Application of the General Framework of Safety Goals for Nuclear Installations to Sweden

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Lloyd's Register
LIFE MATTERS

Overview

- Background and short History of Safety Goals in Sweden
- Application of the Framework
  - Top Level / Primary Safety Goal
  - Upper level / Adequate Protection
  - Intermediate level / General Safety Provision
  - Low level / Specific Safety Provision
- Conclusions

NB! The talk does not present the opinions of the Swedish Radiation Safety Authority nor of the Swedish utilities mentioned and is based on my own interpretation of information obtained.

Input from Wiktor Frid (Swedish Radiation Safety Authority) and
Lars Erik Svenssom (Lloyd's Register Consulting)
is gratefully acknowledged

Nordic background

Nordic project "The Validity of Safety Goals"

NKS (Nordic Nuclear Safety Research)

NPSAG (Nordic PSA Group)

SAFIR (Finnish NPP safety research programme)

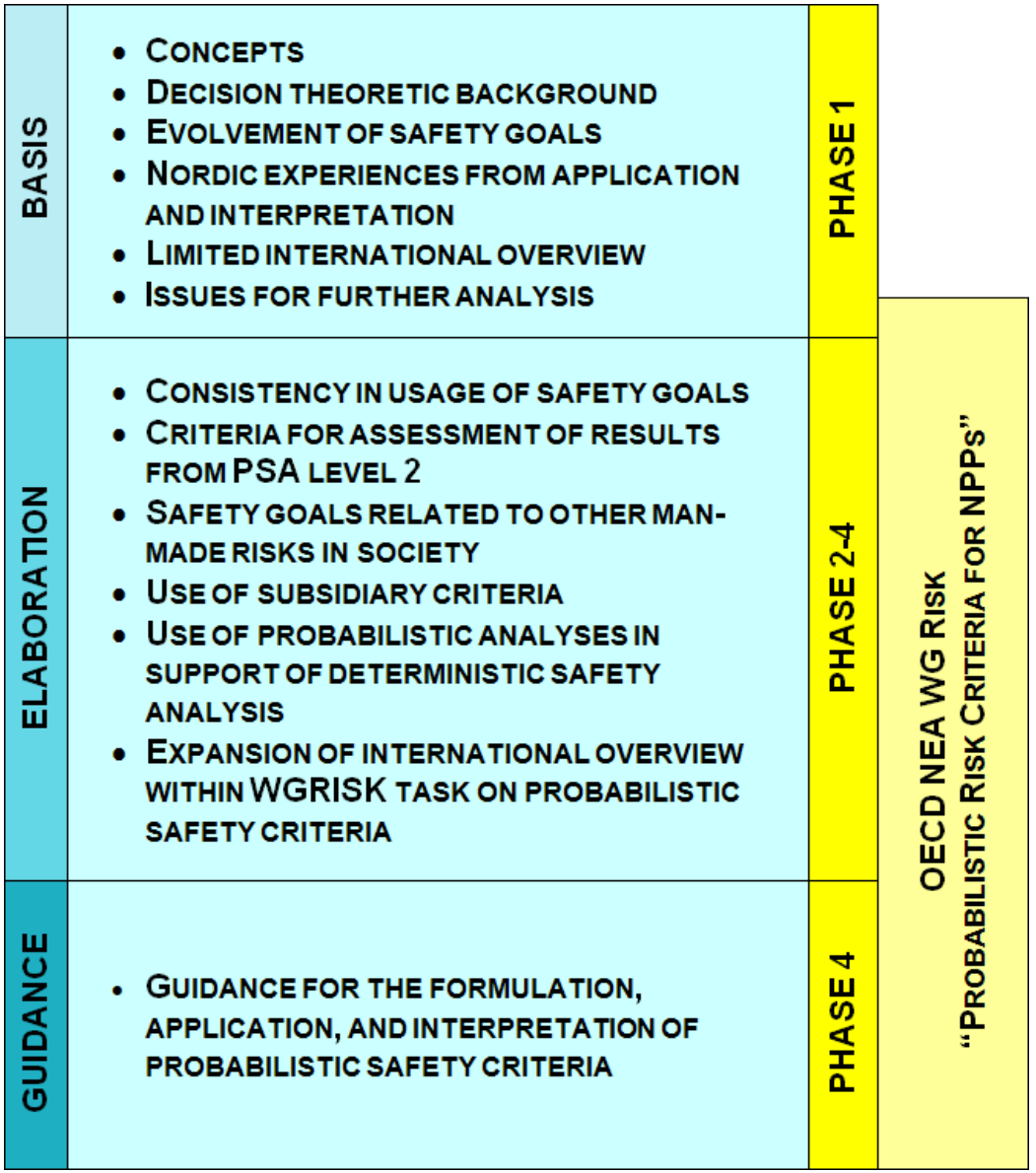
Co-operation with OECD/NEA WGRisk task 2006(2)

2006

2007

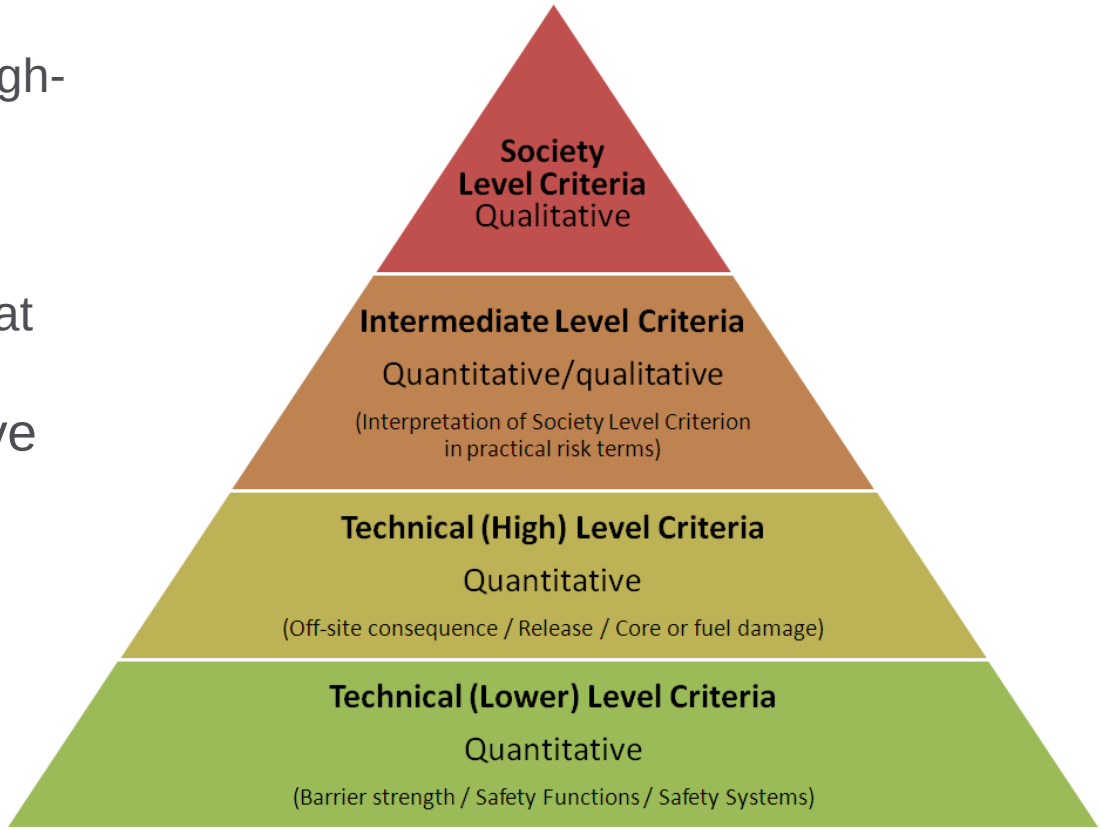
2008

2009



Hierarchy proposed in Nordic PSA Group project

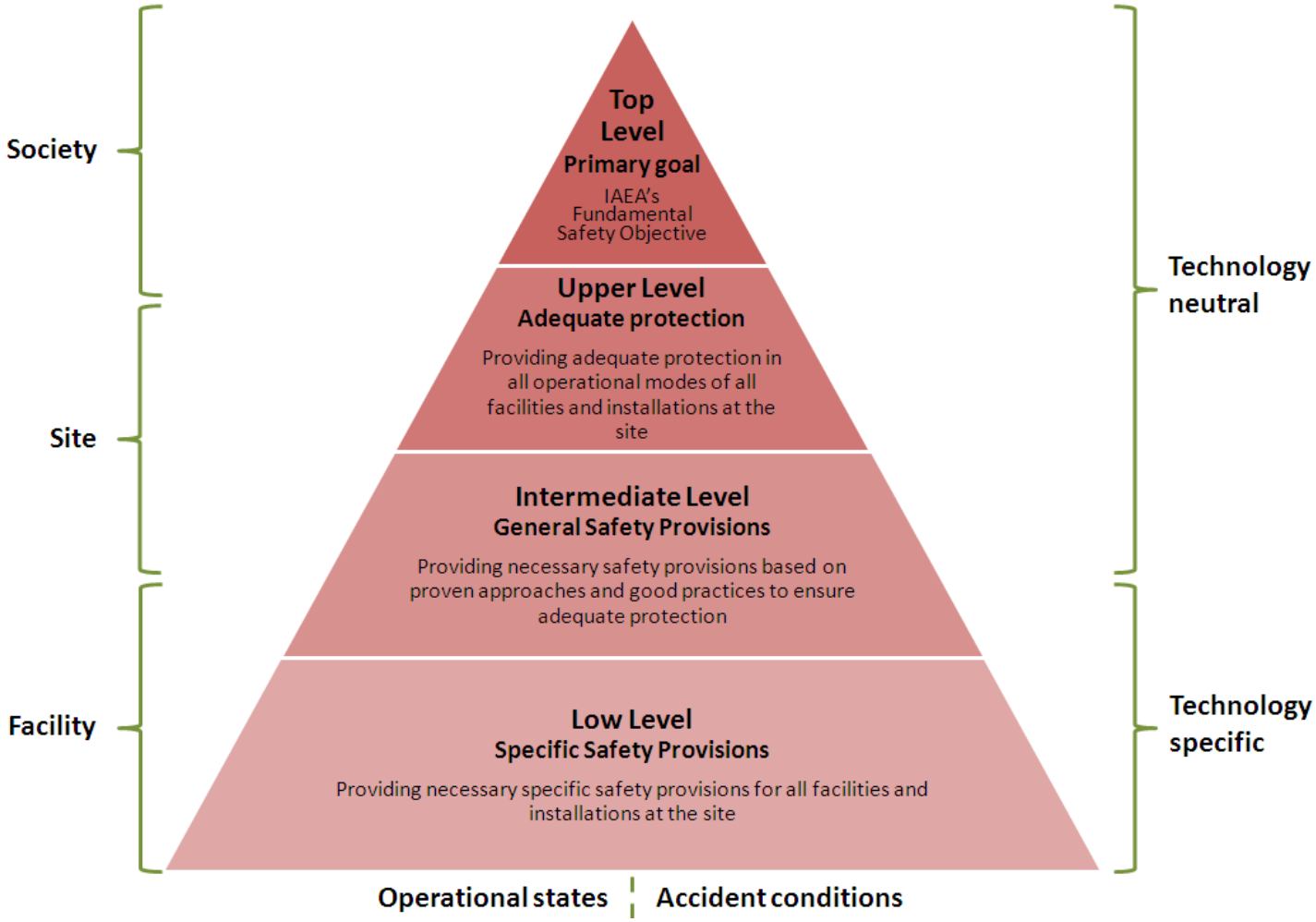
- Society level
  - Legislation expressing high-level requirements
- Intermediate level
  - Interpretation of legal requirements in a way that allows quantification
- Technical level (quantitative requirements); two parts
  - High level
    - Corresponding to PSA Level 1, 2 and 3
  - Lower level
    - corresponding to safety systems and functions



Background – Swedish Radiation Safety Authority (SSM)

- The Swedish regulatory tradition is largely non-prescriptive
  - High-level requirements given
  - Way to fulfil left to licensees
  - Aim of inspections to maintain confidence in fulfilment
- There are no SSM safety goals (probabilistic)
  - Safety goals defined by utilities are implicitly accepted
- There are high-level requirements on how to do PSA
  - High-level requirements given in connection first two PSR:s (mid 80s and mid 90s)
  - The PSA Review Handbook issued by SSM in 2003 [SKI_2003:48] indirectly describes expectations on PSA
    - Focus on organisation, good practice, regular updates, and keeping up to date with state-of the art.
    - Stressing of infrastructure required for high quality PSA activities
- Regulations issued within SSM areas of authority
  - Relate to “Higher Level” and “Intermediate Level” in TECDOC structure
  - Major updates and extensions are ongoing as part of preparation for licensing of new NPP:s in Sweden

Application of TECDOC Hierarchy of Safety Goals

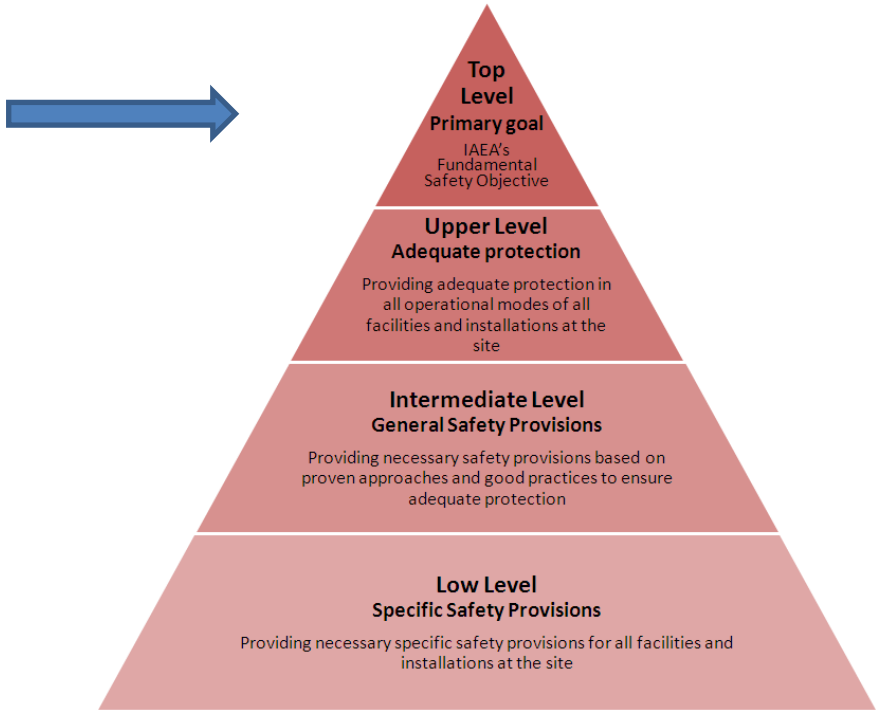


The example matrix (from TECDOC)

TOP LEVEL - PRIMARY SAFETY GOAL: *To protect people and the environment from harmful effects of ionizing radiation*											
UPPER LEVEL SAFETY GOALS: *Ensuring adequate protection in all operational modes of all facilities and installations at the site*											
Operational states					**Accident conditions**						
O1 To protect workers, the public and the environment		**O2** To provide design features for security	**O3** To minimize radioactive waste	**O4** To provide design features to facilitate decommis-sioning	**A1** Risk to life and health of people from the facilities and installations located at the site should be low comparing with risk from other sources to which an individual is generally exposed			**A2** Large off-site releases leading to land interdiction should be practically eliminated		**A3** Safety-security interface should be addressed	**A4** Emergency response should be provided
INTERMEDIATE LEVEL SAFETY GOALS: *Providing necessary safety provisions including technical and organizational measures based on proven approaches and good practices to ensure adequate protection*											
Qualitative **O1-Q1** Management, leadership and safety culture	Deterministic quantitative **O1-D1** To meet ICRP criteria for workers by providing adequate radiation protection measures	...	... ...	...	Qualitative **A1-Q1** Maintaining effective defense-in-depth	Deterministic quantitative **A1-D1** Maintaining allowed doses for workers in DBAs	Probabilistic quantitative **A1-P1** Overall L(E)RF for the site for all events and hazards	Qualitative **A2-Q1** Providing effective SAM design features and SAMG at the site level	Probabilistic quantitative **A2-P1** Probabilistic interpretation of practically eliminated	A3-Q1 Vital area identification at the site level	A4-Q1 Detailed emergency plan
	O1-D2 To meet ICRP criteria for discharges to the environment by providing adequate measures for controlling the discharges				**A1-Q2** Maintaining sufficient safety margins	**A1-D2** Maintaining allowed discharges to the environment in DBAs	**A1-P2** Frequencies of external hazards/ magnitudes for design of site protective features		**A2-P2** Food ban radioactivity levels and accepted frequency		A4-D1 Food ban levels
					A1-Q3 Providing sufficient redundancy and diversity to comply with single failure criterion	**A1-D3** Containment withstanding the crash of a specified size aircraft			**A2-P3** Habitation radioactivity levels and accepted frequency		A4-D2 Habitation radioactivity levels
LOW LEVEL SAFETY GOALS: *Providing necessary specific safety provisions for all facilities and installations at the site*											
					Deterministic quantitative **A1-Q2-INST1(D1)** – max fuel clad temp. for INST1 **A1-Q2-INST1(D2)** – ... for INST1 ---------- **A1-Q2-INST2(D1)** – max fuel clad temp. for INST2 **A1-Q2-INST2(D2)** – ... for INST2		Probabilistic quantitative • LERF for each installation: **A1-P1-INST1(LERF)**, **A1-P1-INST2(LERF)**, • Supplemental goals on CDF as applicable: **A1-P1-INST1(CDF)**, **A1-P1-INST2(CDF)**, ... Instantaneous risk limit	Qualitative **A2-Q1-INST1(SAMG)** **A2-Q1-INST2(SAMG)** Providing effective SAM design measures and SAMG at the facility level		A3-Q1-INST1 A3-Q1-INST12 ... Vital area identification at facility level	
					A1-Q3-INST1 - required three trains of safety systems						

Top Level – Primary Safety Goal

Level	Description
Top Level Primary Safety Goal	Primary safety goal as set out in SF-1 and society level safety goals as defined in national legislation or regulations.



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To protect people and the environment from harmful effects of ionizing radiation

UPPER LEVEL SAFETY GOALS:
Ensuring adequate protection in all operational modes of all facilities and installations at the site

Operational states				Accident conditions						
O1 To protect workers, the public and the environment	**O2** To provide design features for security	**O3** To minimize radioactive waste	**O4** To provide design features to facilitate decommis-	**A1** Risk to life and health of people from the facilities and installa… located at the site should be low compar… sources to which…						
					allowed doses for workers in DBAs	for the site for all events and hazards	**A2-Q1** Providing effective SAM design features and SAMG at the site level	Probabilistic quantitative **A2-P1** Probabilistic interpretation of practically eliminated	A3-Q1 Vital area identification at the site level	A4-Q1 Detailed emergency plan
	O1-D2 To meet ICRP criteria for discharges to the environment by providing adequate measures for controlling the discharges			**A1-Q2** Maintaining sufficient safety margins	**A1-D2** Maintaining allowed discharges to the environment in DBAs	**A1-P2** Frequencies of external hazards/ magnitudes for design of site protective features		**A2-P2** Food ban radioactivity levels and accepted frequency		A4-D1 Food ban levels
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LOW LEVEL SAFETY GOALS:
Providing necessary specific safety provisions for all facilities and installations at the site

				Deterministic quantitative **A1-Q2-INST1(D1)** – max fuel clad temp. for INST1 **A1-Q2-INST1(D2)** – … for INST1 ---------- **A1-Q2-INST2(D1)** – max fuel clad temp. for INST2 **A1-Q2-INST2(D2)** – … for INST2	Probabilistic quantitative • LERF for each installation: **A1-P1-INST1(LERF)**, **A1-P1-INST2(LERF)**, • Supplemental goals on CDF as applicable: **A1-P1-INST1(CDF)**, **A1-P1-INST2(CDF)**, … Instantaneous risk limit	Qualitative **A2-Q1-INST1(SAMG)** **A2-Q1-INST2(SAMG)** Providing effective SAM design measures and SAMG at the facility level		A3-Q1-INST1 A3-Q1-INST12 … Vital area identification at facility level	
				A1-Q3-INST1 - required three trains of safety systems						

TOP LEVEL - PRIMARY SAFETY GOAL: To protect people and the environment from harmful effects of ionizing radiation

Strålsäkerhetsmyndighetens föreskrifter om hantering av radioaktivt avfall och kärnavfall vid kärntekniska anläggningar, SSMFS 2008:22
Kärntekniklagen 1984:3,
Strålskyddslagen 1988:220
Miljöbalken 1998:808
Transport av farligt gods 2006:263

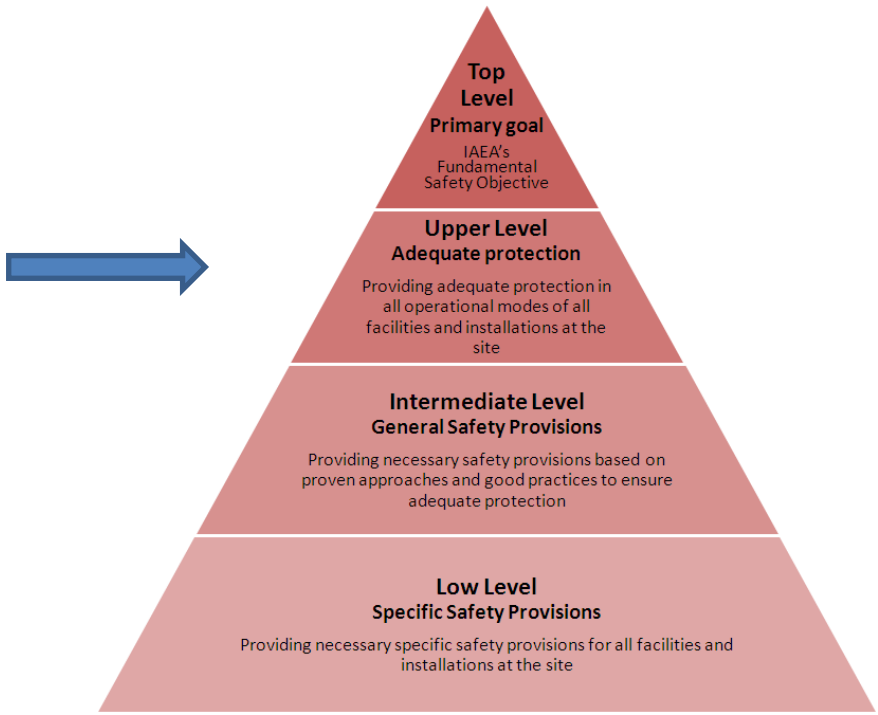
Top level – Primary Safety Goals

- Act on nuclear activities / Lagen om kärnteknisk verksamhet1984:3
- Radiation Protection Act / Strålskyddslagen 1988:220
  - The aim of this Act is to protect people, animals and the environment against harmful effects of radiation.
- SSM Regulation on handling of radioactive waste and spent fuel from nuclear installations, SSMFS 2008:22
  - …minimise amounts of waste and harmful impact from radiation now and in the future…

- Further (less specific) requirements in, e.g., Environmental Code and Laws on Transportation of Dangerous Materials

Upper Level – Adequate Protection

Level	Description
Upper Level Adequate Protection	Interpretation of the top level safety goal in risk terms. This is often done by comparison with the levels of risks coming from other involuntary sources of risk.



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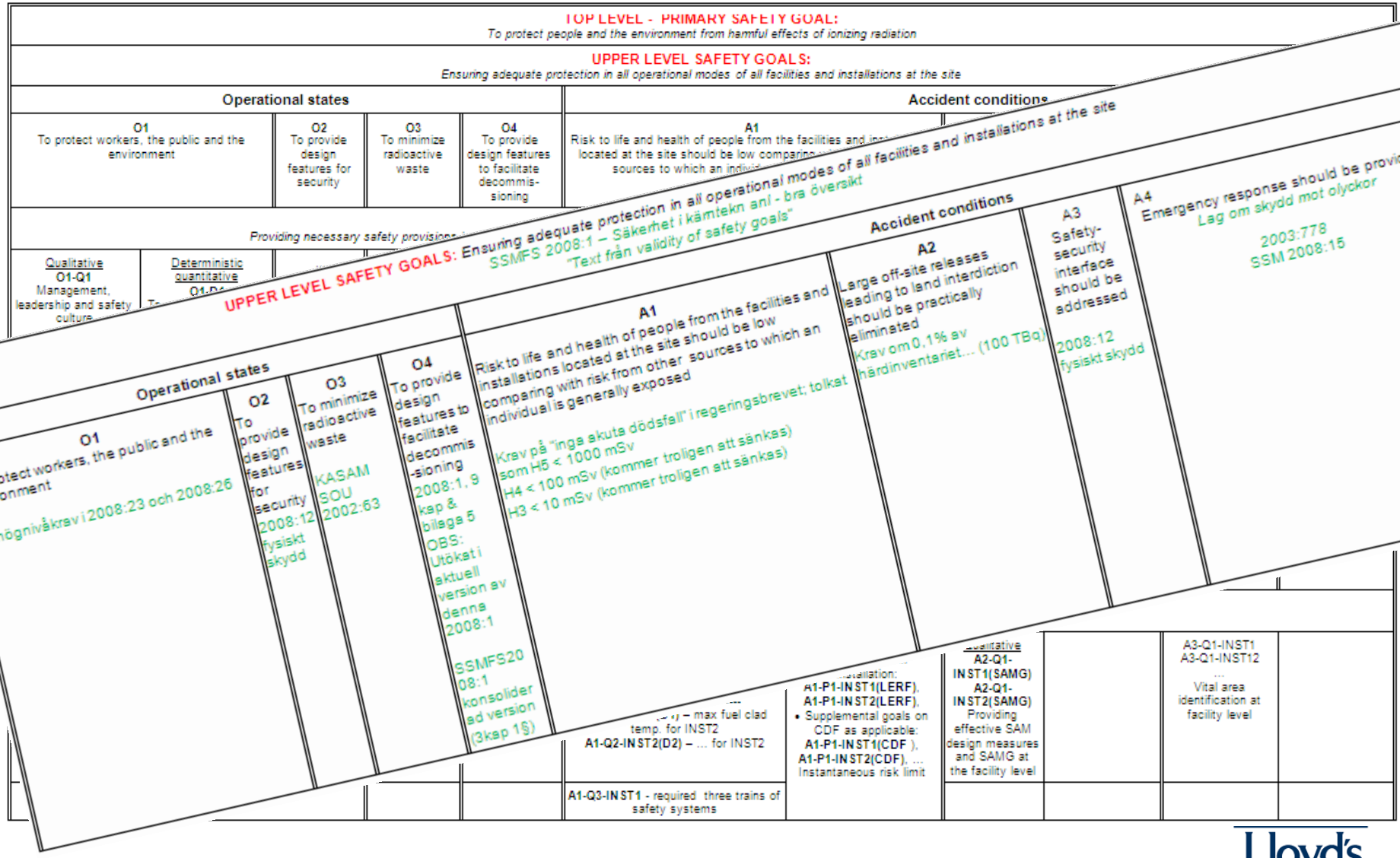

TOP LEVEL - PRIMARY SAFETY GOAL: *To protect people and the environment from harmful effects of ionizing radiation*											
UPPER LEVEL SAFETY GOALS: *Ensuring adequate protection in all operational modes of all facilities and installations at the site*											
Operational states				**Accident conditions**							
O1 To protect workers, the public and the environment	O2 To provide design features for security	O3 To minimize radioactive waste	O4 To provide design features to facilitate decommis-sioning	A1 Risk to life and health of people from the facilities and ins… located at the site should be low comparing… sources to which an individ…				A2 Large off-site releases leading to land interdiction should be practically eliminated Krav om 0,1% av härdinventariet… (100 TBq)	A3 Safety-security interface should be addressed 2008:12 fysiskt skydd	A4 Emergency response should be provided Lag om skydd mot olyckor 2003:778 SSM 2008:15	
Providing necessary safety provisions…											
Qualitative O1-Q1 Management, leadership and safety culture	Deterministic quantitative O1-D1 T…										

UPPER LEVEL SAFETY GOALS: *Ensuring adequate protection in all operational modes of all facilities and installations at the site* SSMFS 2008:1 – Säkerhet i kärnteknisk anl - bra översikt "Text från validity of safety goals"											
Operational states				**Accident conditions**							
O1 To protect workers, the public and the environment Ev högnivåkrav i 2008:23 och 2008:26	O2 To provide design features for security 2008:12 fysiskt skydd	O3 To minimize radioactive waste KASAM SOU 2002:63	O4 To provide design features to facilitate decommis-sioning 2008:1, 9 kap & bilaga 5 OBS: Utökat i aktuell version av denna 2008:1 SSMFS 2008:1 konsoliderad version (3kap 1§)	A1 Risk to life and health of people from the facilities and installations located at the site should be low comparing with risk from other sources to which an individual is generally exposed Krav på "inga akuta dödsfall" i regeringsbrevet; tolkat som H5 < 1000 mSv H4 < 100 mSv (kommer troligen att sänkas) H3 < 10 mSv (kommer troligen att sänkas)				A2 Large off-site releases leading to land interdiction should be practically eliminated Krav om 0,1% av härdinventariet… (100 TBq)	A3 Safety-security interface should be addressed 2008:12 fysiskt skydd	A4 Emergency response should be provided Lag om skydd mot olyckor 2003:778 SSM 2008:15	
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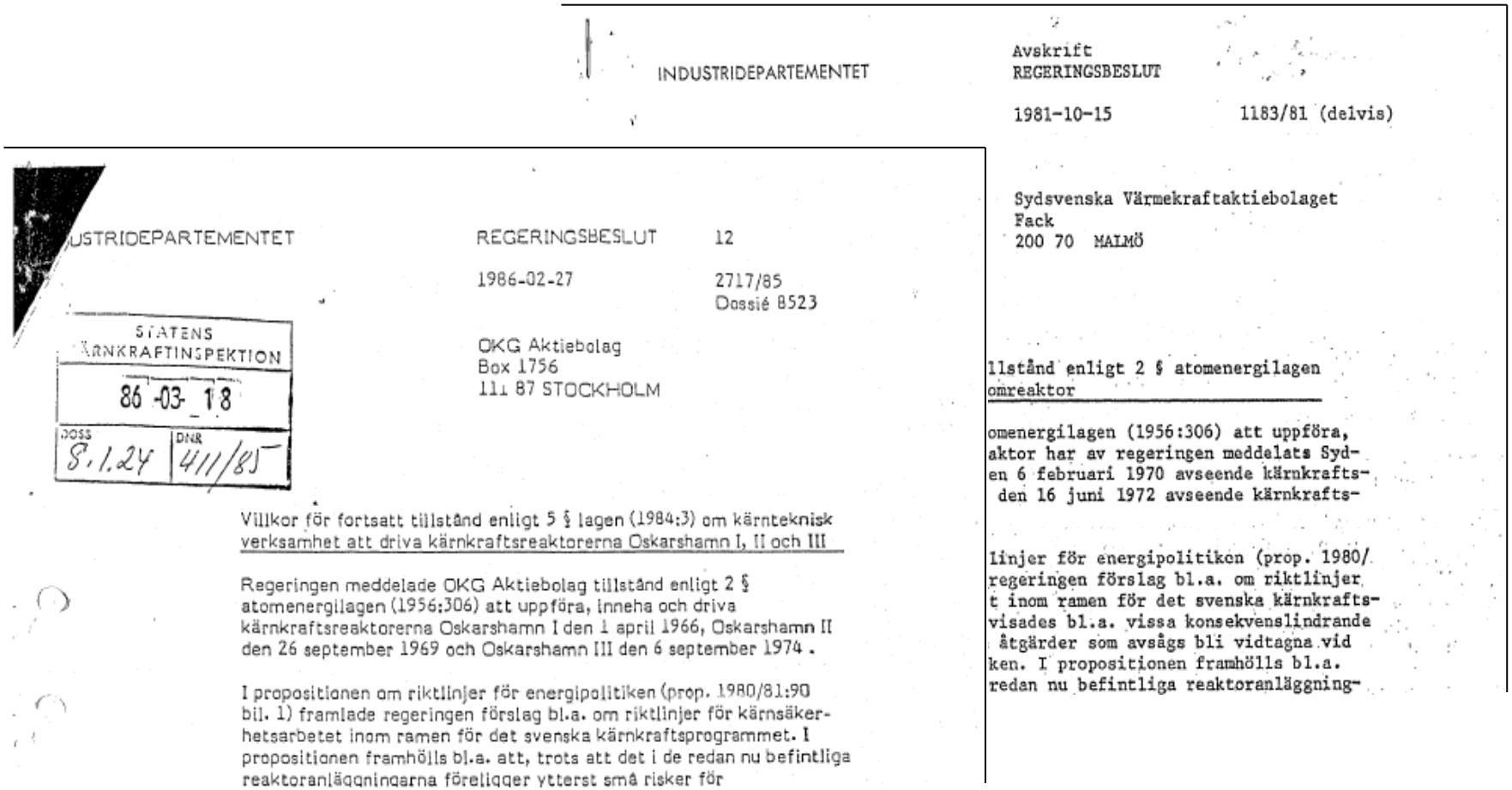
				A1-Q3-INST1 - required three trains of safety systems							

Requirements developed post-TMI



INDUSTRIDEPARTEMENTET

Avskrift
REGERINGSBESLUT

1981-10-15 1183/81 (delvis)

Sydsvenska Värmekraftaktiebolaget
Fack
200 70 MALMÖ

USTRIDEPARTEMENTET

REGERINGSBESLUT 12

1986-02-27 2717/85
Dossié 8523

STATENS
KÄRNKRAFTINSPEKTION
86 -03- 18
DOSS 8.1.24 DNR 411/85

OKG Aktiebolag
Box 1756
111 87 STOCKHOLM

llstånd enligt 2 § atomenergilagen
omreaktor

omenergilagen (1956:306) att uppföra,
aktor har av regeringen meddelats Syd-
en 6 februari 1970 avseende kärnkrafts-
den 16 juni 1972 avseende kärnkrafts-

linjer för energipolitiken (prop. 1980/
regeringen förslag bl.a. om riktlinjer
t inom ramen för det svenska kärnkrafts-
visades bl.a. vissa konsekvenslindrande
åtgärder som avsågs bli vidtagna vid
ken. I propositionen framhölls bl.a.
redan nu befintliga reaktoranläggning-

Villkor för fortsatt tillstånd enligt 5 § lagen (1984:3) om kärnteknisk verksamhet att driva kärnkraftsreaktorerna Oskarshamn I, II och III

Regeringen meddelade OKG Aktiebolag tillstånd enligt 2 § atomenergilagen (1956:306) att uppföra, inneha och driva kärnkraftsreaktorerna Oskarshamn I den 1 april 1966, Oskarshamn II den 26 september 1969 och Oskarshamn III den 6 september 1974 .

I propositionen om riktlinjer för energipolitiken (prop. 1980/81:90 bil. 1) framlade regeringen förslag bl.a. om riktlinjer för kärnsäkerhetsarbetet inom ramen för det svenska kärnkraftsprogrammet. I propositionen framhölls bl.a. att, trots att det i de redan nu befintliga reaktoranläggningarna föreligger ytterst små risker för

SSM – Basis for release related safety goals

"Release mitigating measures after severe accidents"

- Issued in 1986 by SKI and SSI (Swedish Radiation Protection Institute)
  - SKI and SSI merged to form SSM in 2008

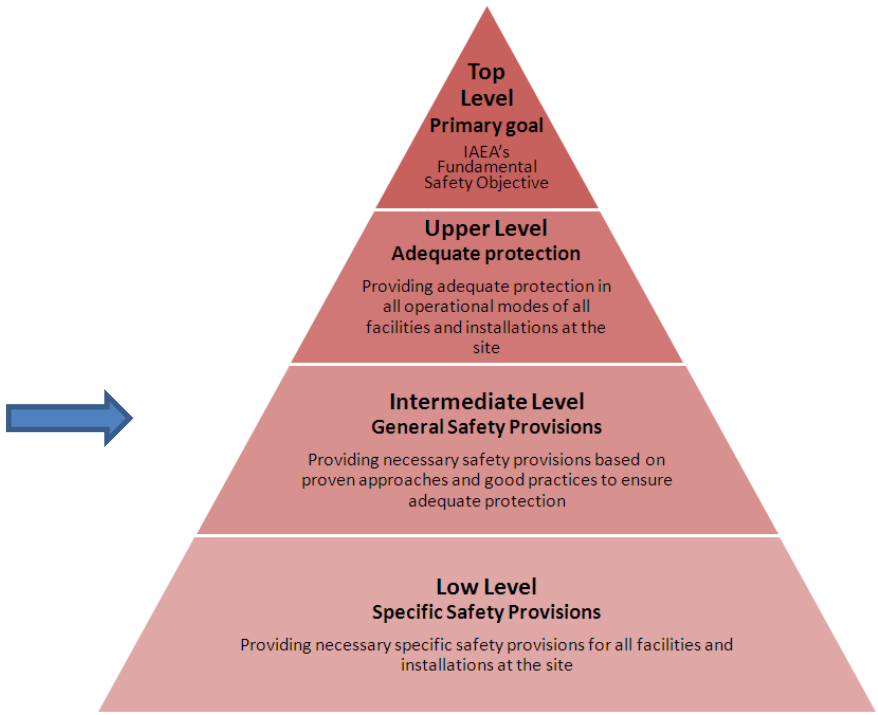
- Acceptance criteria for mitigating systems after a severe accident
  - Events with extremely low probabilities (extremt låga sannolikheter) can be neglected.
    - It is accepted that the filtered venting system cannot handle a reactor vessel rupture.
  - The same requirements on maximum acceptable release of radioactive substances apply to all NPP:s, regardless of location.
    - The justification for this requirement, is that the same level of individual risk shall be achieved at all sites, regardless of population density and property values.

SSM – Basis for release related safety goals, ctd.

- Acceptance criteria for the mitigating systems after a severe accident
  - Long-term ground contamination of large areas shall be avoided
    - This is judged to be fulfilled if the radioactive release after a severe accident is limited to below 0,1 % of the inventory of the caesium isotopes Cs-134 and Cs-137 in a core of 1800MWt, excluding noble gases.
    - 0,1 % / 1800MWt ⇔ 160 TBq of Cs134 and 103 TBq of Cs137.
  - There shall be no short-term fatalities in acute radiation syndrome (akut strålsjuka)
    - This is judged to be fulfilled if the radioactive release after a severe accident is limited to below 1 % of the inventory of a core of 1800 MW, excluding noble gases.
- "Extremely low probabilities"
  - Reactor vessel rupture is given as an example in the SKI/SSI report
  - Concept of residual risk + quantification in WASH-1400
  - Interpreted by licensees ➔ about 1E-7/year
  - However, this frequency is not spelled out in any of the government decisions, neither in the SKI/SSI report.

Intermediate Level – General Safety Provisions

Level	Description
Inter-mediate Level General Safety Provisions	Proven approaches and good practices to achieve the higher level safety goals as well as definition of general requirements on site level.



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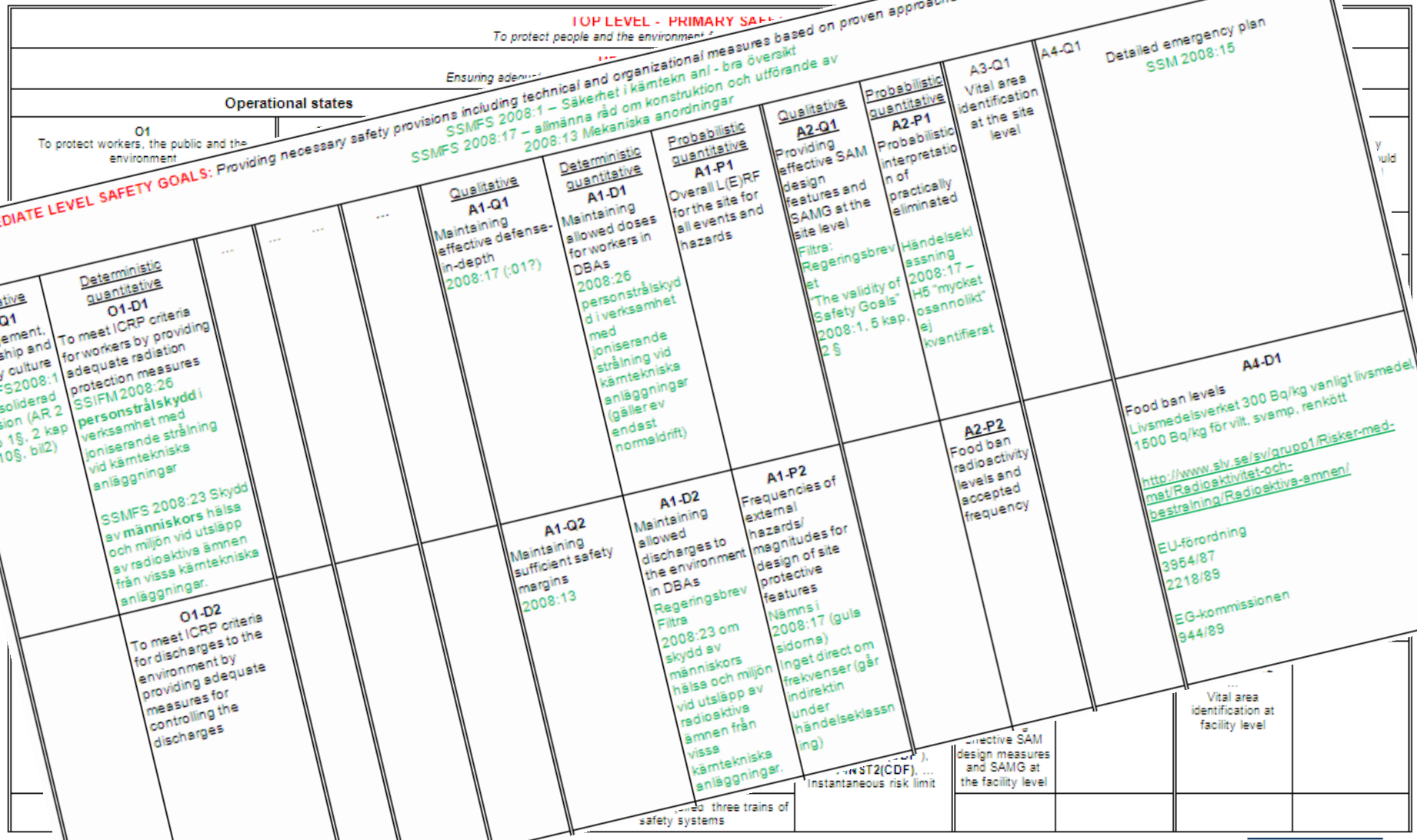


Intermediate Level – some important Regulations from the Radiation Safety Authority

- SSM FS 2008:1 Regulations concerning Safety in Nuclear Facilities
- SSM FS 2008:12 Regulations concerning Security in Nuclear Facilities
- SSM FS 2008:13 Regulations concerning Mechanical Equipment at Certain Nuclear Facilities
- SSM FS 2008:15 Regulations concerning Emergency Preparedness at Certain Nuclear Facilities
- SSM FS 2008:17 Regulations and General Advice concerning the Design and Construction of Nuclear Power Reactors
- SSM FS 2008:23 Regulations on Protection of Human Health and the Environment in connection with Discharges of Radioactive Substances from certain Nuclear Facilities
- SSM FS 2008:26 Regulations on Radiation Protection of Individuals Exposed to Ionizing Radiation at Nuclear Facilities

Examples from two important Regulations

- SSM FS 2008:1 Regulations concerning Safety in Nuclear Facilities
  - Defence in depth
  - Organisation and management
  - Safety criteria and guidelines
  - Safety analysis
  - Review activities
  - Periodic Safety Review
  - Technical Specifications
  - …
- SSM FS 2008:17 Regulations and General Advice concerning the Design and Construction of Nuclear Power Reactors
  - Redundancy
  - Functional and physical separation
  - Single failure
  - Requirements on capacity and robustness of various safety functions
    - Related to event classification
  - ….

Event Classification (SSMFS 2008:17)

Definitions by SSM / No frequency interpretation provided!

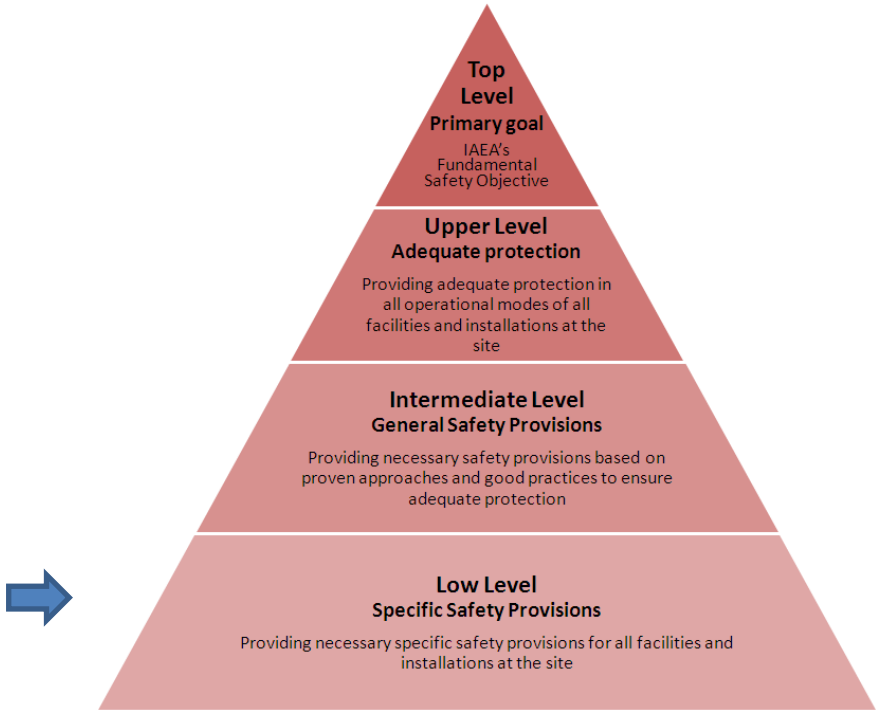
- **Normal operation (H1)**
  - Includes disturbances successfully managed by regular operations and control systems without interrupted operation
- **Anticipated events (H2)**
  - Events that can be expected to occur during the lifetime of a nuclear power reactor
- **Unanticipated events (H3)**
  - Events that are not expected to occur during the lifetime of a nuclear power reactor, but which can be expected to occur if several reactors are taken into account
- **Improbable events (H4)**
  - Events that are not expected to occur; this also includes a number of postulated events that are analysed to verify reactor robustness independently of the event frequency. These events are often called 'design basis events'.
- **Highly improbable events (H5)**
  - Events that are not expected to occur; if the event should nevertheless occur, it can result in major core damage. These events are the basis of the nuclear power reactor's mitigating systems for severe accidents.
- **Extremely improbable events (residual risks)**
  - Events that are so improbable that they do not need to be taken into account as initiating events in connection with safety analysis

Interpretation by industry (approximate)

H2		$F \geq$	1E-2
H3	1E-2	$> F \geq$	1E-4
H4	1E-4	$> F \geq$	1E-6
H5	1E-6	$> F \geq$	1E-7

Low Level – Specific Safety Provisions

Level	Description
Low Level Specific Safety Provisions	Technology and facility specific safety goals aimed at assuring the nuclear installation meets the higher level safety goals.



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					A1-Q3-INST1 - required three trains of safety systems						

EO.N – Oskarshamn NPP:s

- Beginning of 1980s
  - No written procedures for evaluation of PSA results
  - Focus on identifying weak links and on prioritisation of safety improvements
  - Absolute PSA results were considered to be of secondary importance
- End of the 1980s
  - IAEA guidance documents with an increasing focus on safety goals (after Chernobyl)
  - Increased discussion of safety goals also in Sweden

- Safety policy 1995 with safety goals for core damage and large releases
  - 1E-5/year for core damage
  - 1E-7/year for a release involving more than 0,1% of the core inventory excluding noble gases
  - Not mandatory. Violation ➔ "safety enhancing measures were to be prioritised"
- Safety policy updated 2004 (EON Nordic safety policy)
  - Quantitative safety goals deleted from top-level policy document
  - Safety goals slightly revised
  - Core damage criterion still 1E-5/year but applies to severe core damage
  - Criterion for unacceptable releases = frequency shall be considerably lower than 1E-5/year
  - Goals now very similar to IAEA INSAG 12

Application of TECDOC: Concepts involved in defining EON CDF criterion for Oskarshamn NPPs (2004)

Concept	Definition	Example (EON 2004, Oskarshamn NPP)
Consequence	Defines the consequence related to the fuel overheating.	Severe core damage
Metric	Qualifies the consequence (in this case “severe core damage”) in terms of a measurable magnitude.	“Severe” is not qualified, but previous versions of the safety policy have referred to 10 CFR 50.46 (local fuel temperature above 1204 ºC).
Risk metric	Defines how the risk is to be expressed.	Frequency of exceeding the limit. As long as “severe” is not defined, there is some vagueness in the definition of the risk metric.
Frequency/ probability	Defines specific levels related to the frequency/probability.	The criterion is defined as a frequency limit, which is set to $1 \cdot 10^{-5}$ per year.

Vattenfall – Ringhals and Forsmark NPP:s

- Safety goals first discussed end of 80s at Vattenfall central office
  - Company policy for reactor safety in 1990 and 1992 (business area electrical production)
  - High priority given to safety enhancing if
    - core damage frequency > 1E-5/year with high degree of confidence or
    - Or > 1E-7/year for a release involving more than 0,1% of the core inventory of substances causing ground contamination.
- Latest version of the safety policy 2006
  - Safety goals frequencies exactly as in 1992
  - Stresses integrated aspects of safety assessment (deterministic criteria + probabilistic methods + human factors analysis + utilisation of experience feedback)
    - PSA:s shall be realistic and site specific
    - PSA shall be used for verification of balanced safety (jämnstyrkekontroll)
  - Exceedance ➔ correcting actions shall be planned and PSA results shall be part of the basis for planning safety improvements.

Summary of Swedish (probabilistic lower level) safety goals

Authorities	Vattenfall	EON (Sydkraft)
1985 Core damage - Release ”Extremely unlikely” release of more than 0,1 % of the inventory of the cesium isotopes Cs_{134} and Cs_{137} in a core of 1800 MWt, (No frequency defined, but interpreted as < 10^{-7}/year)	**1990** Core damage 10^{-5}/year with a high degree of confidence Release 10^{-7}/year for a release involving more than 0,1% of the core inventory of substances causing ground contamination.	**1995** Core damage 10^{-5}/year Release 10^{-7}/year for release involving more than 0,1% of the core inventory excluding noble gases.
	2006 Core damage 10^{-5}/year for core damage Release 10^{-7}/year for a release involving more than 0,1% of the core inventory of substances causing ground contamination	**2006** Core damage 10^{-5}/year for severe core damage Release Frequency of release involving more than 0,05-0,1% (depending on thermal effect) of the core inventory excluding noble gases shall be considerably lower than 10^{-5}/year.

Conclusions

- Existing laws and regulations provide a good coverage of the four layers of Safety Goals
- Adequate coverage of different facilities and entire life span
- Limited use of probabilistic safety goals; most detailed defined by industry.
- The proposed framework and hierarchy of Safety Goals can be easily applied to the Swedish context
    - This presentation is incomplete: Limited time available, not sufficient to provide a full picture.
- The triangle fully captures the conceptual aspects of the framework and hierarchy, and the matrix provides specific examples
  - Important not to see the matrix as a complete checklist!
  - Good as a completeness check – indicates areas that are lacking or unclearly defined

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