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Sandia National Laboratories

Assessment of Hydrogen Plant Risks for Siting near Nuclear Power Plants

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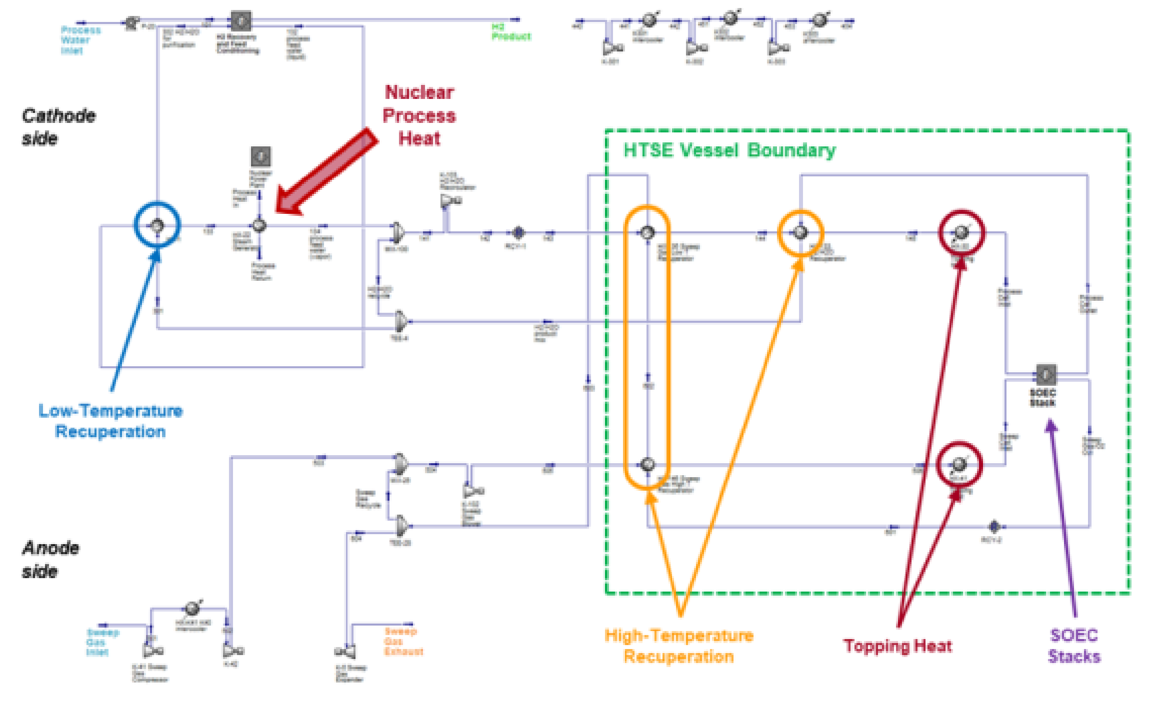
Contents

Background

- Nuclear power plants (NPPs) may use flexible plant operations and generation to take advantage of excess thermal and electrical energy.
- Hydrogen production through high temperature electrolysis is a feasible option for NPPs because the excess thermal and electrical energy produced through normal operation can be used to produce a carbon-free, storable energy source.
- NPPs must show that the operation of such a system is safe and does not pose a significant threat to the high consequence NPP facilities and structures.

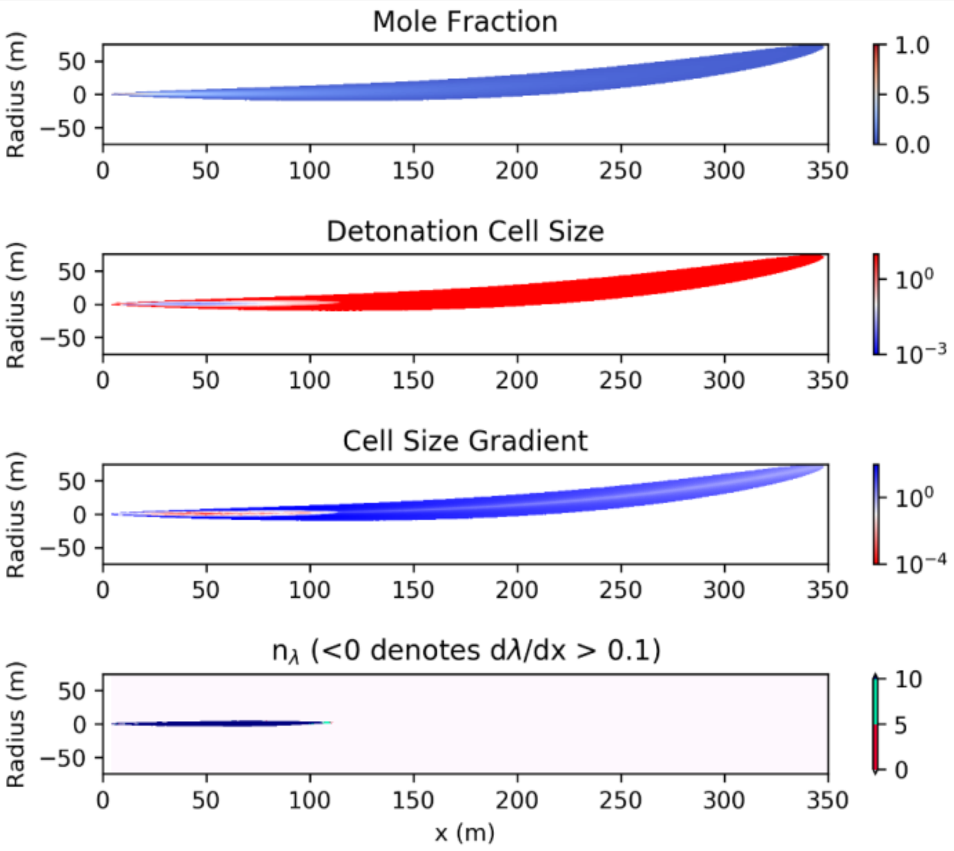


Background (cont'd)

- Investigated the risk of a high temperature steam electrolysis hydrogen production facility (HTEF) in close proximity to an NPP for input into the plant probabilistic risk assessment (PRA)
  - List of components in HTEF
  - HAZOP for accident impact scenarios
  - Leak Frequency
  - Target Fragility
  - Consequence modeling
    - Two scenarios:
      - Detonation of high pressure jet
      - Detonation of accumulated hydrogen cloud
    - Two proximity evaluations
      - Consequence at 1 km from NPP
      - Minimum Separation Distance calculations

Consequence Methodology: High Pressure Jet

- The consequence of an accident in the HTEF system is an important parameter in the overall risk assessment.
- A leak in the system could release an unconfined high-pressure hydrogen jet with the potential to damage surrounding structures.
- The flammable jet released from the leak could result in a detonation, which would expose nearby targets to damaging overpressure.
- Detonations are inherently unstable and depend on critical dimensions and the concentration gradient of the hydrogen jet, which determine if a propagating detonation wave can be supported.
- The limits of the hydrogen concentration in the jet to support detonation reduce the portion of the flammable plume that is available as fuel.
- The overpressure released through detonation of the large plume can be calculated from the detonable region, which is compared to the target fragility criteria to determine if critical damage occurs



Consequence Methodology: Hydrogen Accumulation

- An alternate consequence of a hydrogen leak in the HTEF system is ignition of an accumulated cloud of a hydrogen/air mixture.
- If ignition of the high-pressure hydrogen jet does not occur immediately after the hydrogen release, the hydrogen can accumulate and mix with ambient air before being ignited.
- The total quantity of hydrogen released in this case would contribute to the overpressure experienced by the critical NPP structures.
- The amount of hydrogen released is a function of the system flowrate at the leak location as well as the time to leak isolation.

Scenario Selection: High Pressure Jet

- Scenario identification focused on variation of relevant variables in system
  - Pipe size
  - Pressure
  - Temperature
- Full bore leak for each scenario was evaluated
- Sections of the system carrying hydrogen were identified and evaluated

Scenario	System Section	Temperature (°C)	Pressure (MPa)	Line Sizes (mm)
1	Mix-100 thru HX-KO1	735	0.52	203.2
2				254.0
3				300.0
4	HX-KO1 thru HX-KO2	75	0.48	152.4
5				203.2
6				254.0
7				300.0
8	HX-KO2 thru HX-KO3	75	1.01	88.9
9				101.6
10				200.0
11				254.0
12	HX-KO3 thru K-301	25	2.23	88.9
13				200.0
14				254.0
15	K-301 thru System Output	50	7.00	200.0

Scenario Selection: Hydrogen Accumulation

- Quantity of hydrogen released is a function of system flowrate and time to leak isolation
    - Identified the two systems with the largest hydrogen flowrates
    - Assumed a range of isolation times
    - Assumed 100% of the released quantity is hydrogen
    - Assumed hydrogen is well mixed in air

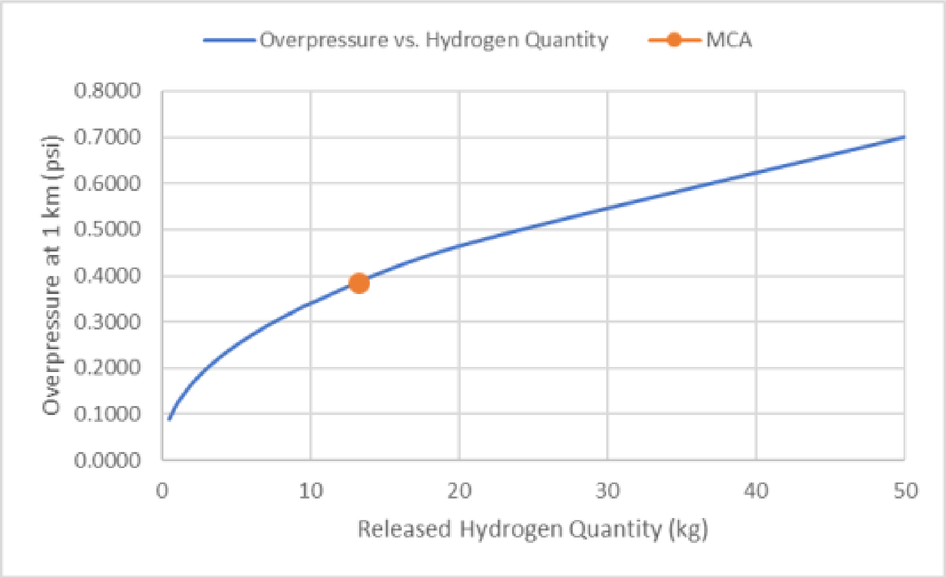
System	Flowrate (nlpm)	Isolation Time (min)	Total Hydrogen Quantity (kg)
Hydrogen Product, 93% H_2	750	5	0.3
		10	0.7
		20	1.3
		30	2.0
		60	4.0
		120	8.1
Hydrogen Product Manifold to Condenser, 62% H_2	1,223	5	0.5
		10	1.1
		20	2.2
		30	3.3
		60	6.6
		120	13.2

Results at Fixed Distance

Immediate Ignition: the largest impulse overpressure at a distance of 1 km away is ~400 Pa (0.06 psi), which is well below the 1 psi fragility failure criterion.

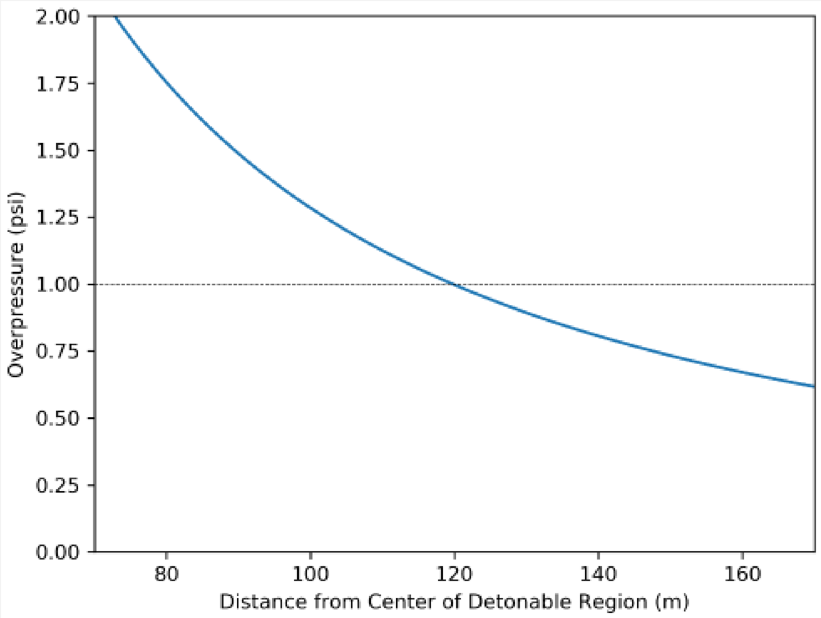
Scenario	Overpressure at 1 km	
	(MPa)	(psi)
1	3.03E-05	0.00440
2	4.37E-05	0.00633
3	5.69E-05	0.00826
4	2.90E-05	0.00420
5	4.68E-05	0.00679
6	6.70E-05	0.00972
7	8.76E-05	0.0127
8	2.16E-05	0.00313
9	2.70E-05	0.00392
10	8.13E-05	0.0118
11	11.9E-05	0.0173
12	4.52E-05	0.00656
13	16.4E-05	0.0238
14	24.0E-05	0.0349
15	38.4E-05	0.0557

Delayed Ignition: the overpressure experienced at 1 km is ~ 0.7 psi for the case that estimates 50 kg of hydrogen released. When compared to the fragility criterion of 1 psi for the static pressure capacity, there is more than a 40% margin.



Set-back Distance: Immediate Ignition

The largest separation distance is ~120 meters away from the NPP.

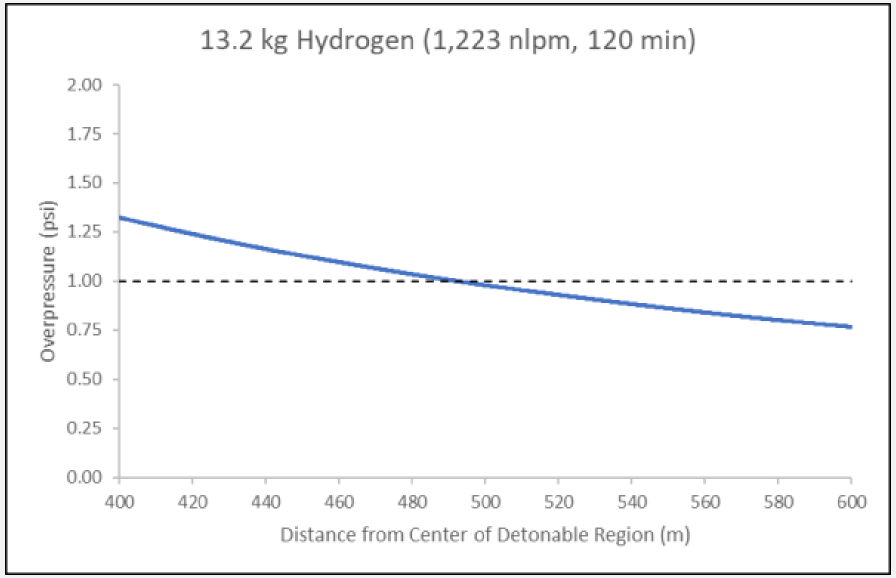


Scenario	Separation Distance (m)
1	18.0
2	23.7
3	28.9
4	17.4
5	24.9
6	32.6
7	39.8
8	14.0
9	16.5
10	37.7
11	50.1
12	24.3
13	63.6
14	84.5
15	119.8

Set-back Distance: Delayed Ignition

The largest separation distance is ~492.1 meters away from the NPP.

System	Flowrate (nlpm)	Isolation Time (min)	Total Hydrogen Quantity (kg)	Separation Distance (m)
Hydrogen Product, 93% H2	750	5	0.3	139.4
		10	0.7	184.9
		20	1.3	227.2
		30	2.0	262.3
		60	4.0	330.5
		120	8.1	418.2
Hydrogen Product Manifold to Condenser, 62% H2	1,223	5	0.5	165.2
		10	1.1	214.9
		20	2.2	270.8
		30	3.3	310.0
		60	6.6	390.6
		120	13.2	492.1



Conclusion

- The consequence of a detonation does not detrimentally affect critical targets at the NPP at a distance of 1 km.
- A full rupture leak was evaluated at different locations in the HTEF system with varying line sizes and system pressures.
- Also, the consequence of detonation of the high-pressure jet release of hydrogen and the detonation of accumulated hydrogen were evaluated as worst-case scenarios.
- The largest overpressure seen at a distance of 1 km away from the accident location was ~0.06 psi for detonation of the high-pressure hydrogen jet and ~0.4 psi for detonation of the MCA accumulated hydrogen cloud.
- This does not challenge the fragility criteria of the critical targets.