COMBUSTION AND NUCLEAR SAFETY

FOR ANS WINTER MEETING – NOVEMBER 2014

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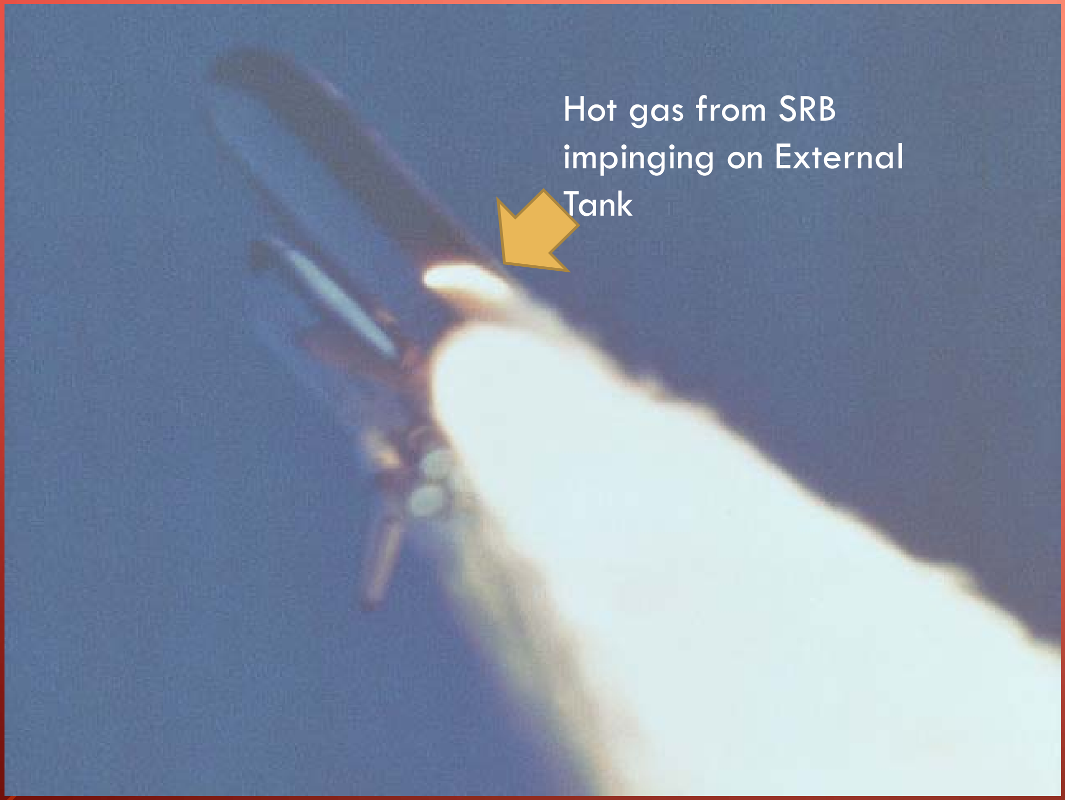
FIRES AND HYDROGEN DURING NUCLEAR POWER REACTOR FACILITY OPERATION (NOT RESULTING FROM CORE MELT)

- Many industrial type of fires in nuclear power facilities led to much research on fire ignition and propagation of fires associated with electrical equipment and insulation.
  - Fire probabilistic risk assessments performed since the 1970's
  - Major modifications to nuclear power plants to reduce risk of fire over last 30 years
- Hydrogen is generated in nuclear power reactors and the off-gas system often contains flammable concentrations.
  - Many incidents of hydrogen explosion or fire in the balance on plant, not on the nuclear side, but no threat to nuclear safety so far from these incidents.
  - Hydrogen is not included as a fire source in PRAs, except in battery rooms.

HYDROGEN INCIDENTS AT SELLAFIELD (65 YEARS OF OPERATIONS): REACTORS, FUEL REPROCESSING, FUEL FABRICATION, WASTE STORAGE AND PROCESSING AND VITRIFICATION

- One significant incident in which a loss of control led to high hydrogen generation and subsequently ignition.
- Small number of cases in which hydrogen accumulated, all without ignition.
- A couple of small events in which ignition (probably static) has occurred during package/canister opening.
- One event in which hydrogen escaped from a distribution line and self ignited
- Cannot predict when hydrogen will accumulate to flammability and, of these cases, when it will ignite.

SHOULD WE LAUNCH BILLION DOLLAR VEHICLES WITH COMBUSTIBLE MATERIALS?



The main engines combust hydrogen and oxygen.
Why isn't there a hydrogen explosion upon every launch like Challenger?

BUILDING FIRES IN INCOMBUSTIBLE BUILDINGS

Structure Fires in Radioactive Material Working Facilities and Nuclear Energy Plants of Non-Combustible Construction and in which No Automatic Suppression System Was Present or the Automatic Suppression System Failed to Operate

Extent of Flame Damage	Fires	
Confined to object of origin	54	63%
Confined to part of room/area of origin	13	15%
Confined to room of origin	0	0
Confined to fire-rated compartment of origin	5	6%
Confined to floor of origin	0	0
Confined to structure of origin	14	16%
Extended beyond structure of origin	0	0
Total	86	100%

Can we predict when, where and how severe fires will occur?

- NFPA 2007. *Structure Fires in Radioactive Material Working Facilities and Nuclear Energy Plants of Non-Combustible Construction, 1980-1998.* Quincy, Massachusetts: National Fire Protection Association.

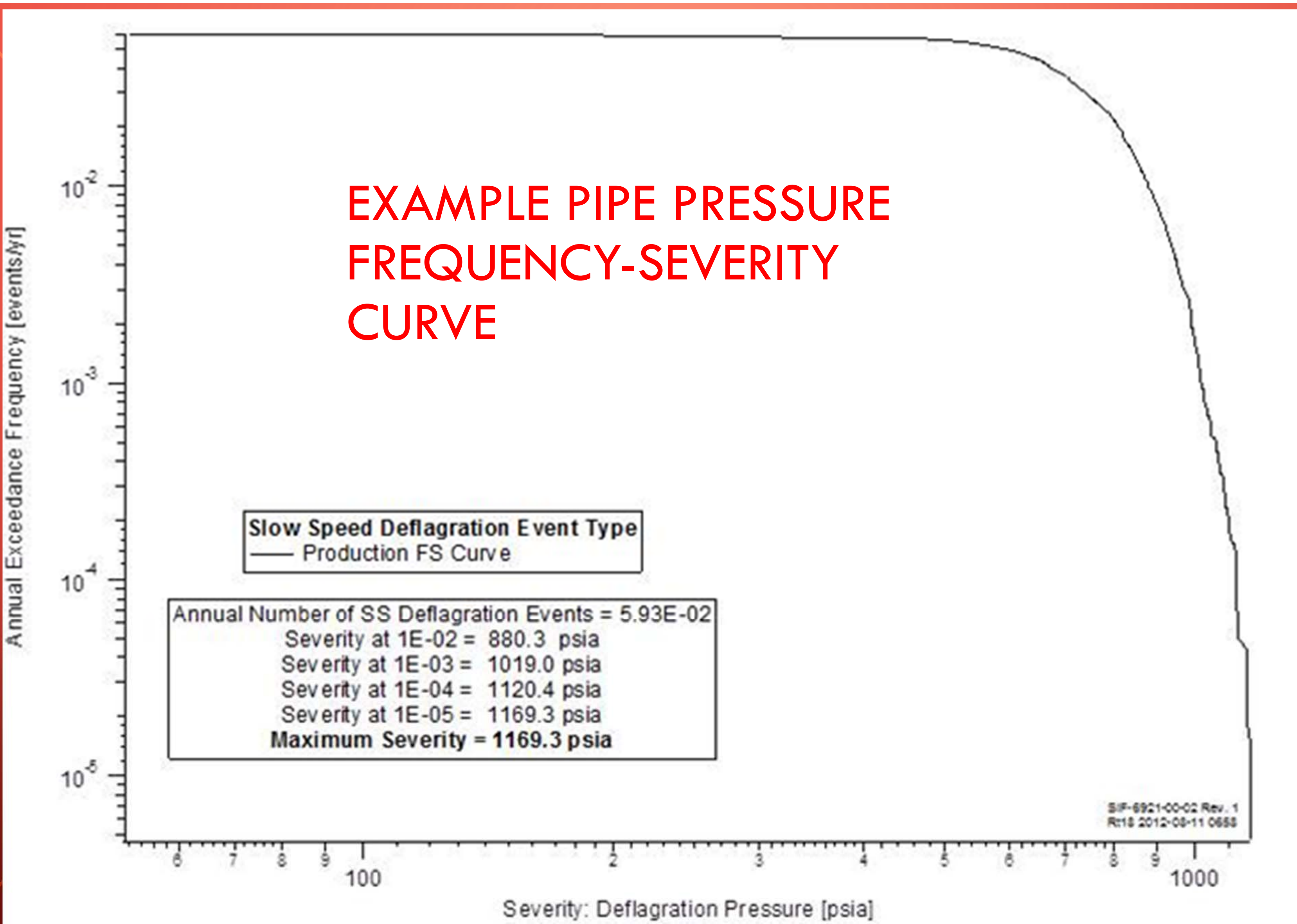
POSTULATED HYDROGEN INCIDENTS AT WTP

- Hydrogen explosions have been postulated within WTP pipes and vessels that contain radioactive aqueous solutions
  - Hydrogen is generated from radiolysis of water and organic materials, and thermolysis of organic materials
  - Typical generation rates in a typical 100,000 gallon vessels are <10 liters/hour
  - For perspective, BWRs produce ~1200 liters/hr in the reactor
  - Most pipes are 4 inch diameter or less and carry liquid intermittently because WTP is a batch plant
    - They can collect hydrogen if the liquid is not moving through the pipes. This happens during normal operation and abnormal events

PROBABILISTIC MODEL OF HYDROGEN IN PIPING

- Probabilistic modeling backed by much research at CIT and SWRI and elsewhere led to F-S curves such as on next slide
  - Uncertainties in equipment failures that would provide conditions for hydrogen accumulation,
  - Uncertainties in conditions for hydrogen bubble creation, piping and vessel geometry,
  - Uncertainties in ignition probability,
  - Uncertainties associated with defining conditions associated with deflagrations and detonations,
  - Uncertainties in calculating pipe pressurization.

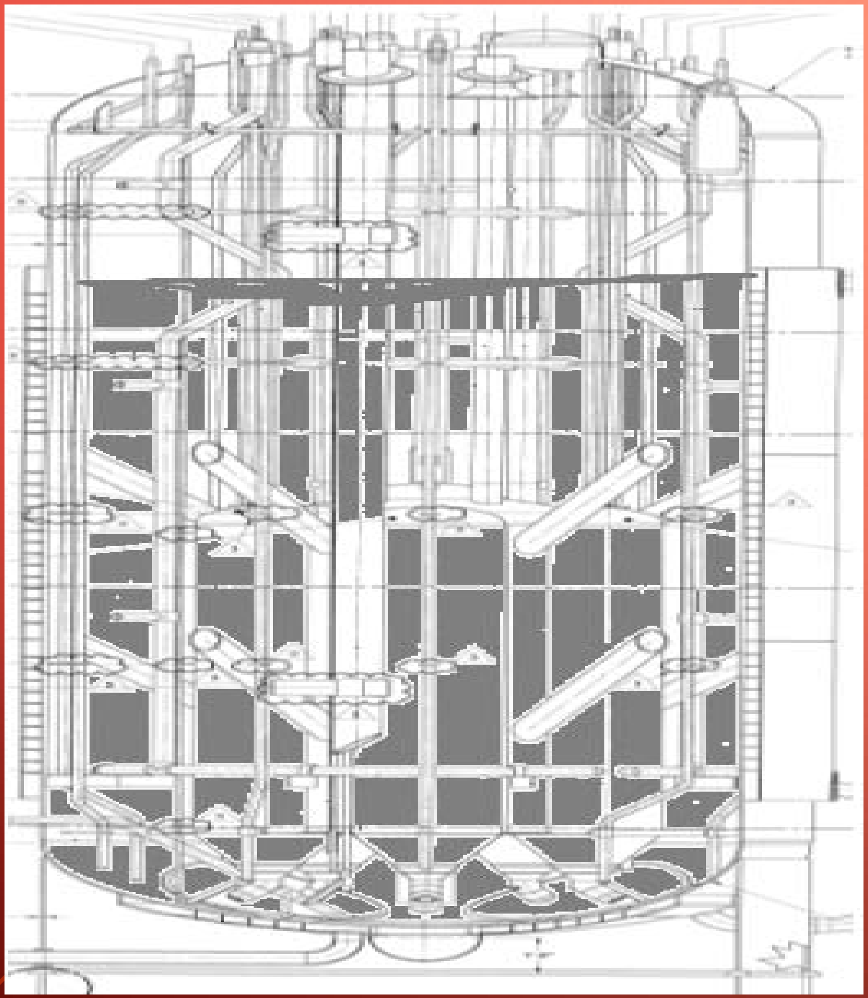
EXAMPLE PIPE PRESSURE FREQUENCY-SEVERITY CURVE



HYDROGEN EXPLOSIONS IN WTP VESSELS?

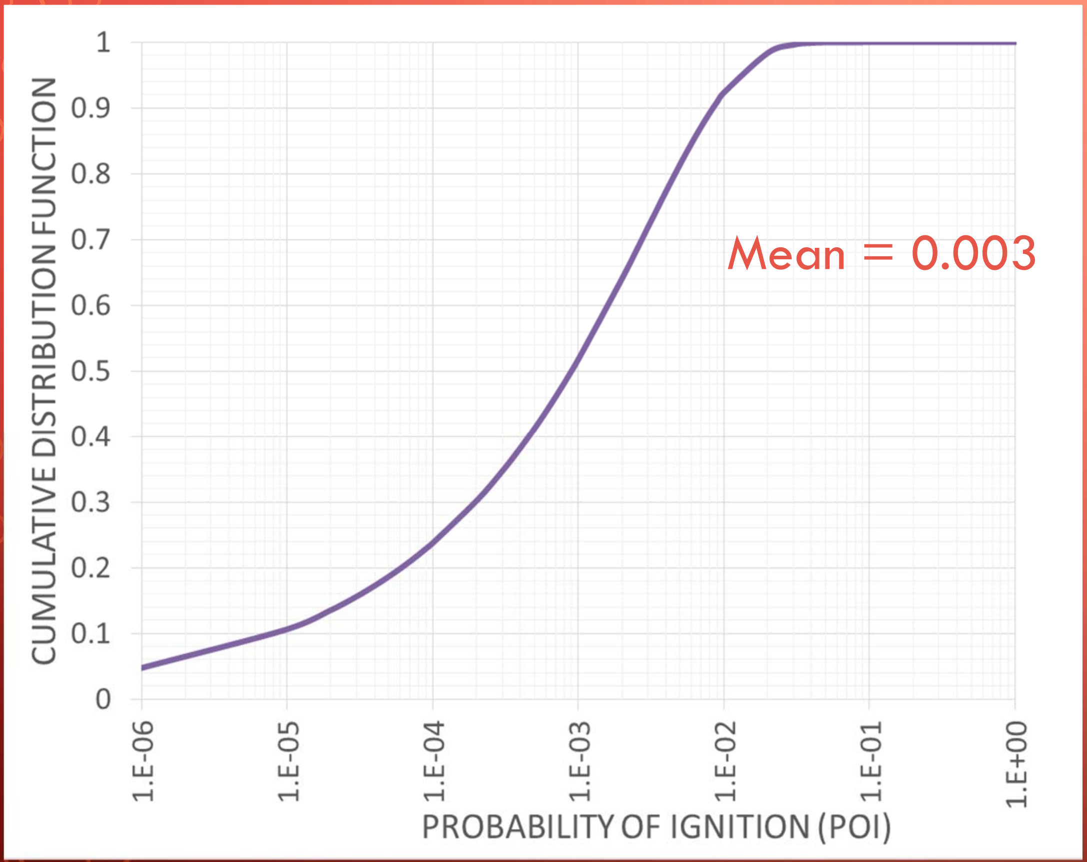
- Hydrogen generation rates are low enough so that explosive mixtures of hydrogen might occur over a time period of weeks to months
- Postulated during abnormal or accident conditions in which ventilation has failed or in-vessel waste mixing has failed

HYDROGEN IGNITION?



- Vessel is electrically grounded, has no moving parts, and no electrical power sources.
- It is within a “black cell” which is a chamber with no doors or windows surrounded by thick reinforced concrete walls.
- Ventilation achieved by 8” to 12” pipe outlet with no closed valves
- The black cell is within a concrete, grounded building
- Walls are a few feet thick
- Significant hydrogen accumulation can occur only when process and equipment have stopped

PRACTICAL ESTIMATE OF UNCERTAINTY IN PROBABILITY OF IGNITION FOR WTP VESSELS



- Data sources:
  - World-wide oil and gas data on ignition from flammable hydrocarbon releases at low flow rate. Ignition sources present.
  - Probability elicitation on hydrogen ignition within non-WTP tanks at Hanford.
- Causes of extended periods of stagnation (weeks to months) without remedial action are very unlikely. When combined with ignition probability, explosions might be on the order of 10^{-6}/yr.

STATEMENTS AND QUESTIONS FOR DISCUSSION

1. Combustion in industrial facilities continues to elude a deterministic analysis that reliably predicts when and where a fire and explosion will occur, how severe it will be, and what the consequences (radionuclide release, investment loss etc.) will be.
2. Is the initiation of a fire or explosion inherently stochastic such that probabilistic methods must be applied?
3. Should nuclear safety analysis of fires rely on worst case accident analysis to define functional safety requirements?
4. Should nuclear safety analysis of fires account for probability vs. severity relationships to provide reasonable assurance of adequate protection?
5. What should be the balance of expenditures between research into fire safety and engineering solutions to reduce frequency and severity?