Presentation Start

Introduction, Motivation and Lecture Outline

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Historical Development of C&S for Hydrogen Infrastructure

- Initial approach by International Code Council ICC (~2003) was to adapt C&S for hydrocarbon fuels to hydrogen
  - Basis for origin of C&S for other fuels was unknown; likely based simply on experience and expert opinion
  - Lack of a technical basis prevented modification for hydrogen applications
- Current approach is to use engineering models and correlations based largely on DOE funded research to provide basis for hydrogen C&S
  - C&S based purely on technical data resulted in often unacceptable requirements for hydrogen systems (unrealistic separation distances)
  - Quantitative Risk Assessment (QRA) must be included
    - QRA accounts for the probability of an event occurring
    - QRA can be used to identify risk drivers and mitigation strategies

Objectives

- Hydrogen C&S need a traceable technical basis:
  - perform physical and numerical experiments to quantify fluid mechanics, combustion, heat transfer, cloud dispersion behavior
  - develop validated engineering models and CFD models for consequence analysis
  - use quantitative risk assessment for risk-informed decision making and identification of risk mitigation strategies
- Provide advocacy and technical support for the codes and standards change process:
  - consequence and risk: HIPOC, NFPA (2, 55, 502), ISO
  - international engagement:
    - HYPER (EU 6th Framework Program), *Installation Permitting Guidance for Hydrogen and Fuel Cell Stationary Applications*
    - ISO TC197, WG11, TG1 on fueling station separation distances
    - IEA Task 19 Hydrogen Safety, recommended analysis practices
    - Global Technical Regulations, fuel system safety

Separation Distances

- Specified distances between a hazard source and a target (e.g., human, equipment, structures, other hazardous materials, ignition sources) which will mitigate the effect of a likely foreseeable incident involving the hazard source that results in an acceptable level of risk to the public and prevents a minor incident escalating into a larger incident
  - Current distances do not reflect high pressures (70 MPa) being used in refueling stations
  - Documented basis for current distances not found

- Several options possible to help establish new separation distances
  - Subjective determination (expert judgment)
  - Deterministically determined based on selected break size (e.g., 20% flow area)
  - Based only on risk evaluation as suggested by the European Industrial Gas Association (IGC Doc 75/07/E)
  - Risk-informed process that combines risk information, deterministic analyses, and other considerations to make decisions

Hydrogen installation to impose no greater risk -- "Just as safe or safer as the current HC infrastructure"

Deterministic (Consequence-Based) Approach

- SNL model used to evaluate separation distances for hydrogen jets
- Model predicts (as function of system volume, pressure, and leak size):
  - Radiant heat flux from hydrogen jet flames
  - Visible flame length for ignited jets
  - Hydrogen concentrations in jets
- Assumes circular orifice for leak geometry and constant pressure – conservative
- Model validated against experiments

Risk-Informed Codes and Standards

- Use of a risk-informed process is one way to establish the requirements necessary to ensure public safety
  - Endorsed by Fire Protection Research Foundation ("Guidance Document for Incorporating Risk Concepts into NFPA Codes & Standards")
  - Comprehensive QRA used to identify and quantify scenarios leading to hydrogen release and ignition
  - Accident prevention and mitigation requirements identified based on QRA
  - Results combined with other considerations to establish minimum code and standard requirements needed for an established risk level

Risk Measures

- Human injury or fatality
  - Individual risk – frequency that an average unprotected person, located at most exposed location, is killed or injured due to an accident
  - Societal risk – frequency that multiple people within an area are killed or injured due to an accident (typically represented on an FN curve)
- Others
  - Economic loss – typically expressed in terms of loss value (lost income and replacement cost)
  - Environmental damage – can be expressed in terms of time required to recover damage to ecosystem

Individual fatality risk deemed most appropriate for establishing generic code requirements

Risk Exposed Persons

- Public – people located outside the facility boundary
- People living and working near the facility
  - People visiting or traveling near the facility
- Customers – people using the facility
  - Limited exposure period
- Facility operators – personnel involved in operation, inspection, and maintenance of the facility
  - Generally assumed these people accept higher risk levels than for customers and outside public

Risk to a person at the lot line was selected for use in the risk analysis

Radiation Heat Flux

- Potential for harm or facility damage is a function of heat flux level and exposure time
- Wide variation in criteria (assumes exposed skin):
  - 1.6 kW/m^2 – no harm for long exposures
  - 4 to 5 kW/m^2 - pain for 20 second exposure
  - 9.5 kW/m^2 -Second degree burns within 20 seconds
  - 12.5 to 15 kW/m^2 - 1% lethality in 1 minute, piloted ignition of wood
  - 25 kW/m^2 - 100% lethality in 1 minute, injury within 10 seconds, ignite wood (long exposure)
  - 35 to 37.5 kW/m^2 - 1% lethality in 10 seconds, damage steel structures (long exposure)

Lecture Outline

- Unintended release behavior
  - Momentum dominated flows
  - Buoyancy dominated flows
- Effect of barriers on:
  - Flame impingement, Radiation, Pressure effects
- Ignition
  - Spontaneous ignition
  - Flammability limits (flame stability)
    - Quiescent flows, Turbulent jets, Detonation, Explosion
- Quantitative risk assessment

Presentation End