Risk measure Large Early Release Frequency (LERF)

for Severe Nuclear Accidents

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Introduction

= Chernobyl and Fukushima accidents proved that severe nuclear accidents are not bound to design or regulations, procedures or safety culture typical of the country where they happened

= nuclear accidents should be perceived, treated and analyzed as to be global and thus the need of commonly accepted safety goals or rather risk targets is really urgent

= what is the current situation in definitions/requirements/regulations/limits for nuclear safety … what are they like?... to what extent are they used ?

= what parameters exist ? are they adequate for safety purposes ?

= necessary to understand the context

Introduction cont.

Two lines exist in the field of nuclear safety:

- legislative-administrative – organizatons/legislations (various goals and purposes) – limits, definitions, requirements
- technical

  - practical – NPP operation (design, fuel cycle, INES)

  - theoretical – calculations, analyses, parameters

Legislation/Organizations/Projects

OECD - 1948 – goal: econ. cooperation

- **EURATOM** - 1957 goal: NPP evolution
- **IAEA -** 1957 goal: peaceful use of nuclear energy, nuclear safety
- **WANO** – 1989, operators goal: production + standards/reliability
- **EU:** 1951/58 (6 countries) – origin in ECSC (European Coal and Steel Community + EEC (Europ. Econ. Community - Maastricht -EU official name **1993** (MOTTO EU: United in diversity),

  goal: free movement of people and goods/services/ capital , unification of legislation...

- **EC** (1950 (EEC)/1958/1967**…**

Legislation/Organizations/Projects

cont.

ENEA European Nuc. Energy Agency 1958 >>

>> OECD-NEA (Nuclear Energy Agency) 1972 (+ USA, Jap.)

goal: A*ssist its Member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for the safe, environmentally friendly and economical use of nuclear energy for peaceful purposes*

CSNI - Commitee on the Safety of Nuclear Installations

WGRISK (Working group on Risk Assessment) = have looked at the technology and methods used for identifying contributors to risk and assessing their importance. Work during much of this period was concentrated on Level-1 PSA methodology. In recent years the focus has shifted into more specific PSA methodologies and risk-informed applications.

Legislation/Organizations/Projects

cont.

INSAG/IAEA 1986 goal: safety

WENRA - 1999 - authorities (West European): goal: safety

SARNET – projects EC for consolidation of integration of European research capacities for severe accidents (FP6 2004-2008, FP7 2009-2013)

goal: to reduce uncertainties and to improve safety

coordination of research resources in Europe

research data preservation and knowledge dissemination and promotion

result: NO HARMONIZATION OF PRACTICES IN SEVERE ACCIDENTS ANALYSES

ENSREG (European Nuclear Safety Regulators Group – 2007)

goal: safety (stress tests after the Fukushima - 2011)

result: "…*national regulators have different approaches to safety and use varying criteria to define safety improvements*." and also "…*there is no consistency in the handling of safety margins across nuclear power plants in Europe*."

ASAMPSA2 – 2008 – 2012 (SARNET continuation)

goal: summarization of needs of current PSAL2 users – designers, authorities, analysts

summary of practices for PSAL2 development

contribution to harmonization of practices for better credibility of analyses

Best-Practice Guidelines for L2 PSA development and applications was prepared, Volume 1,2,3, Advanced Safety ASSESSMENT methodologies: Level 2 PSA, Contract 211594

Legislation/Organizations/Projects
cont.

USA:

The Reactor Safeguard Committee of the Atomic Energy Commission – 1947, first philosophy of nuclear safety (SIR) – idea of geographic isolation

U.S. Atomic Energy Commission

assessment of the largest assumed accident (ATWS, LOCA)

- 1957 **WASH-740**: 3 400 deaths; 43,000 injuries, 7 E9 USD damage

- 1964-65 (JE ZION): 200 000 deaths, 400 000 injuries, 17 E9 USD damage

US NRC

- 1975 **WASH-1400 –** accident development analysis including potential consequences, method PRA (risk assessment) – fault tree and event tree, total core melt assessment: 1/20000 Ry

- 1991 – **NUREG-1150 – identification of shortcomings in consequence analyses** based on Cs137, use of knowledge about TMI2 accident in 1979

- specific studies for NPP ZION and Indian Point

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Legislation/Organizations/Projects
CONCLUSIONS

Globality, harmonization:

- **From [13], 1996: *Finally, the image of nuclear safety is international; a serious accident anywhere affects the public's view of nuclear power everywhere.***
- ***…the means for ensuring the safety of nuclear power plants have improved over the years, and it is believed that commonly shared principles for ensuring a very high level of safety can now be stated for all nuclear power plants;***
- ***The international consequences of the Chernobyl accident in 1986 have underlined the need for <u>common</u> safety principles for all countries and all types of nuclear power plants.***
- ***The comparison of risks due to nuclear plants with <u>other industrial risks</u> to which people and the environment are exposed makes it necessary to use calculational models in <u>risk</u> analysis. To make full use of these techniques and to support implementation of this general nuclear safety objective, it is important that <u>quantitative targets</u>, 'safety goals', be formulated.***

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Legislation/Organizations/Projects

CONCLUSIONS Cont.

- ***The acceptance criteria should be defined for the deterministic assessment and the PSA. These normally reflect the criteria used by the designers or operators and are consistent with the requirements of the regulatory body.***
- ***The criteria should be sufficient to meet***

  General nuclear safety objective

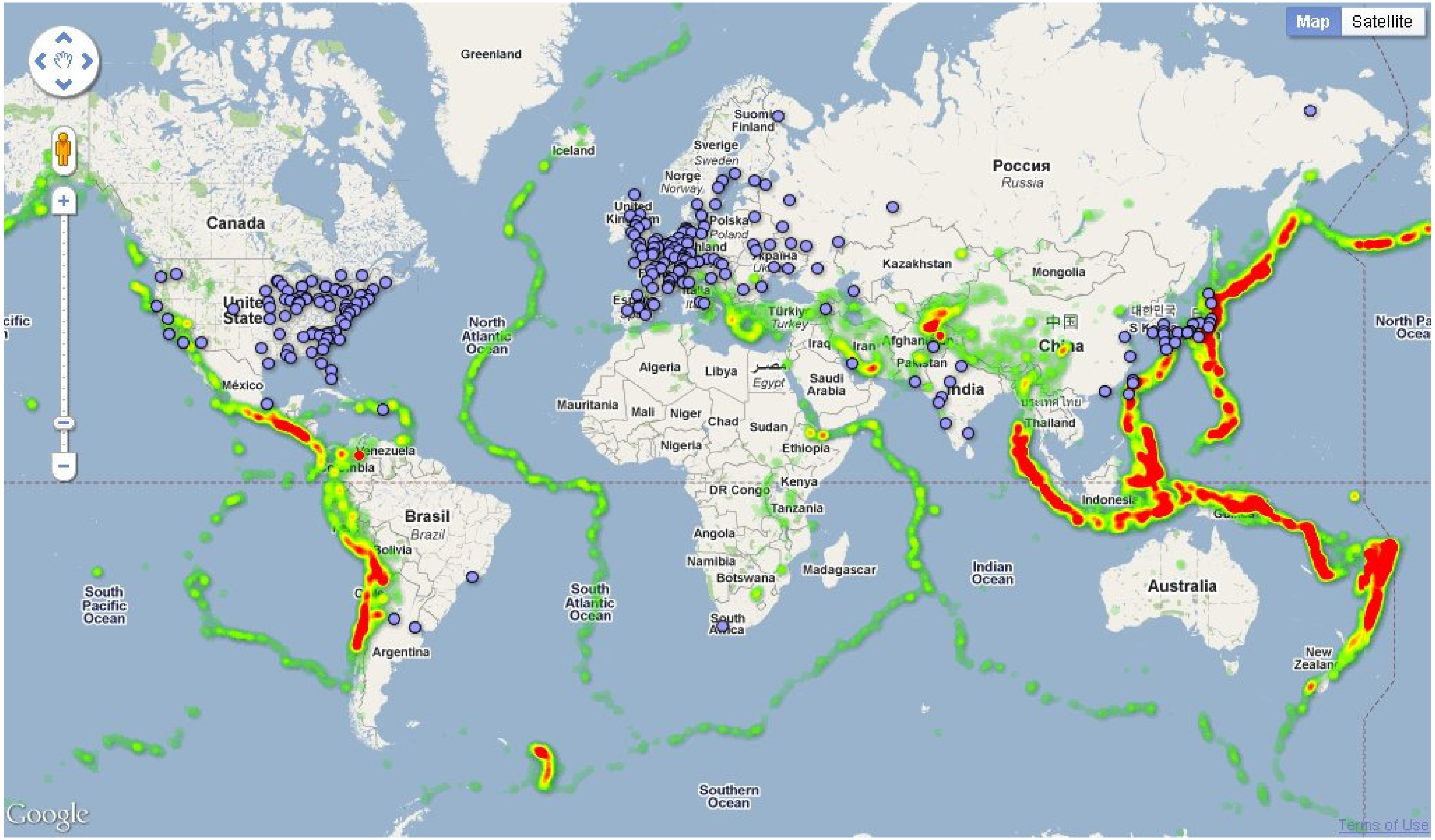
  Radiation protection objective

  Technical safety objective
- **Stress tests: Peer review [29, April/July 2012]: "…*national regulators have different approaches to safety and use varying criteria to define safety improvements.*" and also *"…there is no consistency in the handling of safety margins across nuclear power plants in Europe*."** .

Legislation/Organisations
Basic literature

- *[13] INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP, Defence in Depth in Nuclear Safety, INSAG-10, IAEA, Vienna, 1996.*
- *[1] BASIC SAFETY PRINCIPLES FOR NUCLEAR POWER PLANTS 75-INSAG-3 Rev. 1, INSAG-12, A report by the International Nuclear Safety Advisory Group, 1999*
- *3 Safety objectives*
- *SARNET WP5.1: Status of practices and Guidelines in the EC Level 2 PSA: is harmonization of practices possible in the EC, SARNET-PSA2-D75, TM-42-06-29, November 2006*
- *[2] IAEA Safety Standards for protecting people and the environment, Fundamental Safety Principles, Safety Fundamentals No. SF-1, IAEA, 2006, ISBN 92-0-110706-4, ISSN 1020-525X, Vienna*
- *10 Safety Principles*
- *EC Directive 2009 - [8] Community Framework for the nuclear safety of nuclear installations, Council Directive of The European Union 10667/09, Council of Brussels, 23 June 2009*
- *[29] Peer review report, Stress tests peformed on European nuclear power plants, Stress Test Peer review Board, v12i-2012 04 25, April 2012 .*

Technical line/NPP operation



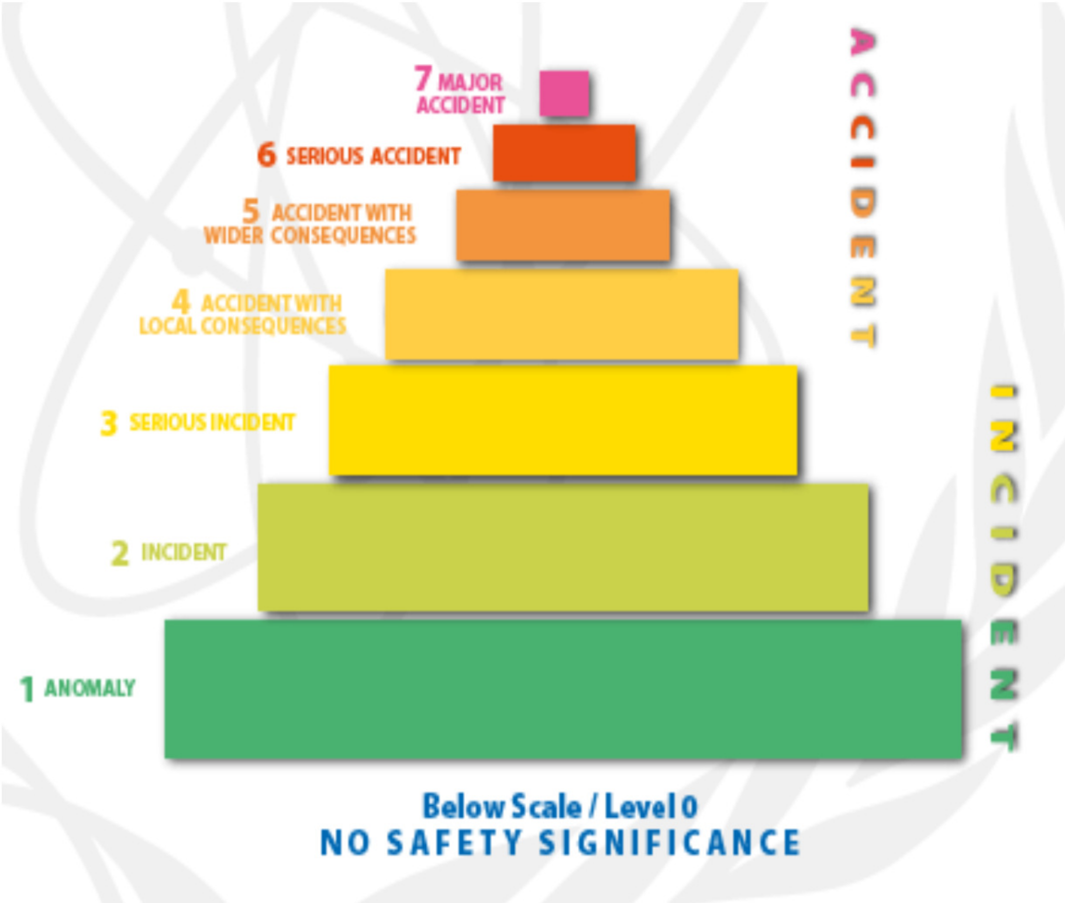
Technical line/NPP operation cont.

- As of March 1, 2011, there were 443 operating nuclear power reactors spread across the planet in 47 different countries, with total 14,500 reactor years of operation
- [123] World Nuclear Association, *www.world-nuclear.org*

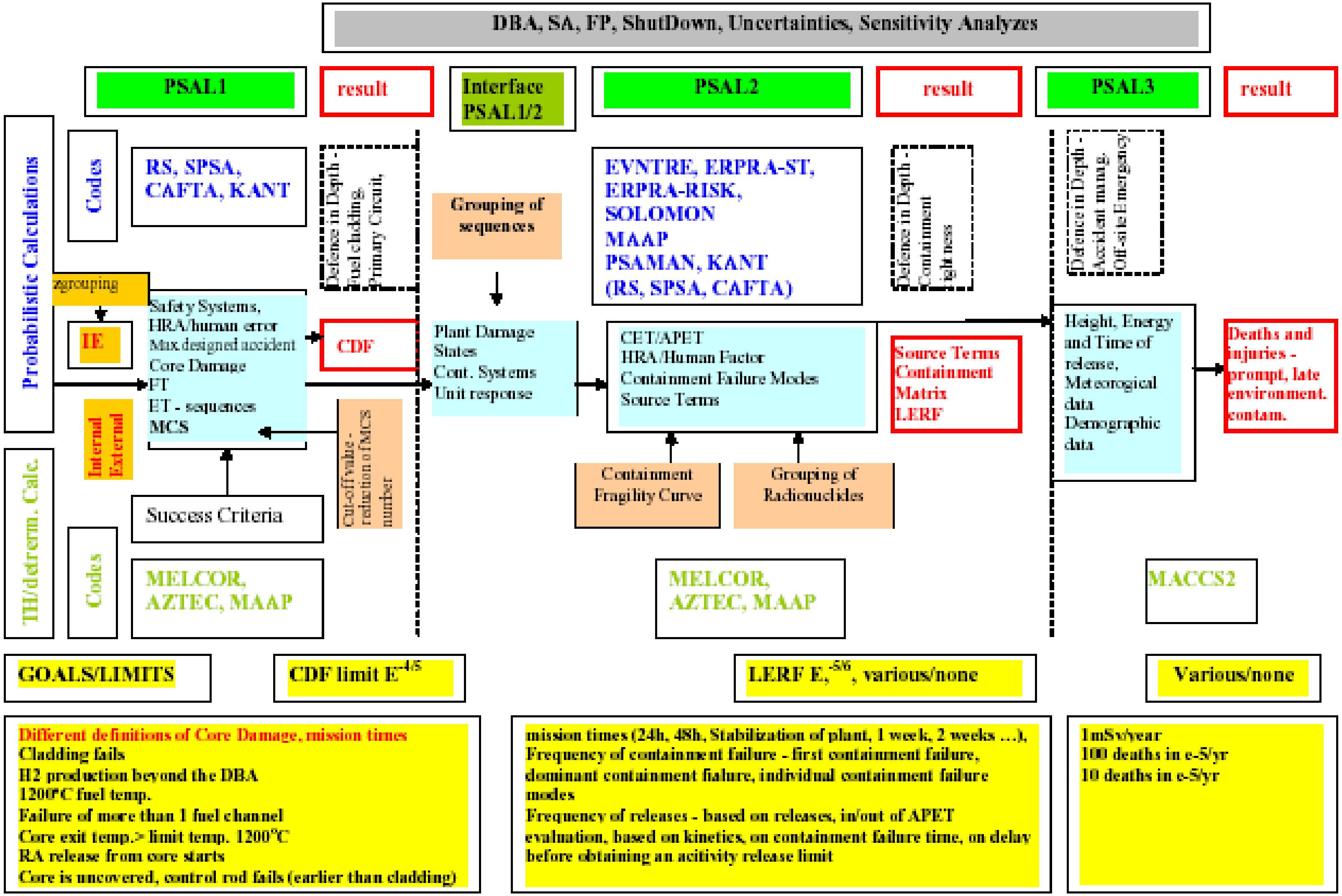
- *Average age/operation of current NPPs:*

  cca 32 years
- *Trend: operation extention, power increase*

Technical line/Operation/INES



Technical line/Analyses



Technical line/Analyses cont.

The most widely used parameters:

- **CDF = E-4/Ry**
- **LERF=E-5/Ry >>> severe accidents – related to consequences (release)**

- **Indirectly: LERF ~~ max. 10% CDF**

Technical line/Analyses cont.

Goal of PSA:

- *Probabilistic Safety Assessment is a comprehensive, structured approach identifying failure scenarios, constituting a conceptual and mathematical tool for deriving **numerical estimates of <u>risk</u>** [1].*
- *Probabilistic analysis is used to evaluate the likelihood of any particular sequence and its consequences. This evaluation may take into account the effects of mitigation measures inside and outside the plant**. Probabilistic analysis is used to estimate <u>risk</u>** and especially to identify the importance of any possible weakness in design or operation or during potential accident sequences that contribute to risk. [1]*
- *The PSA should set out to determine **all significant contributors to <u>risk</u>** from the plant [2].*
- *PSA should address the **contributions to <u>risk</u> arising from all the modes of operation** of the plant. [2]*
- ***<u>risk associated with an accident or an event is defined as the arithmetic product</u> of the probability of that accident or event and the adverse effect it would produce.***

Technical line/Analyses cont.

1. **Diversity of PSAL2 results**

- - Frequency of containment failure - first containment failure, dominant containment failure mode.
- - Individual containment failure modes
- - **Frequency of releases** - based on releases, in/out of APET evaluation, based on kinetics, on containment failure time, on delay before obtaining an activity release limit; this category covers **L(E)RF.**
- - Containment matrix (probability of containment failure modes as a function of accident initial conditions).

This means that the results - showing different phenomena or parameters - are usually not comparable within the cross-checking and thus the consistency and comparability of the results of different PSA L2 studies cannot be ensured.

Technical line/Analyses cont.

2. **Diversity of limits/parameters in particular countries (Holmberg,OECD, 2009)**

= land contamination - Canada,

= longterm health effects (Fi, Sw)

= containment failure frequency (Jap.)

= any countermeasures should be prevented (Germany)

= any release produces 1 death at the site boundary >> no NPP operation (Netherland)

= no criteria (France)

…..

= release frequency (L(E)RF)

Technical line/Analyses/LERF cont.

3. Diversity of criteria

Country	Metric	INES	equivalent		consequences				
			I_{131} [TBq]	Cs_{137} [TBq]	Early Fatalities (distance in km)	Early injuries	Late cancer fatalities	Permanent or temporary loss of Land (km^2)	Number of person relocated temporarily or permanently
US + others	**LERF** (Minimize early cont. failure, cont. bypass, isolation failure, SGTR)	7	$20e^4$ to $> 100\ e^4$	$2e^4$ to $> 10\ e^4$	0 to > 2 (0.2 to > 5)	2 to > 300	8,700 to > 18,000	800 to > 20,000	57,000 to > 2,000,000
Canada	**Limit** 1% of Cs_{137} **core inventory**								
UK	**Limit**, 10,000 TBq I_{131}	6	$1\ e^4$	$< 0.1\ e^4$	0 (0.1)	1	900	1,000	37,000
	Objective, 200 TBq Cs_{137}	6	$0.2\ e^4$	200	0 (0)	0	180	200	8,000
Sweden	0.1 % of **core inventory**	5-6	$> 0.1\ e^4$	> 100	0 (0)	0	150	>100	> 5,000
Finland	**Limit** 100 TBq Cs_{137}	5-6	$> 0.1\ e^4$	100	0 (0)	0	< 100	100	4,000
Canada	**Objective** (new plants) 100 TBq Cs_{137}								
		5 lower limit	**200**	**20**	**0**	**0**	**20**	**< 20**	**<< 800**

Technical line/Analyses/LERF

4. Diversity of parameters/values of LERF

Country	Organisation	Risk metric	Frequency	
UK	Regulator	10^4 TBq I_{131}, or 200 Tbq Cs_{137} or other isotopes	10^{-5} /yr 10^{-7} /yr	Limit Objective
Taiwan	Licensee	Not defined	10^{-6} /yr	Objective
Sweden	Licensee	>0.1% of core inventory	10^{-7} /yr	Objective This is a criteria or safety goal established by the licensees, for L(E)RF from level 2 PSA:s.
Slovak Rep	Regulator	Not defined	10^{-5} /yr	Limit
Japan	Regulator	Containment failure	10^{-5} /yr	Objective
France	Regulator	Unacceptable consequences	10^{-6} /yr	Objective
France/ Germany	Designer of EPR	Not defined	Neg [2]	Objective
Finland	Regulator	100 TBq Cs_{137}	$5x10^{-7}$ /yr	Objective
Czech Rep	Licensee	Not defined	10^{-5} /yr 10^{-6} /yr	Objective for existing plants Objective for new plants
Canada	Licensee	>1% Cs_{137} >1% Cs_{137} 100 TBq Cs_{137}	10^{-5} /yr 10^{-6} /yr 10^{-6} /yr	Limit for existing plants Objective for existing plants Objective for new plants

[1] This numerical safety criterion was defined in the Safety Assessment Principles published in 1992 but does not appear in the revised version of the document published in 2006.

[2] The aim is that the sequences that lead to a large early release should be "practically eliminated".

Technical line/Analyses/LERF cont.

5. Ambiguity of LERF

- **“Early”:**
- - Time frame prior to effective evacuation/ before the effective implementation of off-site emergency and protective measures - e.g. 24 hours
- - Before 12 hours from initiator event
- - 2 hours after vessel failure
- - Within the first 10 hours
- - Release of iodine equivalent (percentage limit) within 5 to 10 hours
- - Before vessel failure

Technical line/Analyses/LERF cont.

- **“Large”:**
- The boundary condition for PSAL2 regarding Large Release which is used in most analyses is interpreted in different countries and by different users differently. Usual limits for “large” are ([44], [45]):
- - Higher than 3% volatile emissions
- - Release requiring public evacuation
- - “Immediate” health effects in the vicinity of the plant
- - Atmospheric release of Cs137 or equivalent, 100 TBq
- - No acute deaths in the vicinity of the plant
- - All release categories with a source term equal or above 10% of the core inventory
- - 1 to 10% of inventory of I131 as a threshold for prompt fatalities
- - 0.1% of Cs137 in the core releases to the environment
- - Source term of all release categories > 10% of core inventory
- - 5-10% of radioiodines
- - Release of iodine - 10% of core inventory of a large reactor is assumed as threshold for prompt fatalities

Technical line/Analyses/LERF
cont.

According to IAEA definition the presence of a source in the vicinity of a person (target) could potentially, in the absence of measures for safety and protection, give rise to exposure of the target to radiation.

Holmberg, OECD, 2009/ASAMPSA2, 2010:

- **LERF is based on protecting the public against prompt fatalities and radiological-induced cancers.**
- **The LERF criterion is based on the time being sufficient for public evacuation before a significant release occur.**

Technical line/Analyses/LERF

cont.

- **6. Parameter LERF <u>not defined for safety purposes</u>**

IAEA definition:

- **Safety involves the prevention or reduction of potential exposure and other risks for the minimization of danger = Ø**

- **Radiation protection involves the prevention or reduction of radiation exposure for the <u>protection of health</u>. = LERF (evacuation)**

Technical line/Analyses/LERF

cont.

7. LERF is not RISK parameter, but ONLY frequency (consequences are missing)

IAEA:

Probabilistic Safety Assessment is a comprehensive, structured approach identifying failure scenarios, constituting a conceptual and mathematical tool for deriving ***numerical estimates of risk*** *[1].*

General nuclear safety objective *[1] corresponds to SF-1 Safety Objective [2]:*

- *To protect individuals, society and the environment by establishing and maintaining in nuclear power plants an effective defence against radiological hazard. In the statement of the general nuclear safety objective, radiological hazard means adverse health effects of radiation on both plant workers and the public and radioactive contamination of land, air, water or food products. The protection system is effective as stated in the objective if it prevents significant addition either to the risk to health or to the risk of other damage to which individuals, society and the environment are exposed as a consequence of industrial activity already accepted. In this application,* ***the risk associated with an accident or an event is defined as the arithmetic product of the probability of that accident or event and the adverse effect it would produce.***

Technical line/Analyses/LERF
cont.

- **8. Numerical value of LERF E-5/Ry is ONLY PRESET, NOT DERIVED, its origin is not fully clear**

  The Role of Probabilistic Safety Assessment and Probabilistic Safety Criteria in Nuclear Power Plant Safety, Safety Series No. 108, Safety Reports, IAEA, Vienna, 1992:

- A large off-site release of radionuclides can have severe societal consequences
- There is at present (*comment: 1992*) **no international consensus on the most appropriate measure of what constitutes a large off-site release**. However, Member States should give serious consideration to establishing their position on a criterion for large off-site release.
- . A large off-site release is defined as one that has severe social implication. **Until such time as an international consensus has been reached, it is suggested that the target frequency for a large off-site release should be 10-6/Ry**

Technical line/Analyses/LERF
cont.

But in the IAEA source from 2001 is stated:

IAEA SAFETY STANDARDS SERIES, Safety Assessment and Verification for Nuclear Power plants, Safety Guide No.NS-G-1.2, IAEA, Vienna, 2001:

- **The acceptance criteria for severe accidents are usually formulated in terms of risk criteria (probabilistic safety criteria).**
- ***Large off-site release of radioactive material:* A large release of radioactive material, which would have severe implications for society and would require the offsite emergency arrangements to be implemented, can be specified in a number of ways including the following:**
- **—As absolute quantities (in Bq) of the most significant nuclides released,**
- **—As a fraction of the inventory of the core,**
- **—As a specified dose to the most exposed person off the site,**
- **—As a release giving ‘unacceptable consequences’.**
- **4.229. Probabilistic safety criteria have also been proposed by INSAG for a large**
- **radioactive release [4]. The following objectives are given:**
- **—10–5 per reactor-year for existing plants,**
- **—10–6 per reactor-year for future plants**

Technical line/Analyses/LERF
cont.

9. LERF focuses ONLY on EARLY consequences/acute fatalities

- Developed for evacuation purposes to provide radiation protection AFTER the accident
- Early/immediate consequences are **the least sensitive part of consequences** – as finally show Chernobyl and Fukushima accidents (in fact no immediate fatalities were reported)

- NOTE:
- Early consequences are considered within hours, days, weeks – up to one-two months, not more

- BUT: **substantial are LONGTERM CONSEQUENCES, MOREOVER NOT ONLY DEATHS !**

Technical line/Analyses/Consequences MACCS2

Table 6. Assessment of Absolute Consequences and Risks per Accident [51]

Releases		Absolute Consequences			Risks per Accident			
					Acute within 10 km	Excess Deaths		
								GLOBAL
INES	I131 equiv. [Bq]	Acute Fatalities	Lifetime Excess Deaths	Lost Land [km2]		within 10 km	within 40km	Excess death for > E^8 population (within 1600 km)
4	< 200	0	0-100	0 - 5	< $1E^{-4}$	< $1E^{-4}$	< $1E^{-4}$	< $1E^{-5}$
5	200-2000	0	100 - 1000	5 - 100	$1E^{-4}$ - $1E^{-3}$	$1E^{-4}$ - $1E^{-3}$	$1E^{-4}$ - $1E^{-3}$	$1E^{-5}$ - $1E^{-4}$
6	2000-20000	0-1	1000 - 10000	100 - 500	$1E^{3}$ - $5E^{-3}$	$1E^{-3}$ - $5E^{-3}$	$1E^{-3}$ - $5E^{-3}$	$1E^{-4}$ - $5E^{-4}$
7 ("Large")	> 20000	0-100	10000 - > 1000000	500 - > 10000	$5E^{3}$ - $5E^{-2}$	$5E^{-3}$ - $5E^{-2}$	$1E^{-3}$ - $5E^{-2}$	$5E^{-4}$ - $2E^{-2}$

Technical line/Analyses/Risk

$$R_{TOT} = R_{Min} + R_{Manuf} + R_{Reprocess} + R_{Trans} + \boxed{\mathbf{R_{NormOp} + R_{DBA} + R_{SA}}} + R_{Decom} + R_{Disposal} \qquad (1)$$

$$R_{OP} = \mathbf{R_{NormOp}} + \mathbf{R_{DBA}} + \mathbf{R_{SA}} \qquad (2)$$

$R_{Incidents}$ $R_{Releases}$ R_{Waste}

$$R_{OP} = \mathbf{\Sigma_m (R_{m\ NormOp} + R_{m\ DBA} + R_{m\ SA})} \qquad (3)$$

Where *m* is number of units on the site

Technical line/Analyses/Risk cont.

ALL the above listed risks consist of the four elements: individual, societal, environmental and cost-related; thus SA risks can be expressed as follows:

$$R_{SA} = R_{indiv} + R_{soc} + R_{enviro} + R_{costs} \qquad (3)$$

Acute deaths	**Lifetime deaths**	Loss of non-agricult.	Lost production
		Loss of waters	Repair
Acute injuries	Lifetime hospit.	Loss/injury terrest.eco.	Clean-up
Loss of property	Condemned area	Loss/injury water eco.	Actuarial deaths
Loss of employment	Interdicted area	Loss/injury aerial eco.	Actuarial injuries
	Crop disposal		
	Milk disposal		

LERF

Industrial risk,

Common Risk Target (to be comparable to industrial risk)

Common Risk Target (minimizing risks)

Technical line/Analyses/Risk cont.

= **GOAL: to make consistent legislative (requirements) and technical lines**

To find <u>objective universal quantitative common risk target</u> with technical basis stemming from existing and accepted definitions and practices using <u>graded approach</u> based on INES scale <u>minimizing releases/consequences</u> for evaluation of common safety risk limit for severe accidents of NPPs representing <u>no significant risk contribution</u> to the risks stemming from other industrial activities taking into account globality of the nuclear safety issue.

- **Discussion on current defence-in-depth philosophy should be presented followed by risk-benefit rough analysis to discuss the IAEA Safety Principle 4 *"<u>Facilities and activities that give rise to radiation risks must yield an overall benefit</u>"*.**

CONCLUSIONS

1. ORIGINAL IDEA

PSAL2	=	INES	=	consequences	(tab.6)
theoret.		Real accid.		theoret.	
				real longterm statist. - Chernobyl	

2. ORIGINAL IDEA OF COMMON RISK TARGET

CRT = f x c	=	postulates, definitions, requirements
tech.		legis.

Put into real life and practical use <u>existing definitions and requirements</u> in documentation

- **Safety involves the prevention or reduction of potential exposure** and other risks **(for the <u>minimization of danger</u>). <u>MISSING!!</u> CRT**
- **Radiation protection involves the prevention or reduction of radiation exposure (for the protection of health). (LERF)**

3. ADVANTAGE: PSAL3 would not be necessary

CONCLUSIONS cont.

In the proposed Risk Target concept I try to join my professional experience of PSA analyst as well as expert for operational event evaluation where I use the IAEA INES scale. The concept starts from the constant risk approach and its quantitative value should then compared with commonly used definitions of acceptable and tolerable risk levels.

The basic concept of Common Risk Taget (CRT) I first developed within the European Project ASAMPSA2 and it is described in **Chapter 6 of ASAMPSA2 Best Practice PSA L2 Guidelines – highest level document for performing PSAL2 analyses**.

The basic concept **was accepted as a good basis for common measure of severity of nuclear accidents by majority of participating PSA L2 European experts and other independent world experts.**

Currently I have developed the final version of CRT.

CONCLUSIONS cont.

- Substantial is to see things and phenomena in CONTEXT (legislative and technical lines of safety)

- SAFE OPERATION OF NPPs SHOULD BE OF OUR PROFESSIONAL PRIORITY, THUS THE ADEQUATE LIMIT/TARGET IS URGENTLY NECESSARY!