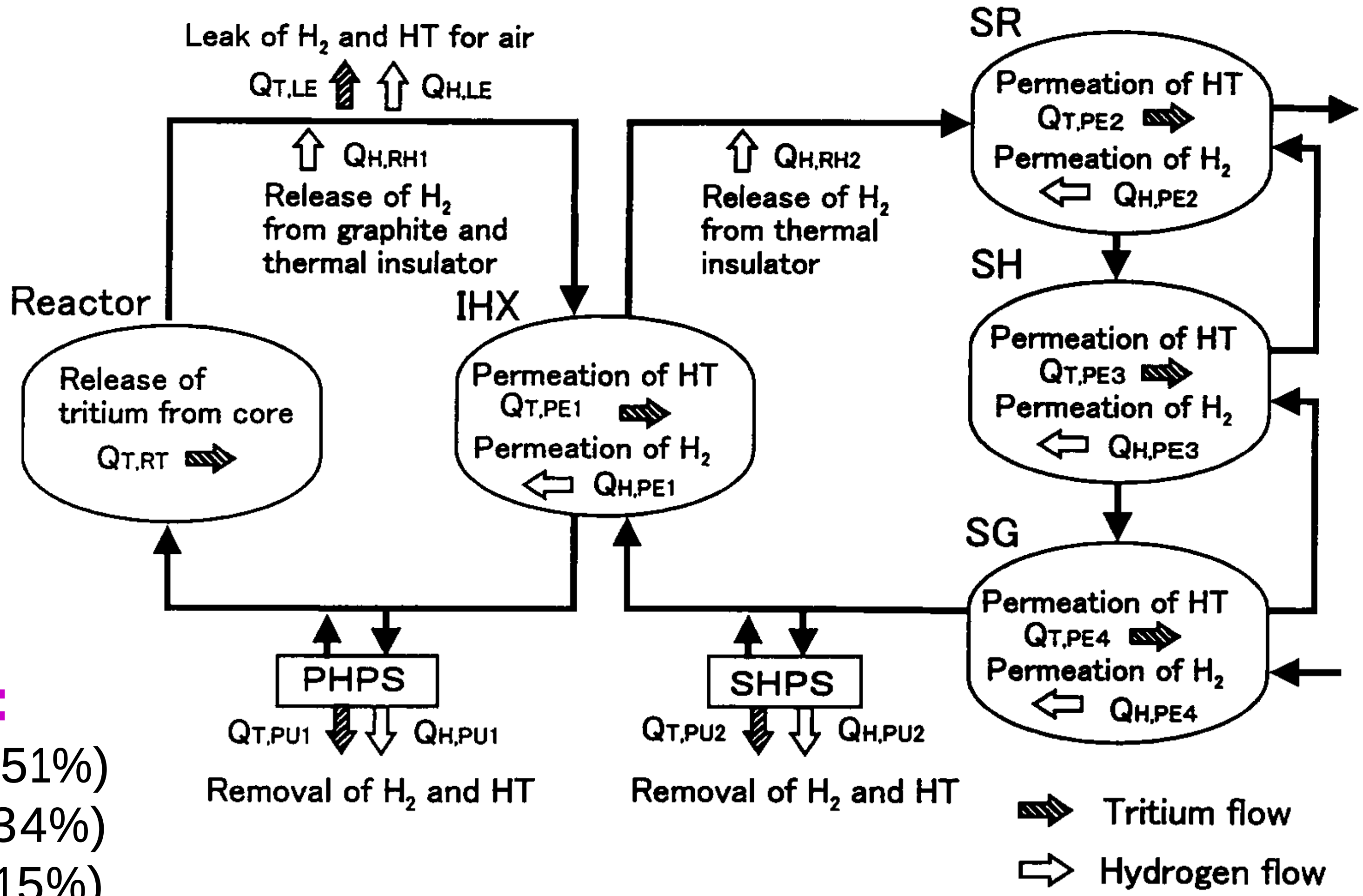


$$CH_4 + H_2O \rightarrow 3H_2 + CO$$

Potential Hazards in HTTR/SR Complex

- Tritium transportation from core to product gases;
- Thermal turbulences induced by problems in steam reforming system;
- Fire and explosion of flammable mixtures with process gases.

Tritium and Hydrogen Flow Paths

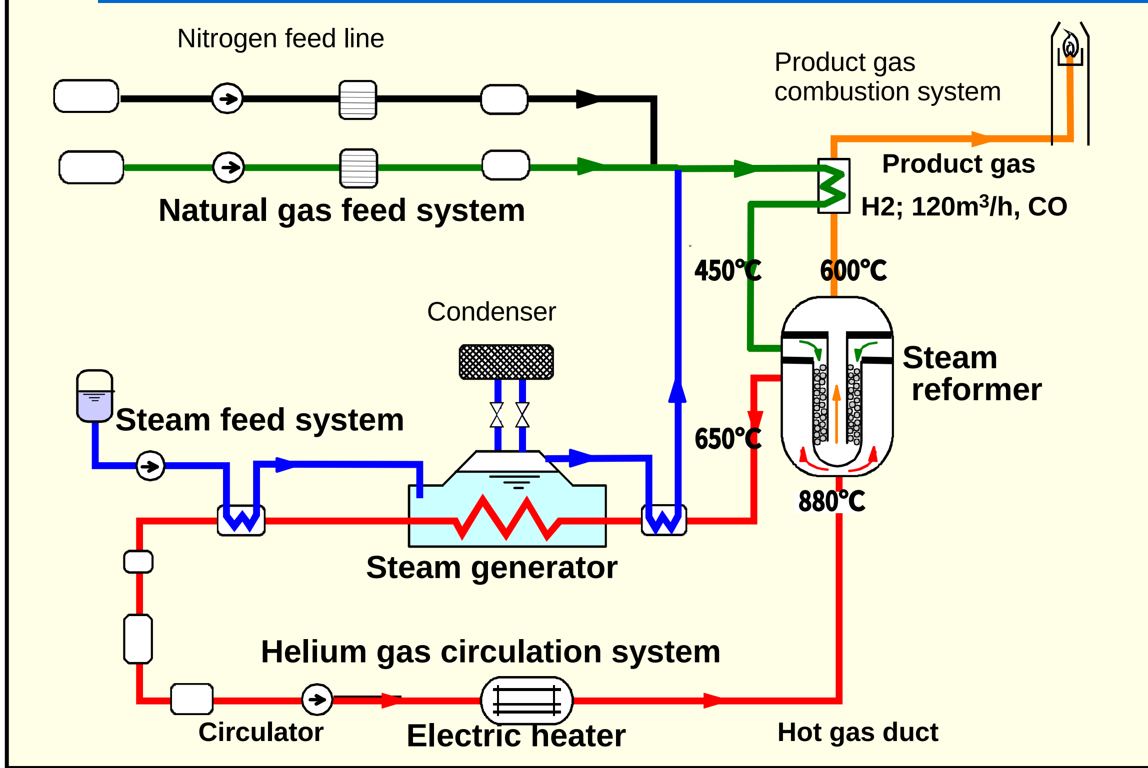


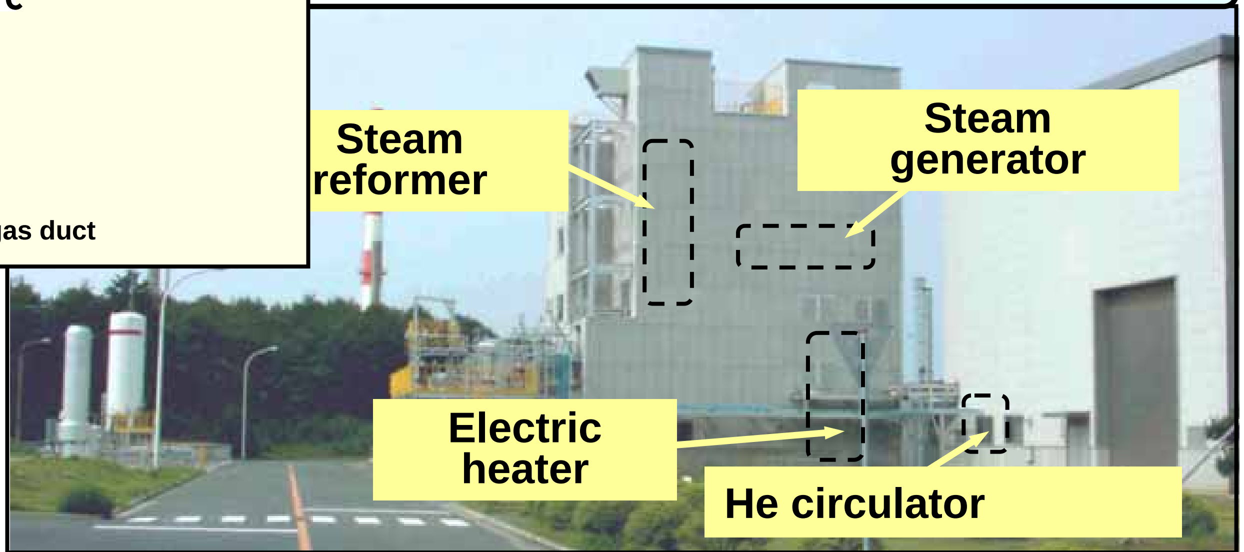
Sources:
- fission (51%)
- lithium (34%)
- helium (15%)

Problem Tritium

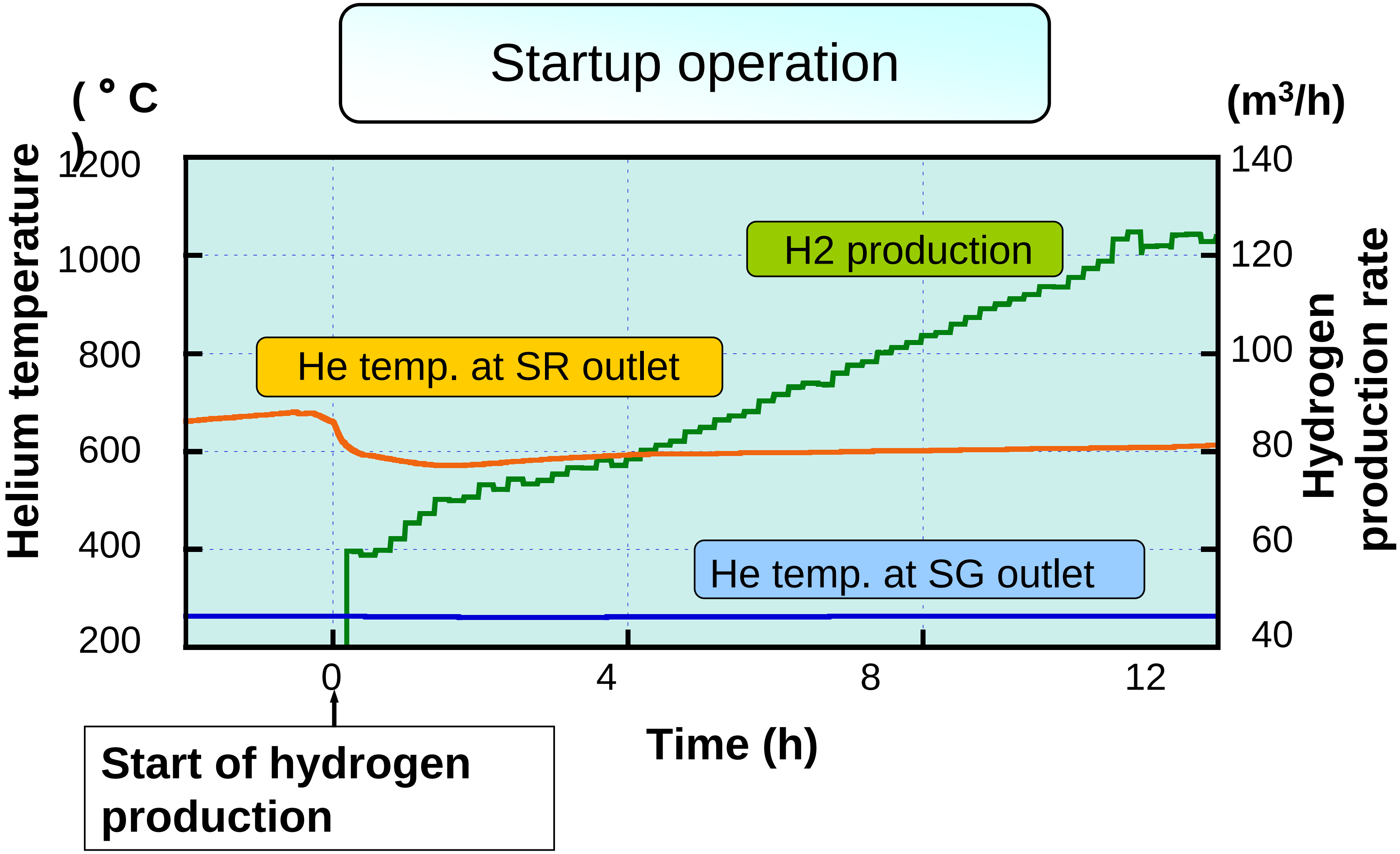
- **High mobility of both HT and H_2 at high temperatures**
  - radiation problem to consumer
  - corrosion problem in graphitic core structures
- **Measures of reducing HT and H_2 transport**
  - oxide layers (doping with O_2)
  - gas purification system
  - intermediate circuit (doping with H_2O)
- **Results from JAERI calculations and tests**
  - HT level in product gas deemed sufficiently low
  - permeability of oxide layer reduced by factor 100-1000
- **Limit as defined in German legislation**
  - 0.5 Bq/g (applies to any fabricated product)

Steam Reforming Out-of-Pile Pilot Plant



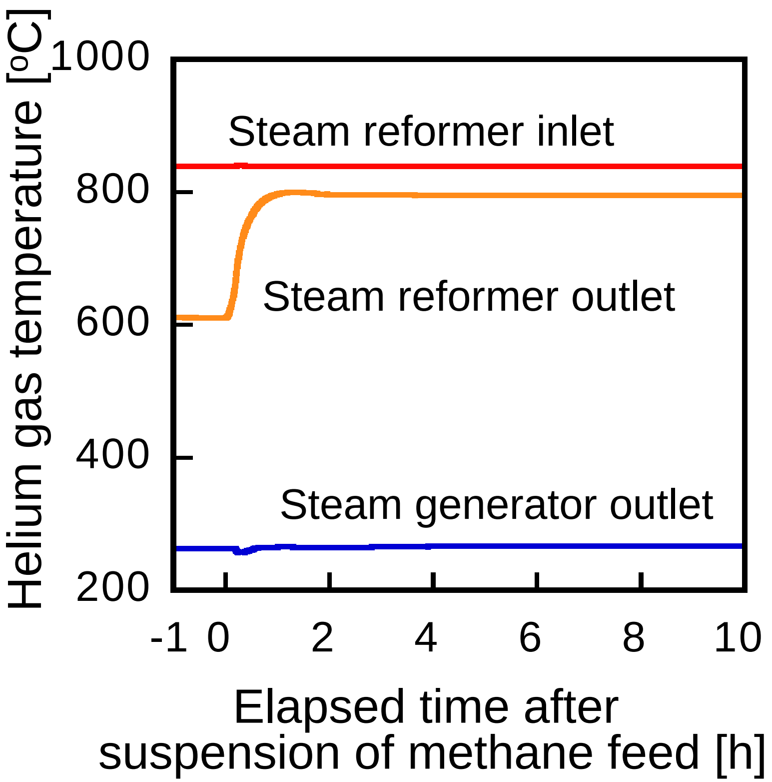


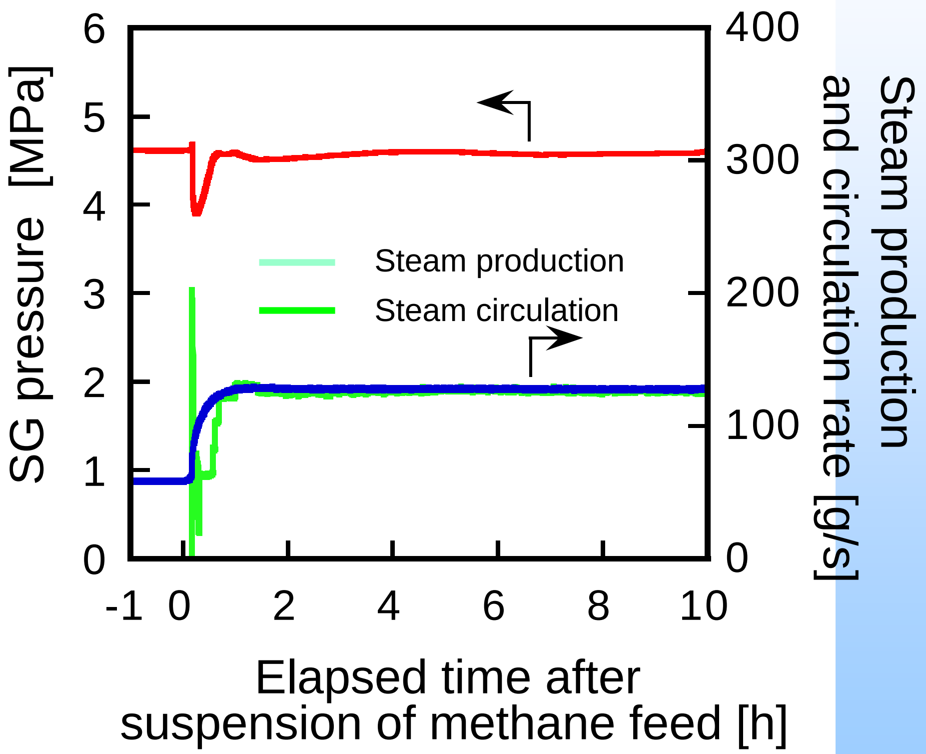
HTTR/SR System Controllability Test



HTTR/SR System Controllability Test

Loss of feed gas (chemical reaction)

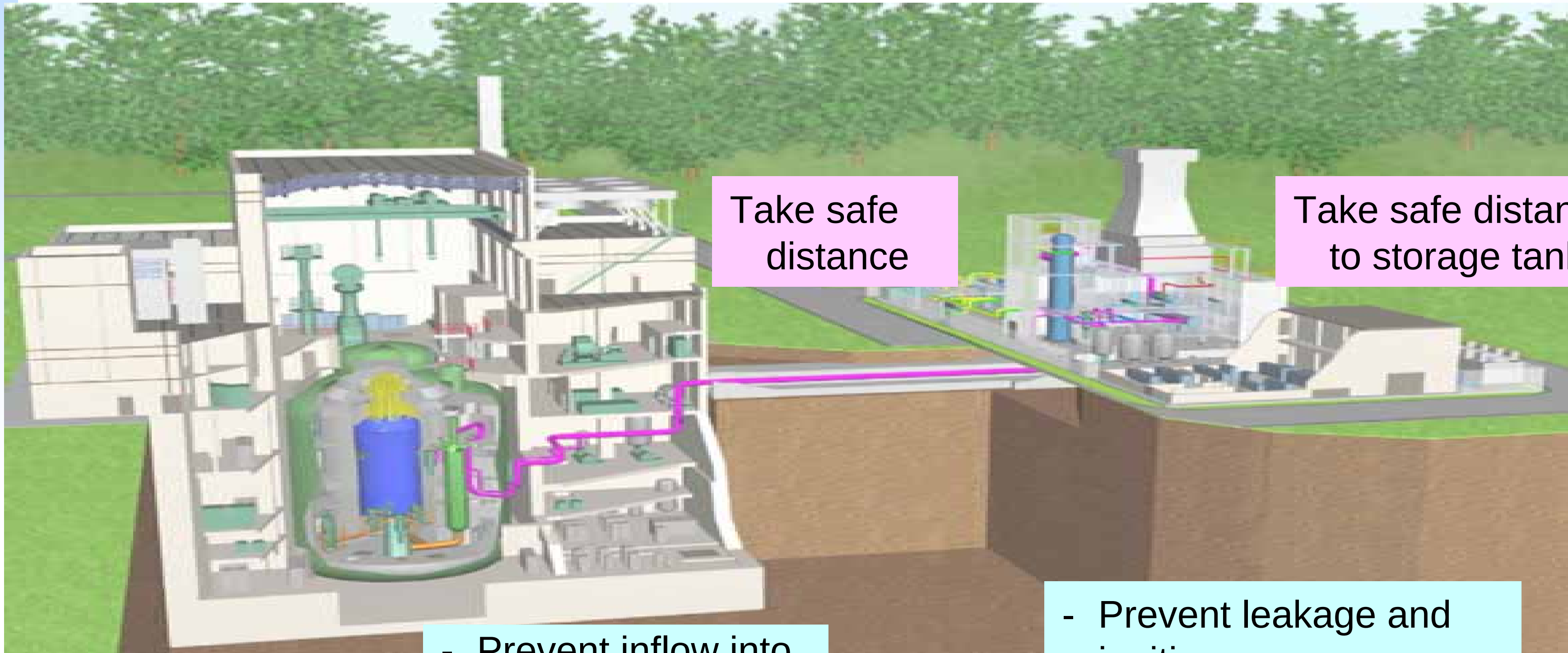




Safety Design against Fire and Explosion

Reactor System

Hydrogen Production system



Take safe distance

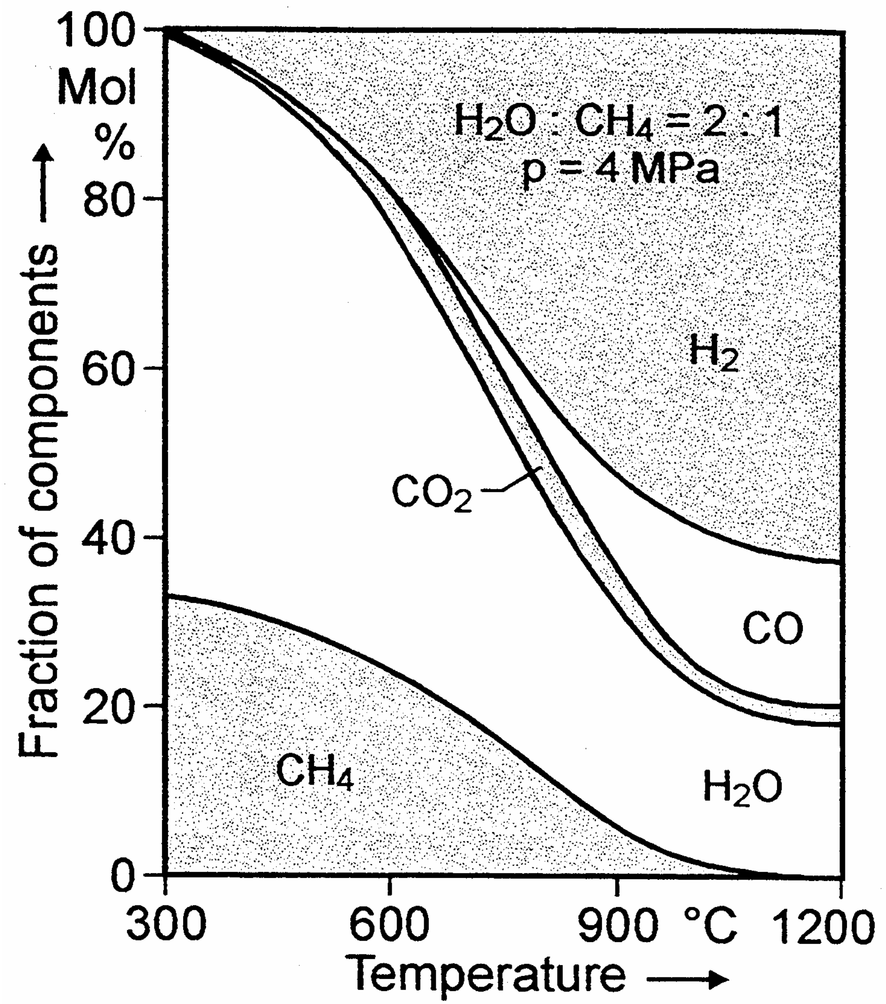
Take safe distance to storage tank

- Prevent inflow into nuclear building

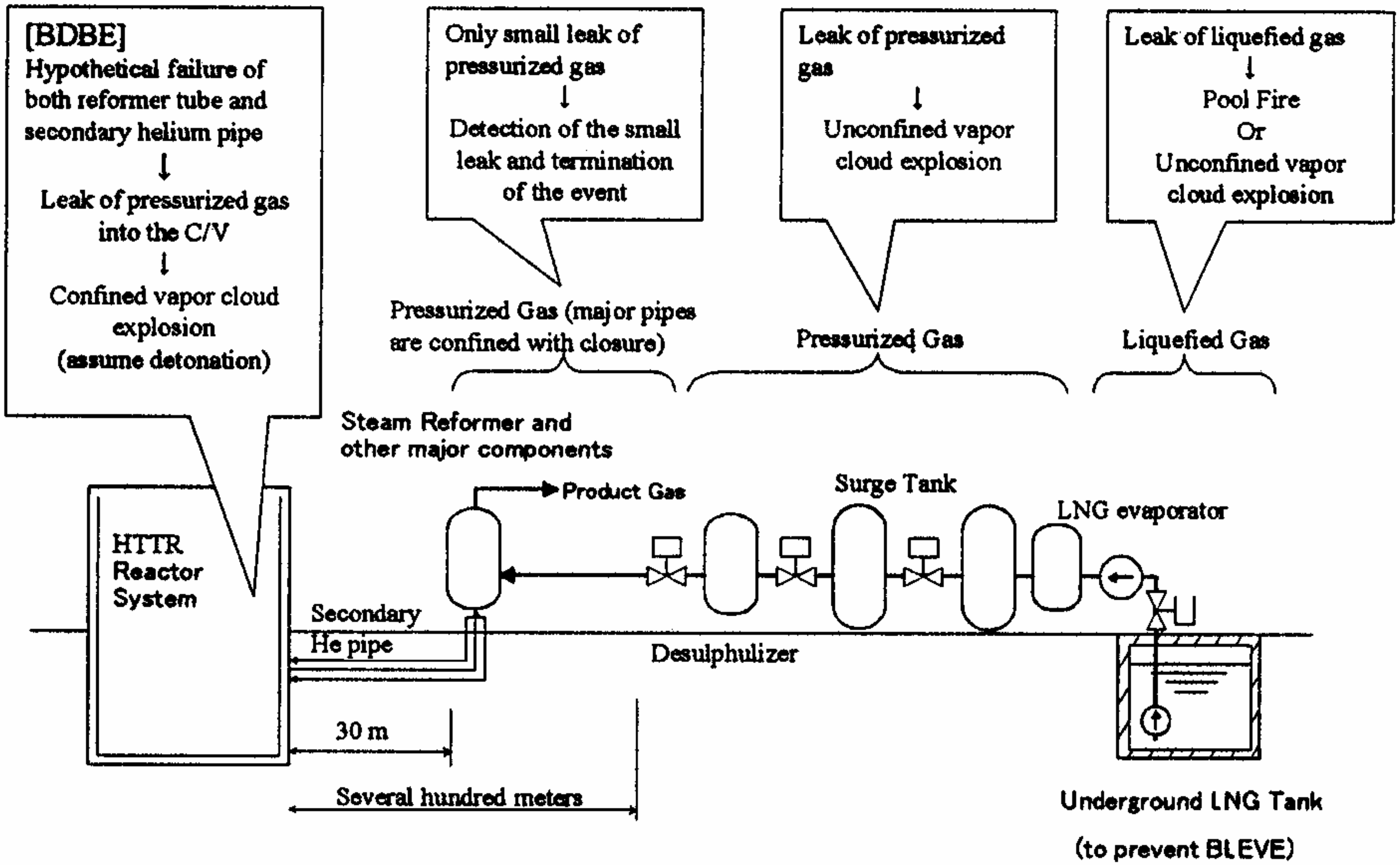
- Prevent leakage and ignition

- Detect leakage and shut off natural gas line

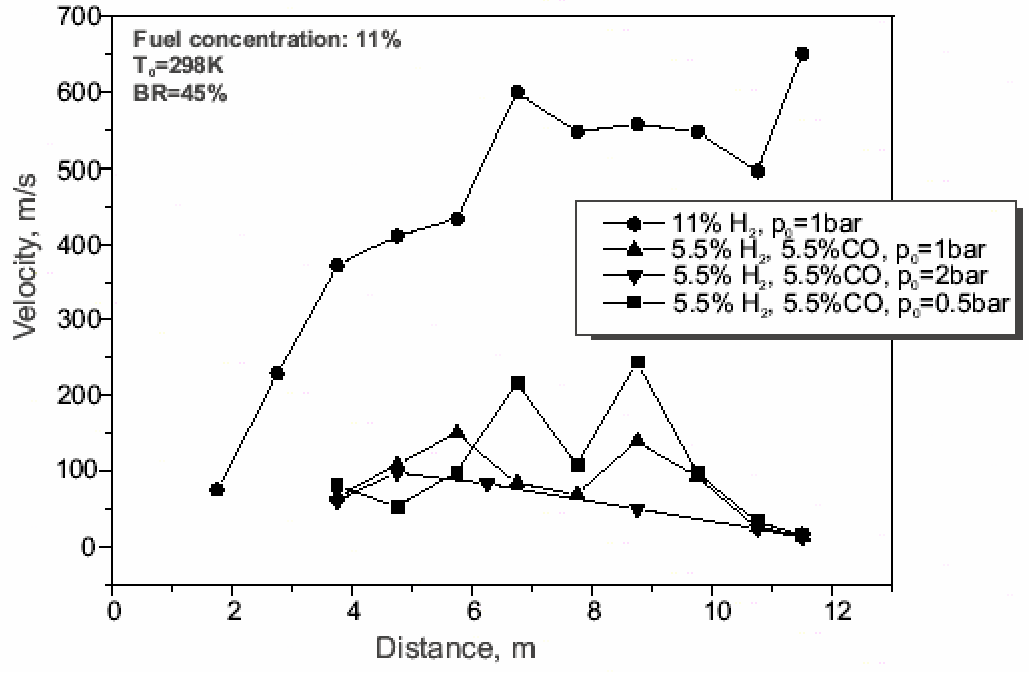
Equilibrium Process Gas Distribution

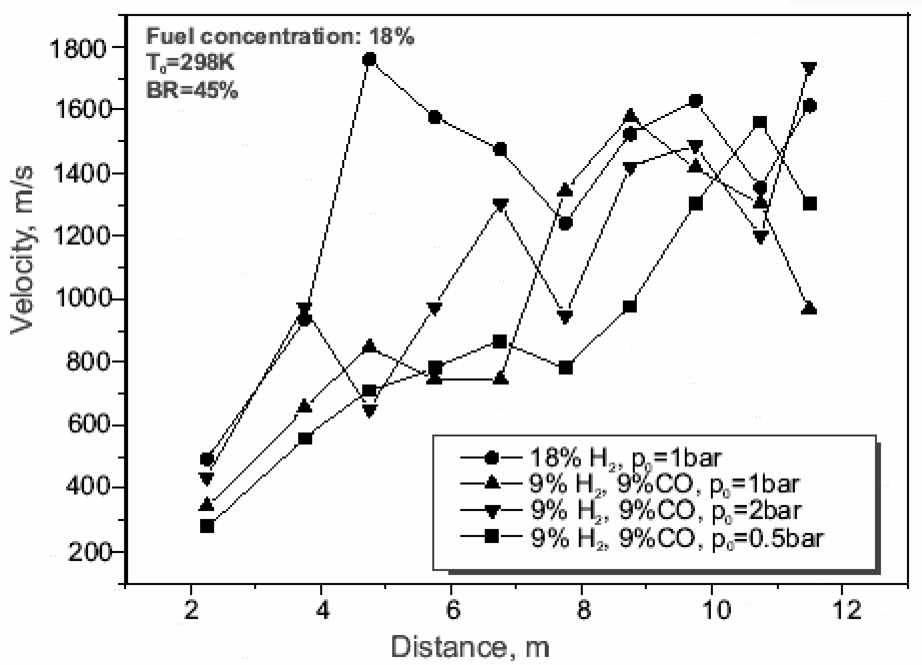


Possible Effects of Fire/Explosion Accidents



Flame Velocities of H_2-CO-Air Mixtures

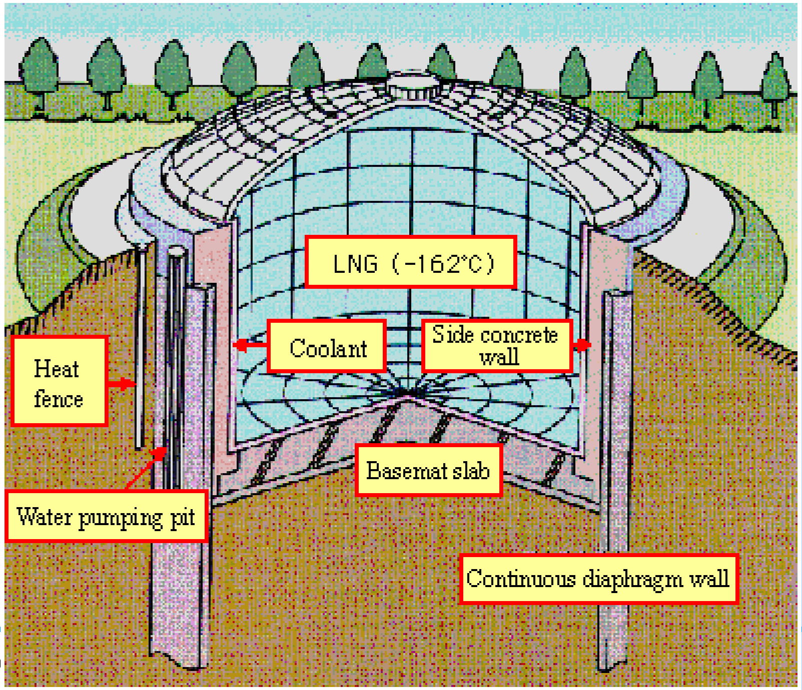




Breitung, FZK, 2000

Potential Hazards of LNG Storage

- Boil-off;
- Tank „roll-over“ (e.g., by ageing, heat input);
- Change of material properties at cryo temp.;
- BLEVE type catastrophic failure of storage tank (Boiling Liquid Expansion Vapor Cloud Explosion);
- Rupture of tank or pipeline;
- Cryogenic burns of personnel.



Safety Distance

$$R = k * M^{1/3}$$

with R: safety distance [m]

M: mass of flammable substance [kg]

k: factor 2.5-8 for working building

22 for residential building

200 for no damage

German BMI Guideline (1974) for the Protection of NPP against External Explosions

Protection by means of safety distance

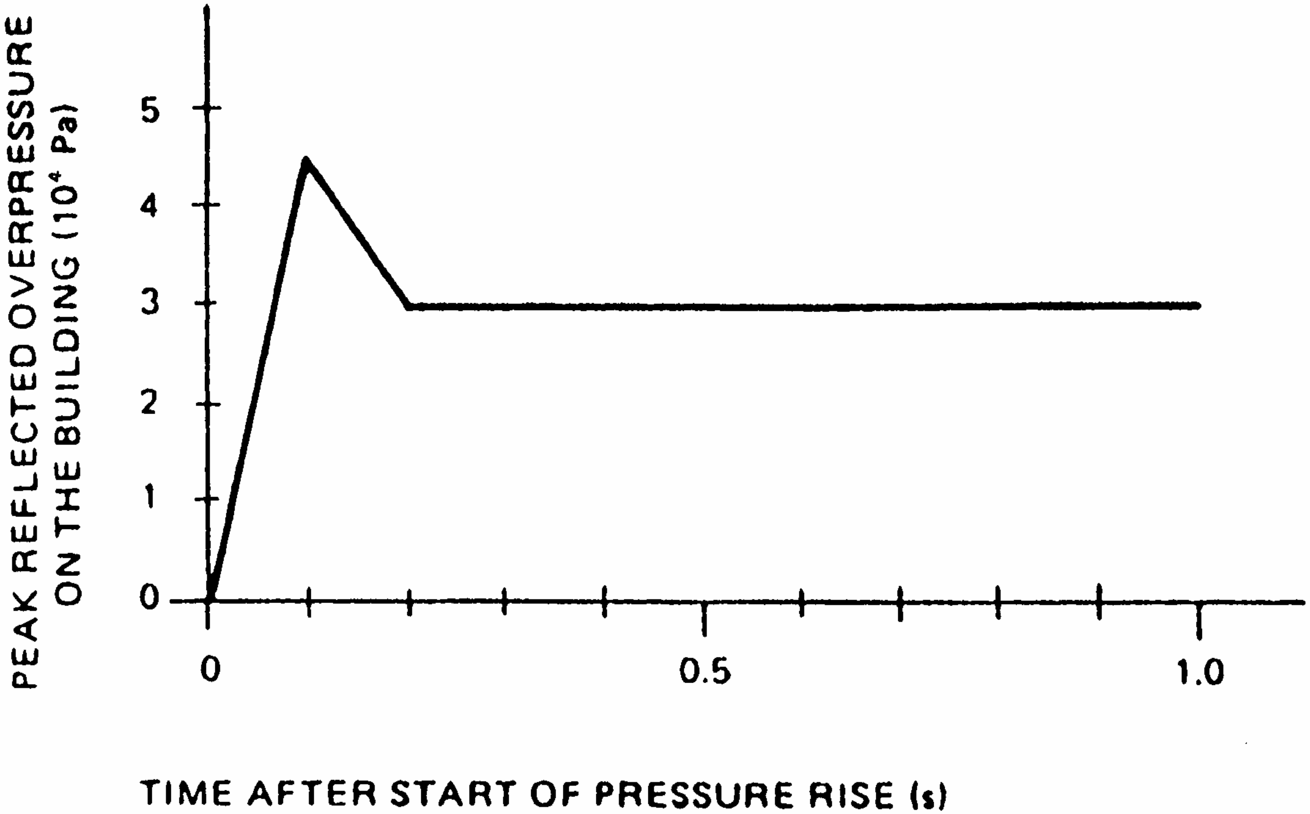
$$R = 8 * M^{1/3}$$

100% for unsaturated HC and non-liquefied gases
50% for gases liquefied under pressure
10% for gases liquefied at low temperatures
0.3% for combustible liquids
TNT equivalent for explosives

Minimum Distance: $R \geq 100$ m

German BMI Guideline (1974)

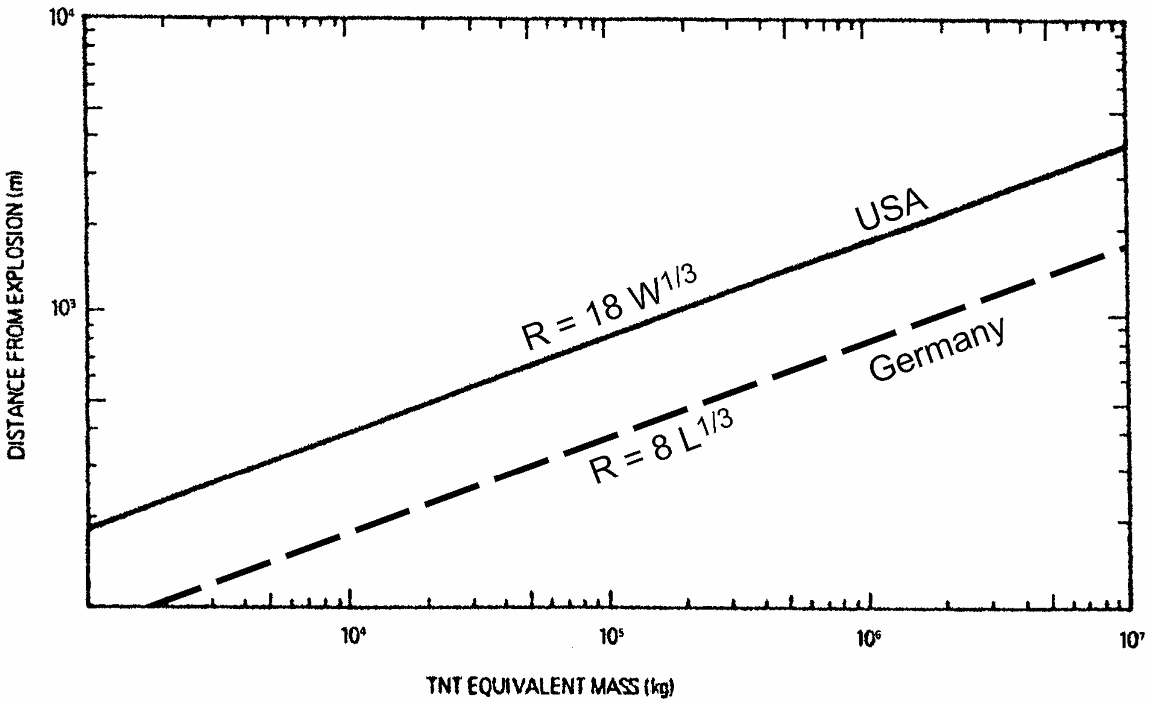
Protection by means of design against pressure wave



German BMI Guideline (1976)

- Guideline was the result of experts‘ opinion.
- Guideline was confirmed by PNP gas cloud program that gas mixtures typical for PNP cannot generate pressures beyond the design curve.
- **However**, Guideline is not to be applied to process heat HTGRs.
- If applied to HTTR/SR:
  k = 3.7 → **R = 205 m** for LNG storage tank
  (not considered: inventory in steam reformer)

US Regulatory Guide 1.91 (1975)



LNG: 400 m^3 → 169 t → 1859 t TNT

R = 2.2 km

(or show that attendant risk be sufficiently low)

Conclusions (1)

- Methane combustion occurs most certainly as flash fire with insignificant pressure wave.
- Detonantion of methane-air vapor cloud has never been observed in field trials nor accidents.
- Only for more reactive gases, overpressures > 30 kPa could be measured. Here partial detonations may not be excluded (IAEA).
- BLEVE type combustion has never been reported to have occurred in an LNG storage vessel. Cannot occur in underground container.

Conclusions (2)

- Safety distance of „more than 300 m" between HTTR and LNG tank would meet German BMI Guideline, but not the US Regulatory Guide 1.91.
- If reactor building is well designed to withstand pressure wave from outside,
  impact on components inside is covered by resp. Design against airplane crash and earthquake.