HYDROGEN IMPLEMENTING AGREEMENT

17th 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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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

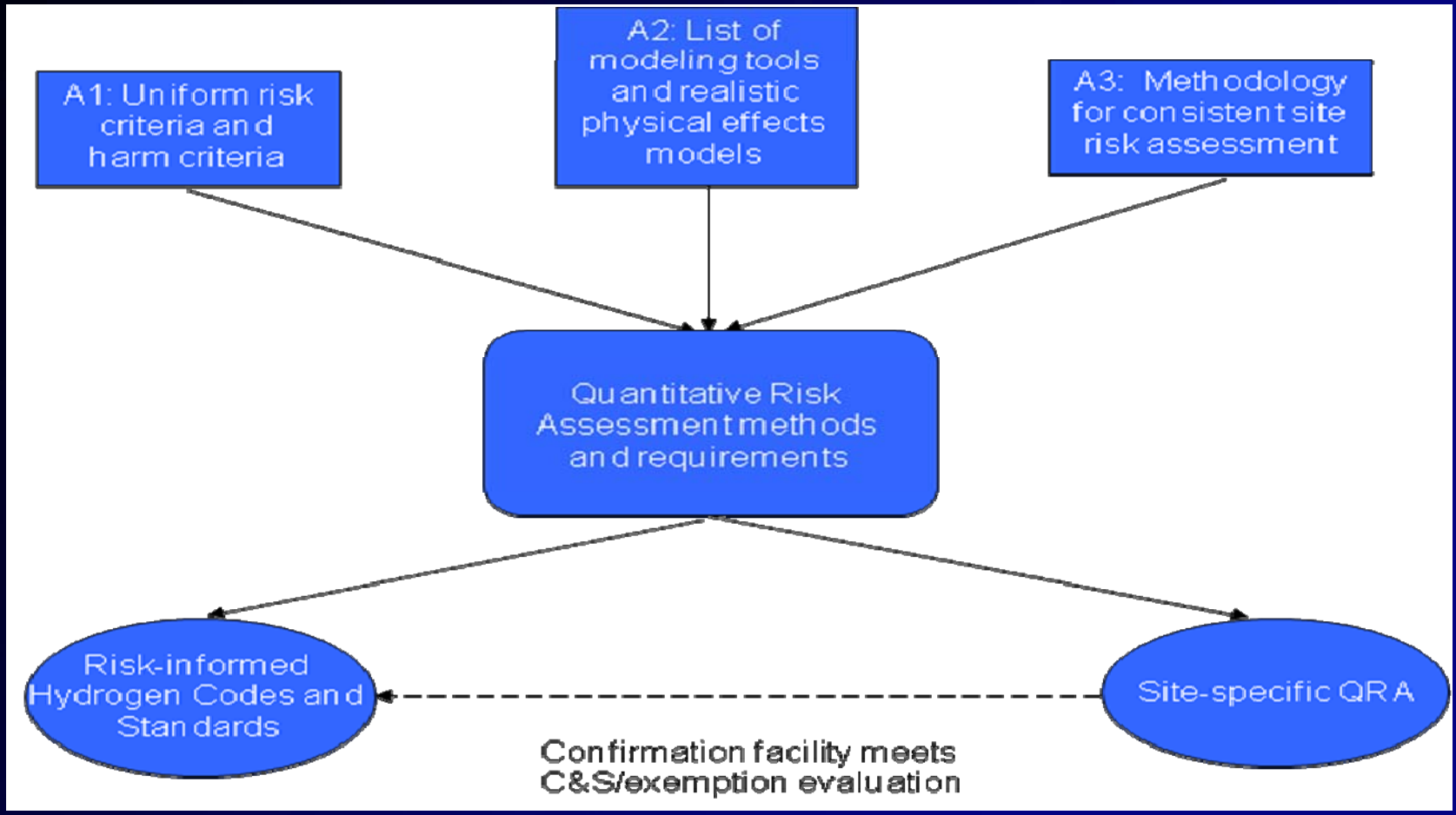
Task 19 Organization

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

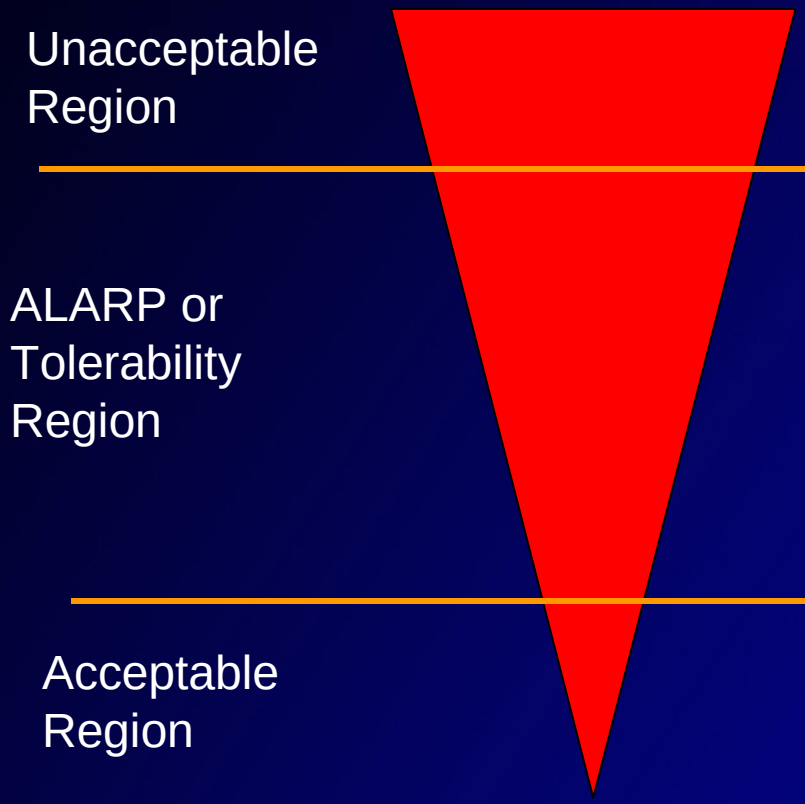
Risk Exposed Persons

- Public (3rd Party) – people located outside the facility boundary
  - People living and working near the facility
  - People visiting or traveling near the facility
- Customers (2nd 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

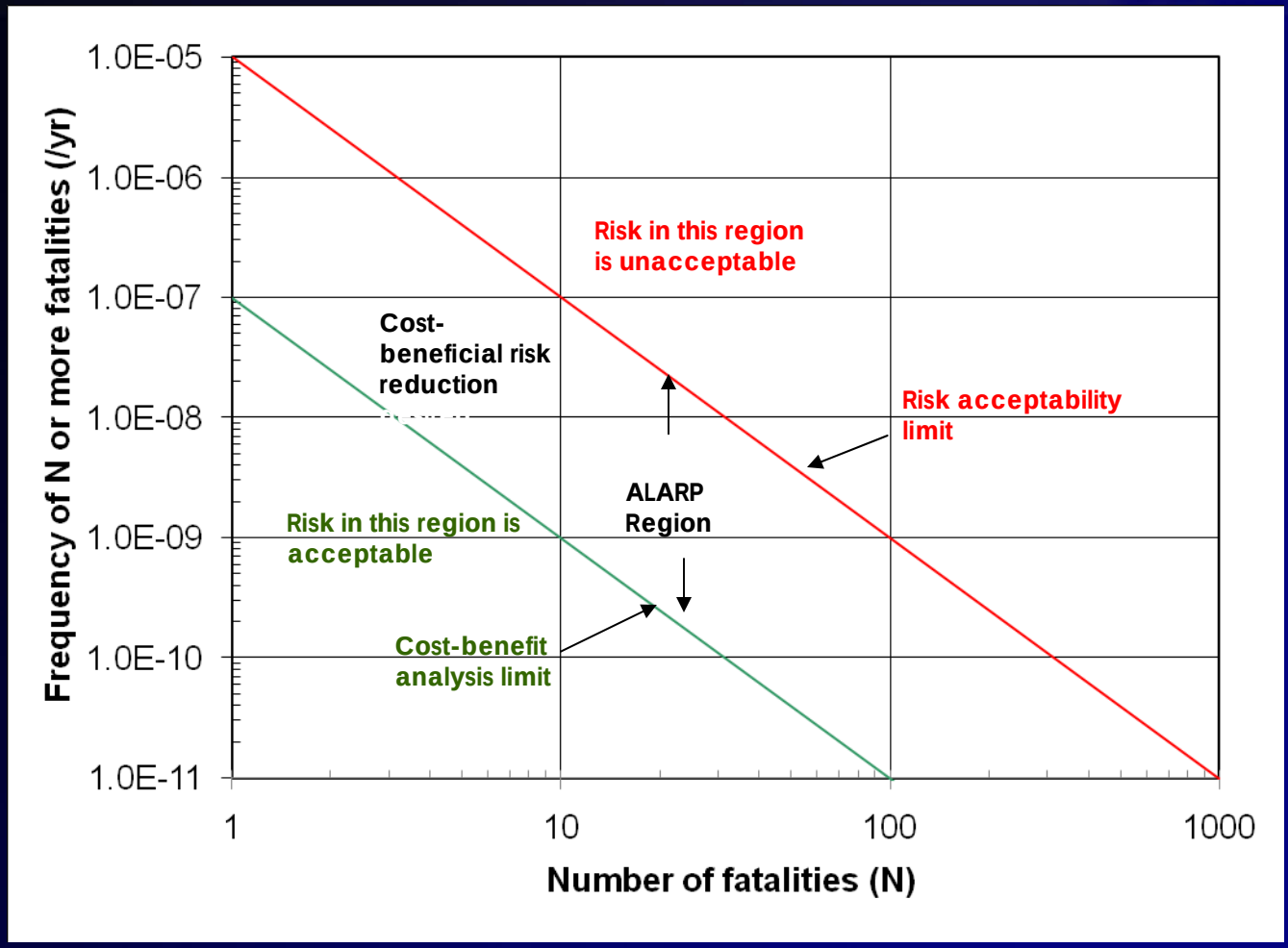
Risk tolerable if reduction cost exceeds improvement achieved

Acceptable Region

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 ~2×10^{-5}/yr and ~3×10^{-4}/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 ~ 2-4×10^{-4}/yr; risk of injury ~ 0.09/yr in U.S.
    - Fraction of total risk from just fires (1.3×10^{-5}/yr in the U.S.) and explosions (6×10^{-7}/yr in the U.S.)

Survey of Risk Criteria

Individual Risk (3rd 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 (5×10^{-7}/yr).
  - EIHP has specified the value to be 1% of the average fatality death rate of 1×10^{-4}/yr or 1x10-6/yr;
  - EIGA has suggested an individual risk value of 3.5×10^{-5}/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 (2nd Party)

- European Integrated Hydrogen Project – 1×10^{-4}/yr

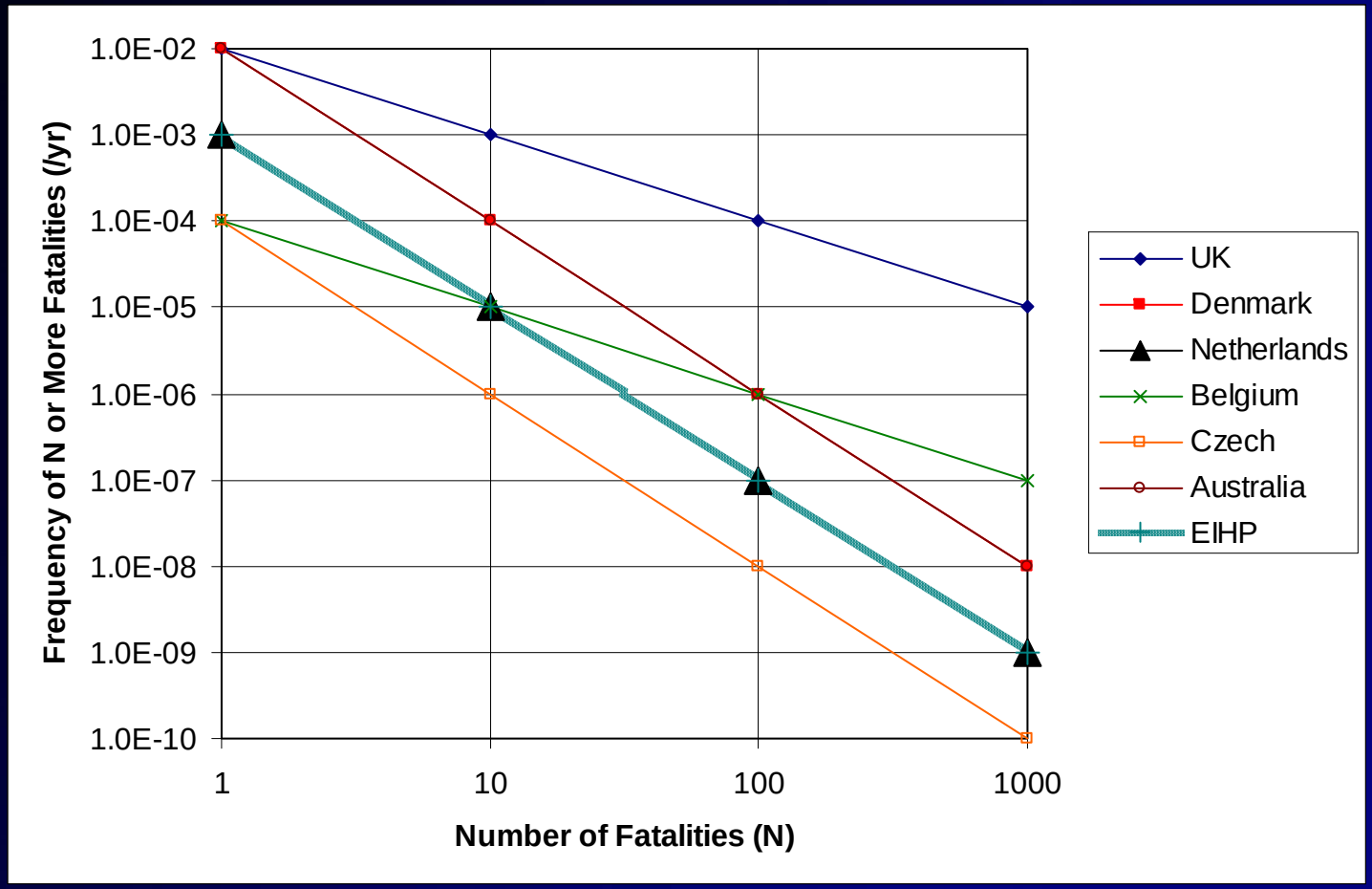
Worker risk (1st Party)

- European Integrated Hydrogen Project – 1×10^{-4}/yr
- United Kingdom – 1×10^{-3}/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 (1st 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 ConocoPhilips Offshore

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

$FAR_{All\ onboard}$ < 10

$FAR_{exposed\ group}$ < 25

Impairment of Main Safety Functions

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

1×10^{-4} per year per type of accidental event

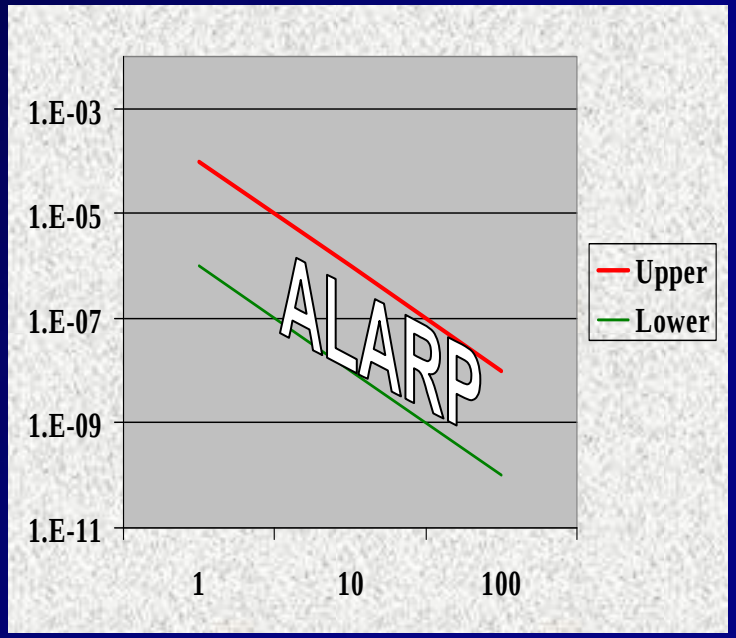
Norwegian Petroleum Directorate guidelines suggest alternatively to use a total frequency of 5×10^{-4}/yr for all accidents for all safety functions

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 < $1x10^{-5}$/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 – $1x10^{-7}$/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 $x10^{-5}$/yr for acceptable risk curve and $1x10^{-7}$/yr for cost-benefit analysis limit curve

Developed by IEA HIA Task 19 experts

Preliminary Guidance on 2nd & 1st Party Risk Criteria

Customer (2nd Party) and Worker Risk (1st Party):

- **Conventional Approach: use traditional frequency of fatality per year (like in individual risk). Suggested acceptable risk for both 2nd and 1st party < $1x10^{-4}$/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 statisitics 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^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
  - 25 kW/m^2 - 100% lethality in 1 minute, injury within 10 seconds
  - 35 to 37.5 kW/m^2 - 1% lethality in 10 seconds

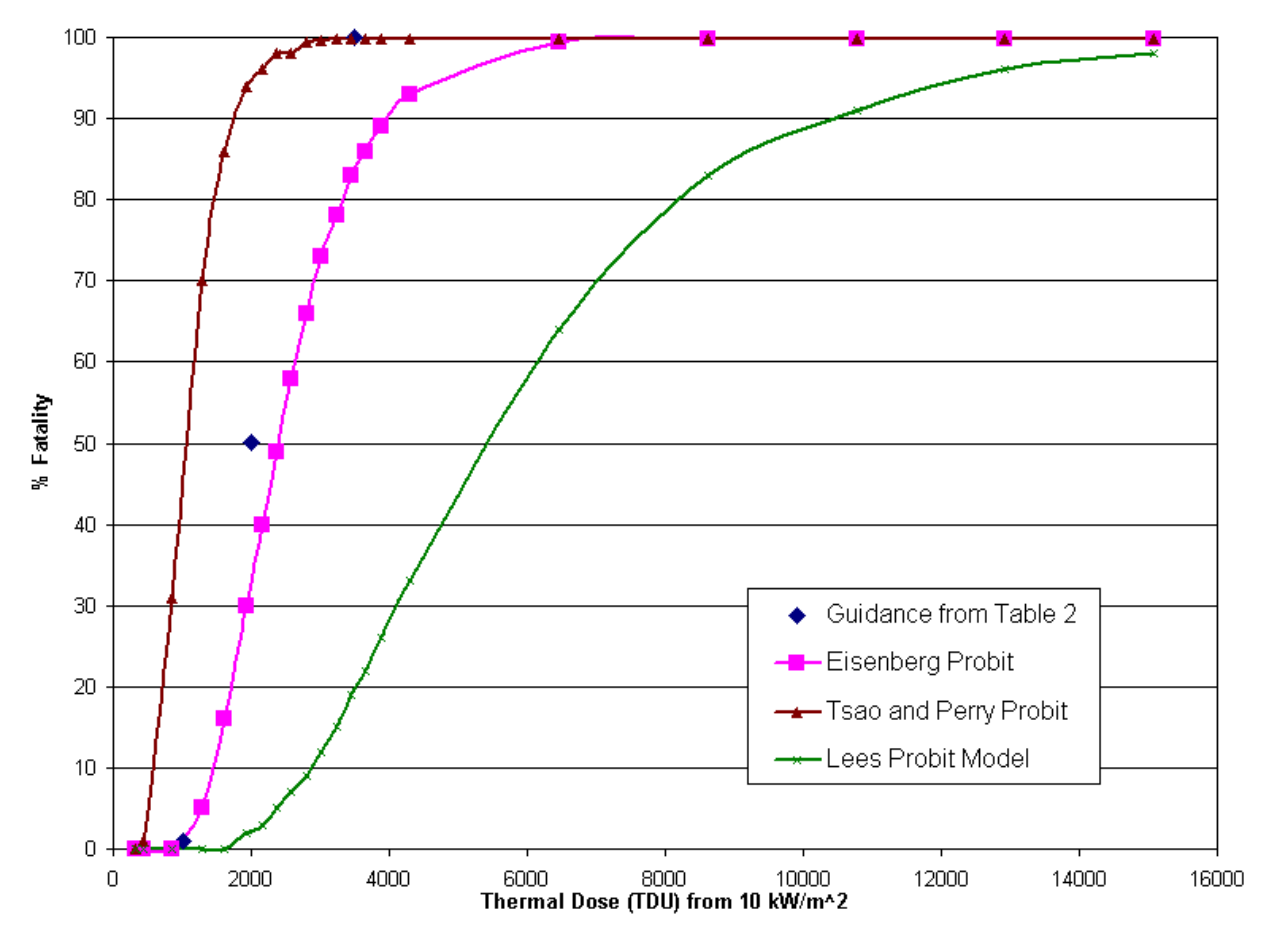
Thermal Dose

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

Harm Caused	Radiation Thermal Dose $(kW/m^2)^{4/3}s$	
	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)

EFFECT	Impairment Criterion	Remarks
Heat load	20 kW/m^2	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_2S	500 ppm H_2S	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.

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Thank You!

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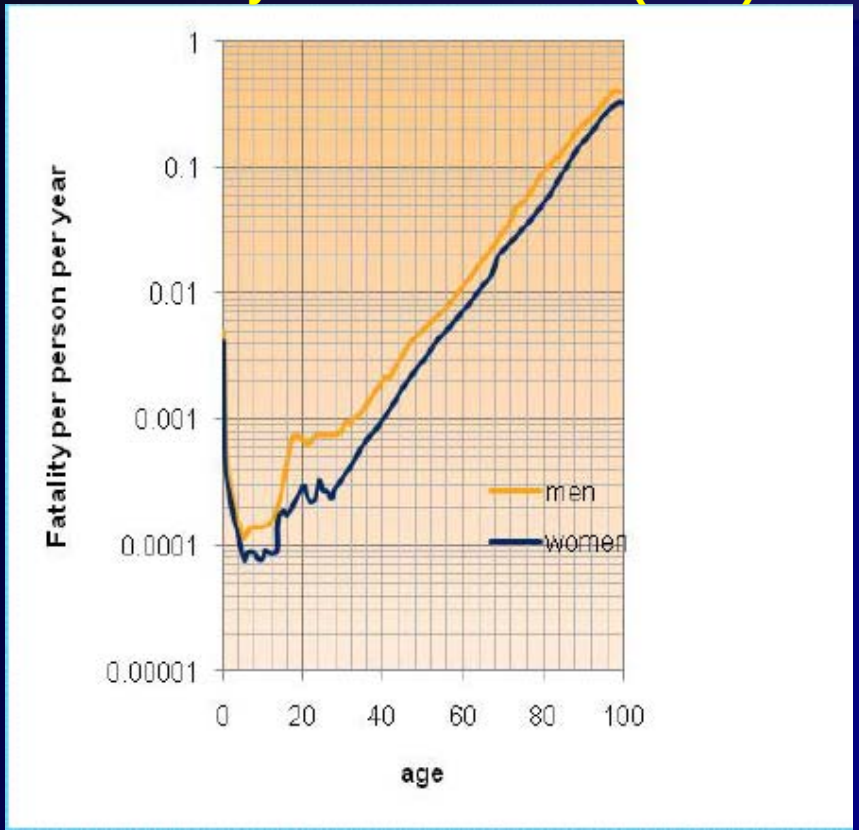
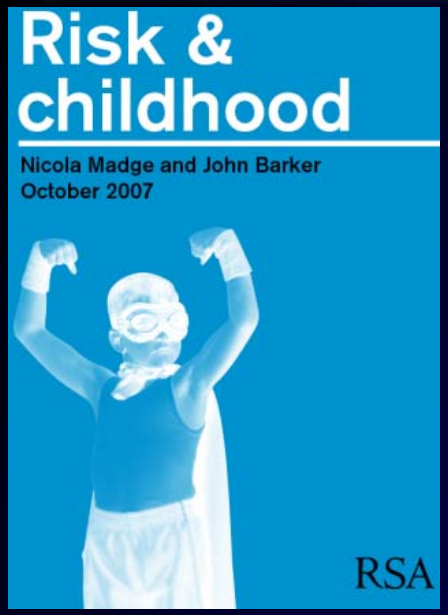
Risk of Fatality in Developed World

Courtesy of Frank Markert (RISO)



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

Estimate of Children's Risk in UK



0.03 per million	children sustain serious injuries in playgrounds each year
less than **one per million**	children are murdered by a stranger each year
6 per million	children each year are abducted by a stranger
17 per million	children under 16 are killed while passengers in vehicles and about 7 per million are killed as pedestrians each year
32 per million	children under the age of 15 die from cancer each year
73 per million	children are murdered every year, mainly by parents
1,500 per million	11 to 18 year-olds were involved in knife crime in London over a four-month period in 2006
2,000 per million	children are diagnosed with cancer before the age of 15
2,400 per million	children under 16 have road accidents every year
5,000 per million	children die before the age of one year
9,000 per million	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
40,000 per million	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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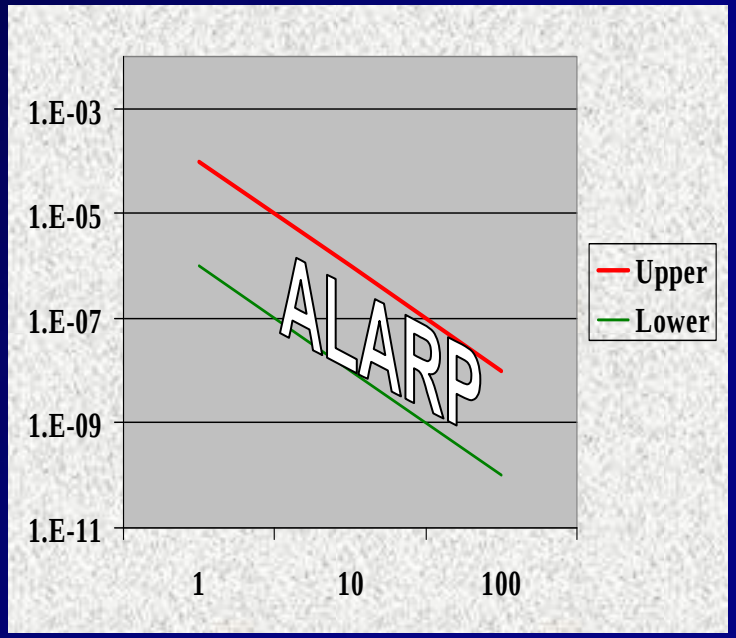

Leading Risk Indicators: Tolerance Limits:
(HRS User Interface project, DNV and StatoilHydro)

- 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)