



HYDROGEN IMPLEMENTING AGREEMENT

# *17<sup>th</sup> World Hydrogen Energy Conference*

## *Session: Design Considerations for Real World Conditions*

**Brisbane, Australia – 17 June 2008**

IEA HIA Task 19 Hydrogen Safety Effort In  
Developing Uniform Risk Acceptance Criteria For  
The Hydrogen Infrastructure

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AN IMPLEMENTING AGREEMENT OF THE INTERNATIONAL ENERGY AGENCY



# Outline of Presentation

1. **Review** task description and **Subtask A** Work Plan
2. **Risk and safety** concepts and definitions
3. **Risk acceptance criteria** review
4. **Preliminary guidance** on risk acceptance criteria
5. **Harm criteria** overview
6. **Summary**

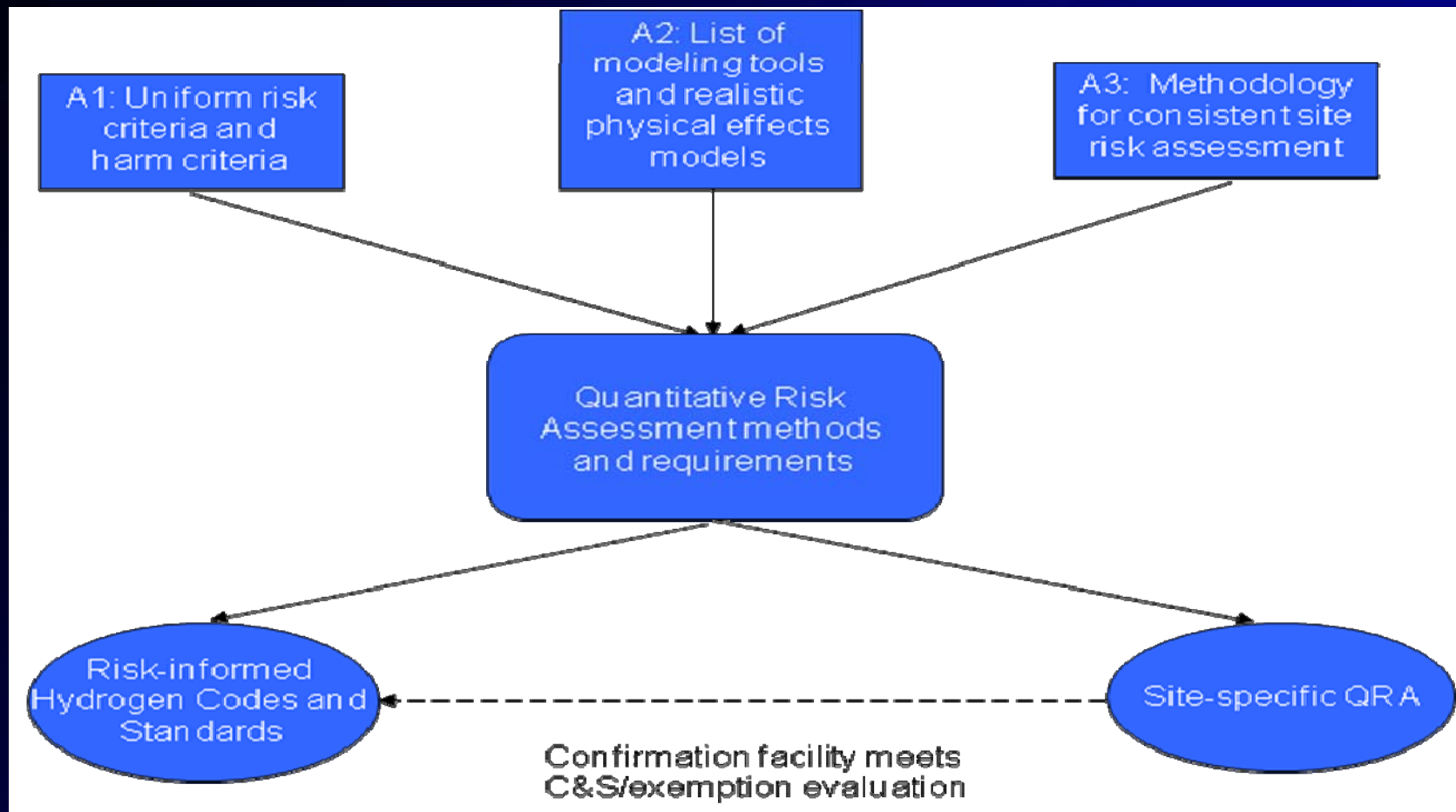


# Task 19 Organization

- A. **Risk Management:** Risk and safety definitions and concepts, link with risk-informed C&S, engineering physical effects models, methodology for consistent site QRA
- B. **Experimental & Testing Program:** Evaluate the nature and consequences of safety-related events under a range of real-life scenarios, environments and mitigation measures
- C. **Information Dissemination:** Develop targeted information packages for stakeholder groups



# Subtask A – Work Plan & Activities Interface



# Goal of Activity A1

- Discuss risk and safety concepts
- Develop uniform risk acceptance criteria
  - Types of risk measures
  - Risk targets
  - Survey currently used risk criteria
  - Provide guidance on selection of uniform risk acceptance criteria
- Develop uniform harm criteria for use in hydrogen QRA
  - Define criteria for all types of hydrogen accidents
  - Survey of currently used measures
  - Provide guidance on selection of uniform harm criteria
- Develop link to risk-informed codes and standards



# Safety and Risk

## □ Definition:

✓ **Safety is freedom from unacceptable risk** (ISO/IEC Guide 51:1999)

## □ This effectively means that:

- ✓ Risk is the technical (quantitative) measure of safety as ***safety cannot be calculated while risk can***
- ✓ Society accepts the fact that ***there is neither absolute safety nor zero risk***
- ✓ Society, de facto, establishes acceptable levels of risk or ***risk acceptance criteria***

## □ Definition:

✓ **Risk criteria – terms of reference by which the significance of risk is assessed** (ISO/IEC Guide 73:2002)

## □ Conclusion :

- ✓ Safety depends on acceptable level of risk, i.e. ‘terms of reference’ that are subject to public perception or political / regulatory decisions
- ✓ Risk criteria, hence, affect only the level of acceptable risk (i.e. ***safety***), but ***NOT the risk value itself (unless physical changes are made)***



# Risk Measures

- **Human injury or fatality**
  - Individual risk – probability that an average unprotected person, permanently located at a certain location, is killed or injured due to an accident
  - Societal risk – probability 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



# Risk Exposed Persons

- **Public (3rd Party)** – people located outside the facility boundary
  - People living and working near the facility
  - People visiting or traveling near the facility
- **Customers (2<sup>nd</sup> Party)** – people using the facility
  - Limited exposure period
- **Facility operators (1st Party)** – personnel involved in operation, inspection, and maintenance of the facility
  - Generally assumed these people accept higher risk levels than for customers and outside public



# As Low As Reasonably Practicable (ALARP)

- There is no zero risk situations
- Managing risk to a reasonable level is achievable
- **Acceptable risk** represents the level below which an investment should be made to further reduce risk
  - Cost-benefit analysis
- Acceptable risk represents the *minimum risk* level that must be *obtained, regardless of cost*
- The ALARP principle is that the *residual* risk should be **As Low As Reasonably Practicable** – risk reducing measures are feasible and their costs are not larger than the benefits



# ALARP Concept – Individual Risk

Unacceptable  
Region

Risk must be reduced  
regardless of cost unless there  
are extraordinary circumstances

ALARP or  
Tolerability  
Region

Risk tolerable only if reduction  
cost is grossly disproportionate to  
the benefits gained

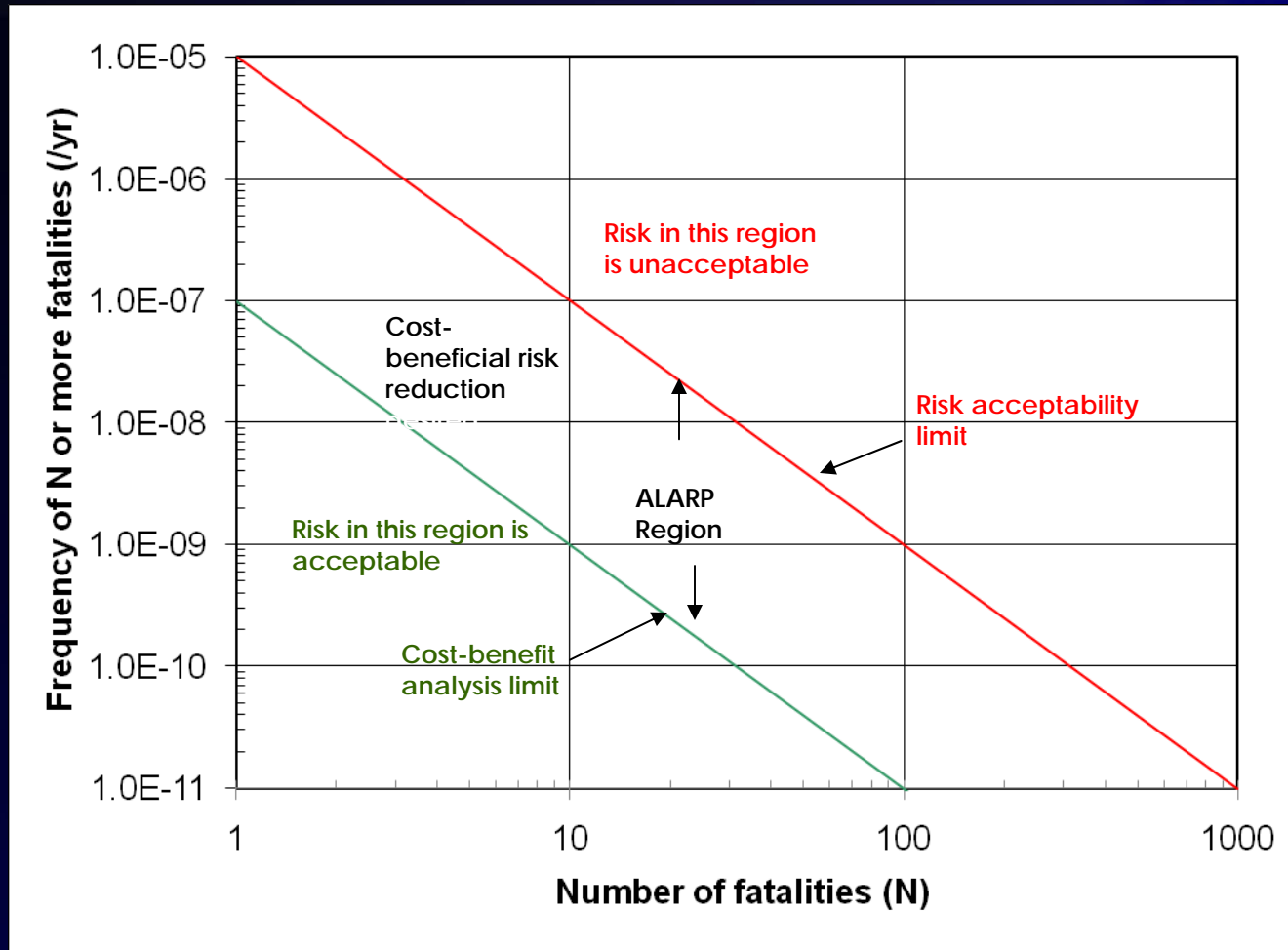
Acceptable  
Region

Risk tolerable if reduction cost  
exceeds improvement achieved

Necessary to maintain assurance  
that risk remains at this level  
and/or reduced further if  
reasonably practical

Negligible Risk

# ALARP Concept – FN Curve



# Risk Acceptance Criteria

- Uniform risk acceptance criteria are required for development of risk-informed codes and standards
- Options for selecting risk criteria:
  - Based on *statistics* from existing stations (gasoline and CNG)
    - limited data available
    - data includes accidents other than accidental releases
    - NFPA data for gasoline stations in U.S. suggests frequency of deaths and injuries per station are  $\sim 2 \times 10^{-5}/\text{yr}$  and  $\sim 3 \times 10^{-4}/\text{yr}$ , respectively
  - Based on *estimated risk* for existing stations
    - limited analyses are available
    - differences in facilities affects comparison of data
  - Comparing with *general risk in society* – hydrogen should not increase the general risk level in society
    - Risk of death  $\sim 2\text{-}4 \times 10^{-4}/\text{yr}$ ; risk of injury  $\sim 0.09/\text{yr}$  in U.S.
    - Fraction of total risk from just fires ( $1.3 \times 10^{-5}/\text{yr}$  in the U.S.) and explosions ( $6 \times 10^{-7}/\text{yr}$  in the U.S.)



# Survey of Risk Criteria

## Individual Risk (3<sup>rd</sup> Party)

- Public risk measures expressed in terms of fatalities
- Some organizations and countries suggest using the fraction of the total risk from all other unintentional injuries
  - **USNRC** safety goal for nuclear power plants is 0.1% of accidental death rate ( $5 \times 10^{-7}/\text{yr}$ ).
  - **EIHP** has specified the value to be 1% of the average fatality death rate of  $1 \times 10^{-4}/\text{yr}$  or  $1 \times 10^{-6}/\text{yr}$ ;
  - **EIGA** has suggested an individual risk value of  $3.5 \times 10^{-5}/\text{yr}$  (~1/6 the average fatality risk)
- Some countries use harm criteria only (e.g., France) and some do not have numerical criteria (e.g., Germany, U.S., Canada)

## Customers (2<sup>nd</sup> Party)

- European Integrated Hydrogen Project –  $1 \times 10^{-4}/\text{yr}$

## Worker risk (1<sup>st</sup> Party)

- European Integrated Hydrogen Project –  $1 \times 10^{-4}/\text{yr}$
- United Kingdom –  $1 \times 10^{-3}/\text{yr}$

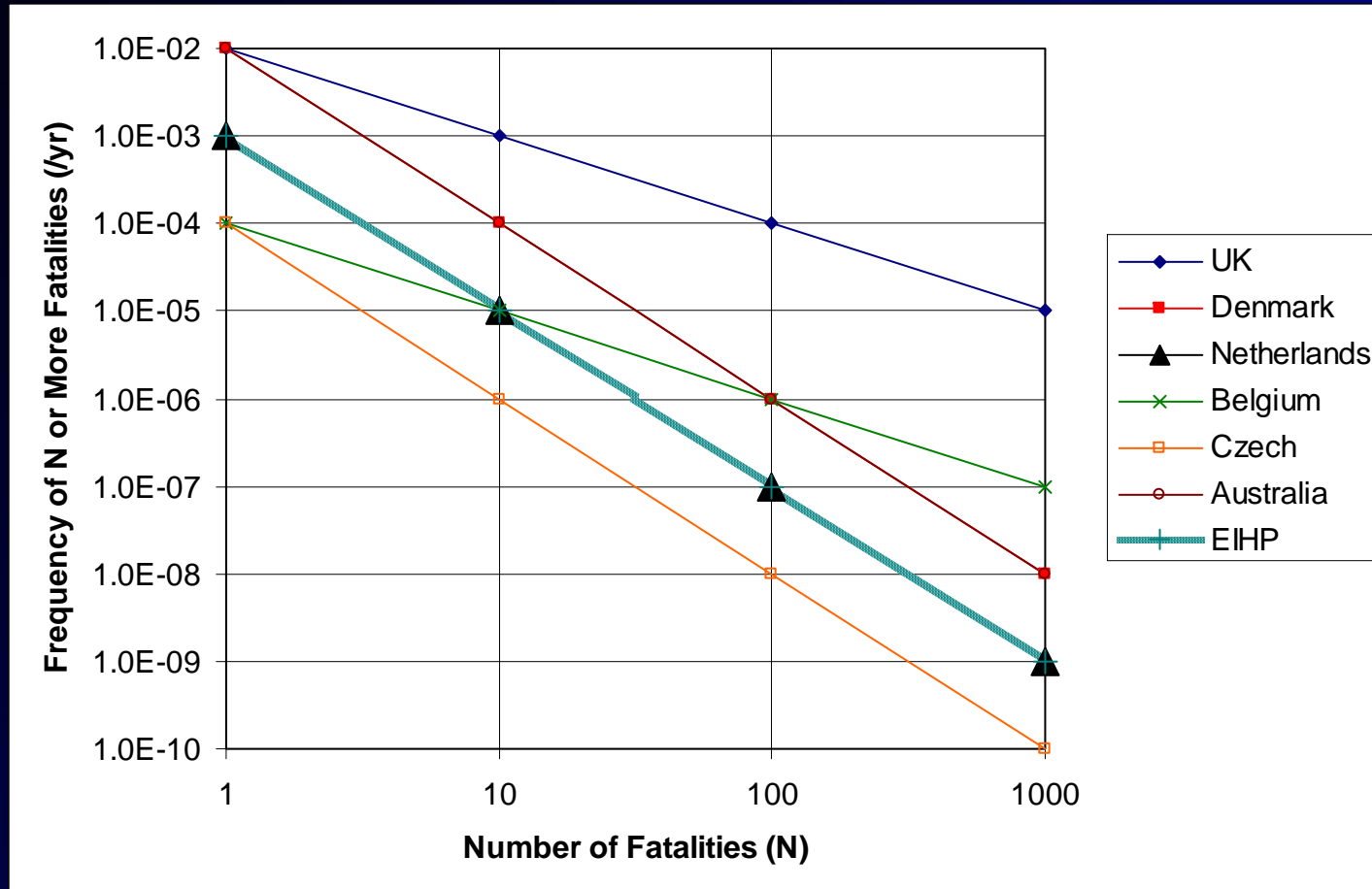


# Survey of Individual Risk Criteria for Public

| Individual Risk Criteria | United Kingdom                              | The Netherlands   | Hungary     | Czech Republic  | Australia                   |
|--------------------------|---|---|-------------|---|-----------------------------|
| $10^{-4}$                | Intolerable limit for members of the public |   |             |   |                             |
| $10^{-5}$                | Risk has to be lowered to ALARP             | Limit for existing installations, ALARA principal applies                         | Upper limit | Limit for existing installations, risk reduction applied. | Limit for new installations |
| $10^{-6}$                | Broadly acceptable risk level               | Limit for new installations and general limit after 2010, ALARA principal applies | Lower limit | Limit for new installations                               |                             |
| $10^{-7}$                | Negligible level of risk                    |   |             |   | Negligible level of risk    |
| $10^{-8}$                |   | Negligible level of risk  |             |   |                             |



# Survey of Societal Risk Criteria for Public



# Acceptance Criteria in Norway: Legal Basis

## Acceptance criteria for major accident risk and environmental risk

The operator shall set acceptance criteria for major accident risk and environmental risk.



Acceptance criteria shall be set for:

- a) **the personnel** on the facility **as a whole (1<sup>st</sup> party)**, and for groups of personnel which are particularly risk exposed,
- b) **the loss of main safety functions** as mentioned in the Facilities Regulations Section 6 on main safety functions,
- c) **pollution** from the facility,
- d) **damage done to third party.**



(Norwegian Petroleum Directorate Regulations relating to management in the petroleum offshore activities. Last amended 21 December 2004)

# Example: Risk Criteria in ConocoPhillips Offshore

**Personnel Risk – FAR** (the statistical *expected number of fatalities per 100 million exposed hours*)

$$FAR_{\text{All onboard}} < 10$$

$$FAR_{\text{exposed group}} < 25$$

## Impairment of Main Safety Functions

The probability of impairment of any main safety function shall be less than

$1 \times 10^{-4}$  per year per type of accidental event

Norwegian Petroleum Directorate guidelines suggest alternatively to use a total frequency of  $5 \times 10^{-4}/\text{yr}$  for all accidents for all safety functions



# Example: Risk Criteria Onshore Norway

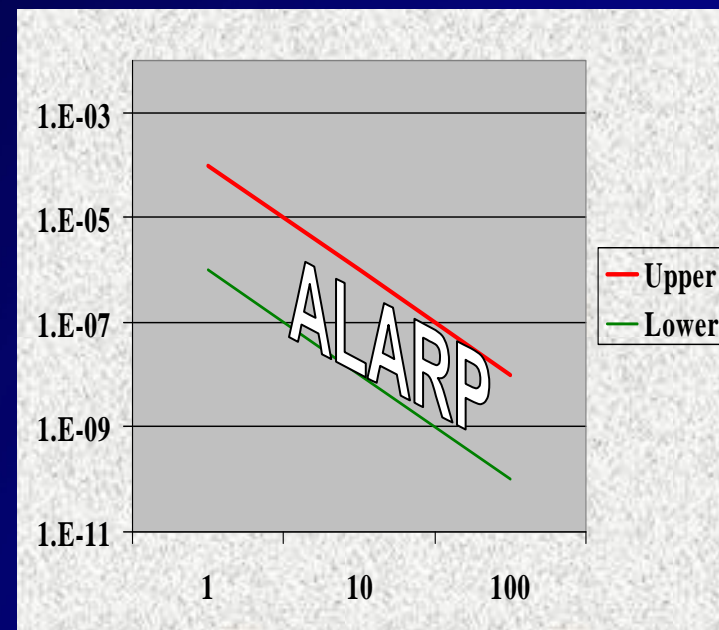
- Personnel Risk Onshore installations

- Snøhvit LNG plant:  $FAR_{All\ Personnel} < 5$

- Third party risk:

Individual: Most exposed individual: Fatality risk  $< 10^{-5}$  per year  
(Statoil)

Societal : F-N curve



# Preliminary Guidance on Public (3rd Party) Risk Criteria

## Individual Risk – ALARP with following criteria:

- ✓ 24/7 exposure – site independent – generic and more conservative guideline
- ✓ Most exposed individual – site specific guideline
- Acceptable risk level  $< 1 \times 10^{-5}/\text{yr}$ 
  - ✓ Basis – Comparative risk to gasoline stations, 10% of risk to society from all other accidents, representative value used by most countries
- Cost-benefit analysis limit –  $1 \times 10^{-7}/\text{yr}$ 
  - ✓ Basis – Representative of most countries

## Societal Risk – Adopt EIHP ALARP FN curve

- ✓ Basis – risk aversion factor of 2 and with a pivot point for 10 fatalities of  $1 \times 10^{-5}/\text{yr}$  for acceptable risk curve and  $1 \times 10^{-7}/\text{yr}$  for cost-benefit analysis limit curve

*Developed by IEA HIA Task 19 experts*



# Preliminary Guidance on 2<sup>nd</sup> & 1<sup>st</sup> Party Risk Criteria

## Customer (2<sup>nd</sup> Party) and Worker Risk (1<sup>st</sup> Party):

- **Conventional** Approach: use traditional frequency of fatality per year (like in individual risk). **Suggested acceptable risk for both 2<sup>nd</sup> and 1<sup>st</sup> party  $< 1 \times 10^{-4}/\text{yr}$** 
  - ✓ Basis – Order of magnitude higher than the individual acceptable risk value
  - ✓ Both customers and workers accept higher risk vs general public not using the refuelling facility
- **Alternative** approach – **use FAR** similar to oil & gas / process industry approach (per 100 million hrs).
  - ✓ Option 1: FAR can be calculated from gasoline station statistics (**e.g. NFPA data**) and adopted for hydrogen stations
  - ✓ Option 2: use existing statistics for gasoline cars: e.g. **FAR for drivers is 25 and for passengers is 29 per 100 million hrs (UK)**
    - Both drivers and passengers should accept **at least the same level of risk** for vehicle refuelling as they accept while using their vehicles

*Developed by IEA HIA Task 19 experts*



# Some Issues Being Explored

- Use of risk “Guideline” versus “Criteria”
  - Conveys concept that we are providing guidance
  - In risk-informed space, more than risk is considered
  - Large uncertainty in risk evaluations
  - However, in some countries decisions are based on comparison to risk criteria
- Guidance on uncertainty assessments and impact on decision making
  - Evaluate epistemic (parameter, modeling, completeness) uncertainties
  - Do we use the mean, median, or a percentile when comparing to guideline?
- Guidance on cost-benefit evaluation in ALARP
  - What guidelines should be used?



# Harm Criteria

- **Harm criteria** are required for full range of accidents modeled in QRA
  - Jet fires, flash fires, pool fires, vapor cloud explosions (VCEs), Boiling Liquid Expanding Vapor Explosion (BLEVE), and detonations
- **Types of harm criteria**
  - Thermal effects (radiation and convective heat flux)
  - Overpressure effects (direct and indirect)
  - Others (asphyxiation, cryogenic)?



# Radiation Heat Flux

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



# Thermal Dose

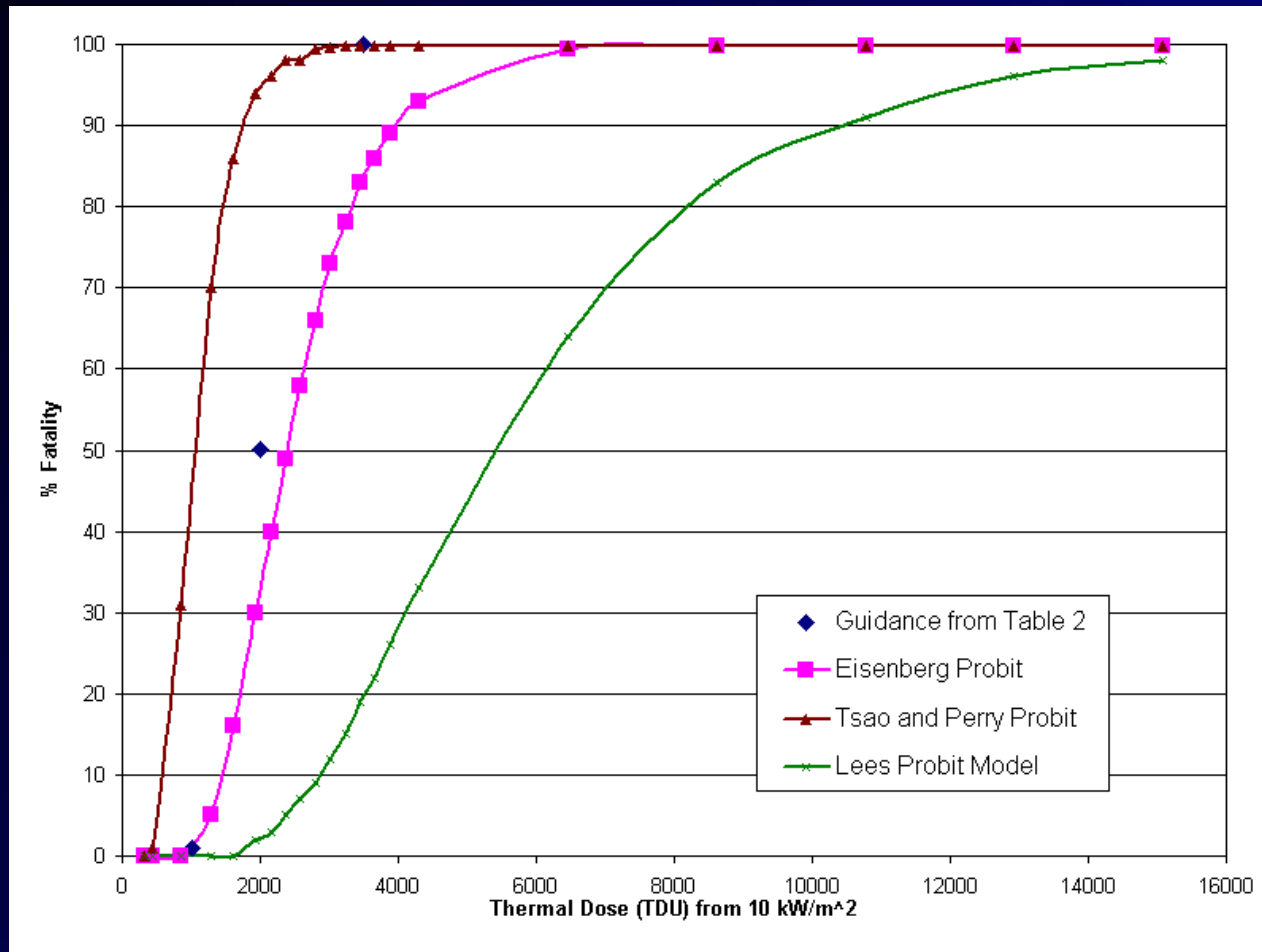
- Alternate method is to evaluate thermal dose =  $I^{4/3}t$

| Harm Caused  | Radiation Thermal Dose ( $\text{kW/m}^2 \cdot \text{s}^{4/3}$ ) |          |
|--|---|----------|
|  | Mean  | Range    |
| Pain   | 92  | 86-103   |
| Threshold first degree burn  | 105   | 80-130   |
| Threshold second degree burn   | 290   | 240-350  |
| Threshold third degree burn  | 1000  | 870-2600 |
| Source: Human Vulnerability to Thermal Radiation Offshore, HSL/2004/04 |   |          |

- Several Probit functions are available to evaluate probability of fatality or injury as function of thermal dose
- LD50 can be used as a criteria



# Probit Comparison



# Overpressure Effects

- There are both direct and indirect overpressure effects on people
- Main direct effect is sudden increase in pressure that occurs as blast wave passes

| Peak Overpressure (psig) | Effects on Unprotected People            |
|--------------------------|--|
| 12                       | Severe injury or death from direct blast |
| 10                       | Serious lung damage                      |
| 8                        | Fatal head injury                        |
| 5                        | Eardrum rupture                          |
| 1.2                      | No serious injury                        |

- Indirect effects include fragments from blast source and structures, and building collapse



# Human Impairment (Impact) Criteria (Norway Example)

| <b>EFFECT</b>    | <b>Impairment Criterion</b>    | <b>Remarks</b>  |
|------------------|--------------------------------|---|
| Heat load        | 20 kW/m <sup>2</sup>           | Lethal incident radiation flux for well clothed personnel (North Sea standards)   |
| Flash fire       | Inside LFL                     | 100% lethality for personnel trapped within LFL   |
| Explosions       | Inside combusting cloud        | 100% lethality for personnel trapped within a combusting cloud (regardless of overpressure)   |
| Explosions       | Subject to structural collapse | Lethal overpressure (based on whole body translation, within T15 range)   |
| Explosions       | 1-2 bar                        | Threshold value for eardrum damage: 1 bar. For lung damage: 2 bar   |
| H <sub>2</sub> S | 500 ppm H <sub>2</sub> S       | Lethal concentration of hydrogen sulphide (short exposure)  |
| Oxygen depletion | 10 %                           | Oxygen concentrations below 10% cause rapid loss of judgment + comprehension, followed by loss of consciousness, death within minutes (Stensaas, 1991). |



# Summary

- Collaboration during first three years has proven extremely valuable and has laid the foundation for significant and valuable products during the follow-on period (2008-10).
- Draft guidelines for uniform risk acceptance criteria have been developed and need to be tested.
- **Harm criteria guidelines are being developed.**
- Other issues to be addressed:
  - Differentiation between risk-informed and risk-based approach
  - Uncertainties in risk evaluation
  - Guidance on cost-benefit analysis
- **IEA HIA Task 19 experts are committed to this work and would welcome additional participation.**



*International Energy Agency Hydrogen  
Implementing Agreement . . .*

[www.ieahia.org](http://www.ieahia.org)

*. . . A Model R,D&D Collaboration in an  
interdependent world*



# Thank You!



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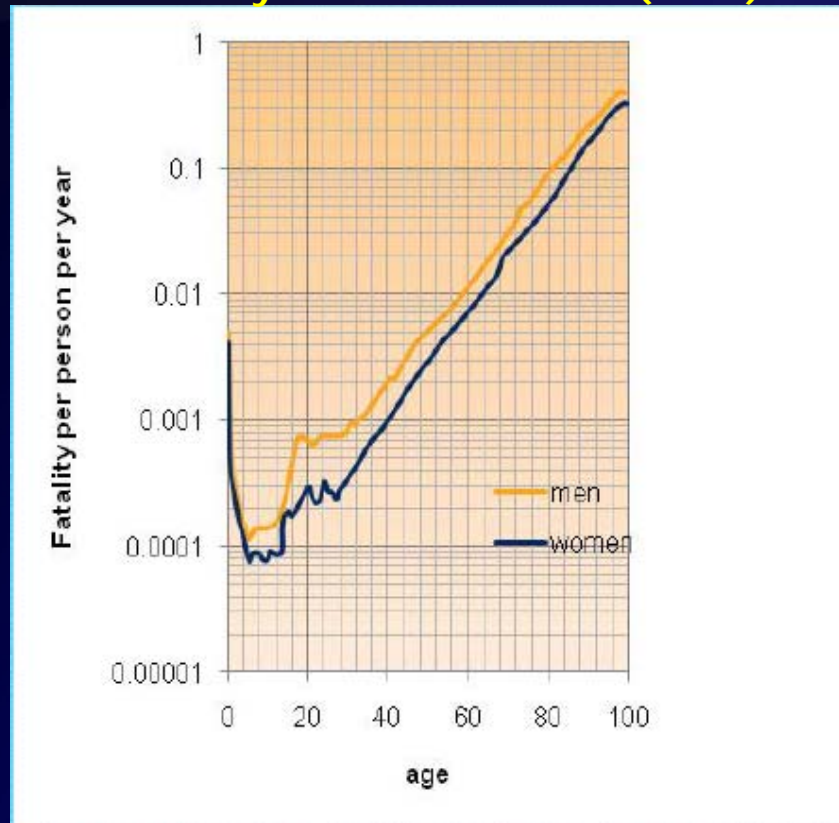


Finland  
Dr Heikki Kotila



# Risk of Fatality in Developed World

Courtesy of Frank Markert (RISO)



Mortality rate in Denmark; 5 years average 2000-2005; all causes. compiled by Danmarks Statistics

# Estimate of Children's Risk in UK

## Risk & childhood

Nicola Madge and John Barker  
October 2007



RSA

|                                  |  |
|----------------------------------|--|
| <b>0.03 per million</b>          | children sustain serious injuries in playgrounds each year   |
| less than <b>one per million</b> | children are murdered by a stranger each year  |
| <b>6 per million</b>             | children each year are abducted by a stranger  |
| <b>17 per million</b>            | children under 16 are killed while passengers in vehicles and about 7 per million are killed as pedestrians each year  |
| <b>32 per million</b>            | children under the age of 15 die from cancer each year   |
| <b>73 per million</b>            | children are murdered every year, mainly by parents  |
| <b>1,500 per million</b>         | 11 to 18 year-olds were involved in knife crime in London over a four-month period in 2006   |
| <b>2,000 per million</b>         | children are diagnosed with cancer before the age of 15  |
| <b>2,400 per million</b>         | children under 16 have road accidents every year   |
| <b>5,000 per million</b>         | children die before the age of one year  |
| <b>9,000 per million</b>         | 16 to 19 year-olds are diagnosed with chlamydia each year, while more than 1,000 per million are diagnosed with gonorrhoea and over 5,000 per million are diagnosed with genital warts |
| <b>40,000 per million</b>        | are sexually abused by a parent, carer or relative at some time before the age of 16   |



# Development of Risk Criteria

Some figures from 'Coping rationally with risks  
(basis: The Netherlands, population 16 million)

DALY's = loss of healthy years

Courtesy of Koos Ham (TNO)

| Risk factor                      | Fatalities/yr | DALYs   |
|----------------------------------|---------------|---------|
| Smoking cigarettes               | 20,000        | 444,000 |
| Heavy body weight                | 8,000         | 170,000 |
| Alcohol                          | 2,200         | 195,000 |
| No body exercise; unhealthy food | 15,000        | 272,000 |
| Air pollution, fine dust         | 1,300         | 1,800   |
| Accidents (traffic + home)       | 3,300         | 137,000 |
| Radiation in houses (Rd)         | 800           | 7,900   |
| Legionella in drinking water     | 80            | 560     |
| Major accidents                  | 1             | 40      |



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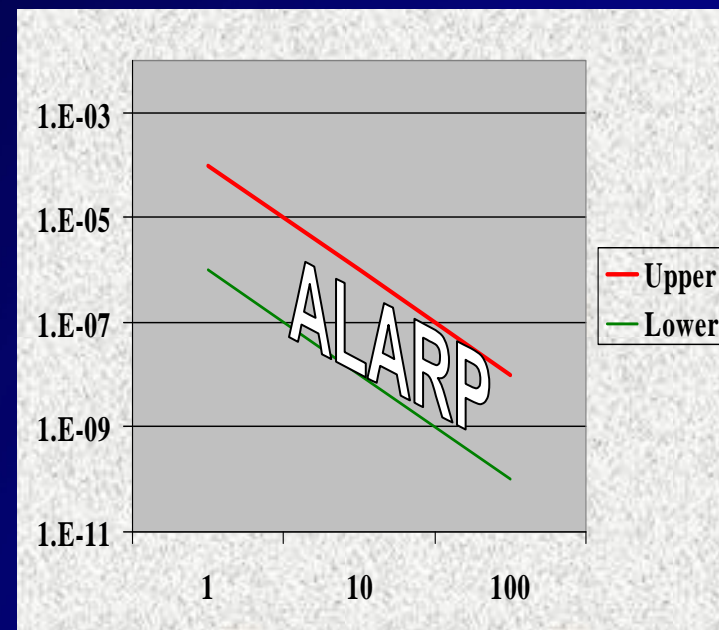
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- Third party risk:

Individual: Most exposed individual: Fatality risk  $< 10^{-5}$  per year  
(Statoil)

Societal : F-N curve



# Leading Risk Indicators: Tolerance Limits: (HRS User Interface project, DNV and StatoilHydro)

- Defined acceptable *number of shut downs* of the HRS *per year*
- Defined acceptable HRS *down-time per year* (how much of the time is the HRS not available for filling of vehicles by customers).

**Registering and monitoring of the indicators should be linked with an assessment of the performance indicators**

Photo: Terje S. Knudsen (StatoilHydro)

