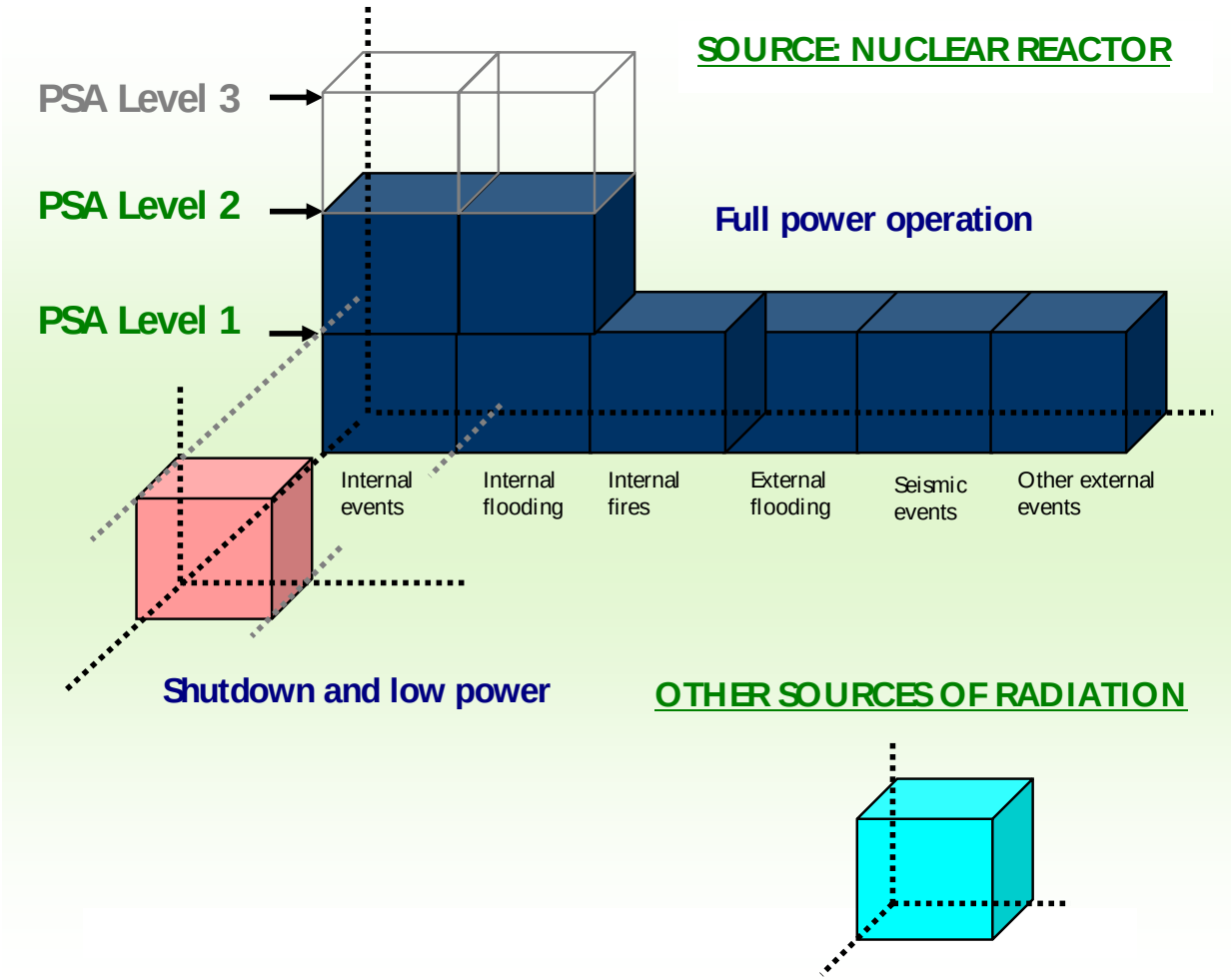
HISTORY OF PSAS FOR NPPS

A short overview

Overview of History of Scope of PSA



Sixties (1): WASH-740

- 1957 WASH-740 :"Theoretical Possibilities and Consequences of Large Nuclear Power Plants" by US-AEC
  - Estimated 3400 deaths & 43.000 injuries
  - Probability 1.10^{-5}/year to 1.10^{-9}/year
  - Economic damage estimated: 7 billion US $

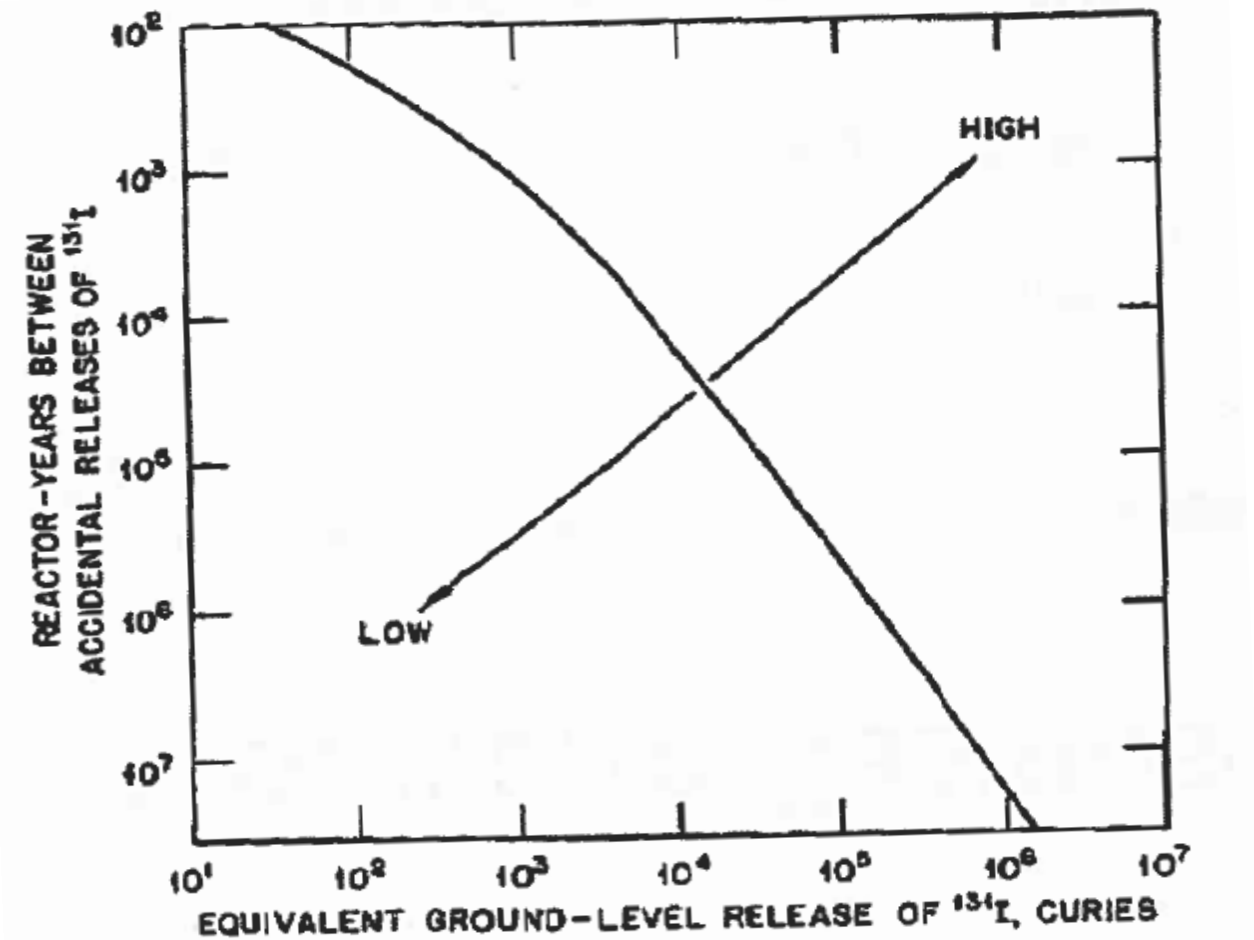
- Update in 1964-1965
- Larger reactors
- 45.000 deaths & 100.000 injuries
- Economic damage estimated:17 billion US $

Assumptions very unrealistic; worst case scenarios, meteorological conditions, no containment, etc.

SIXTIES (2)

- 1960 'Reg' Farmer first Gas Cooled Reactor PRAs to address siting issues
- Early sixties development of event trees for sequence modeling by Farmer
- 1966-1967 Reg. Farmer proposal of safety goal. *Frequency versus release of ^{134}I equivalent in Curies, e.g. 10^{-7}/year for a release of 10^{6} Ci I^{131} equivalent*

FARMER's RISK CRITERION



Leatherhead, UK; September 9, 2010

Seventies (1): WASH-1400

- 1975 WASH-1400, Reactor Safety Study or Rasmussen Report. First real attempt to calculate the risk in more or less same manner we do it today by Fault Trees & Event Trees. The report concluded that: ***"the risks to the general public was acceptably small, compared to other tolerable risks."***
- Reviewed in 1975 by Lewis Committee (American Physical Society), which broadly endorsed the methodology as the best available, but might be subject to large uncertainty

Seventies (2): WASH-1400

- Many data: rule of thumb!
- Limited understanding of severe accident phenomena
  - Some External Events included (airplane crash). Figures of 10^{-6} – 2.10^{-7} for airplane crash per year per site calculated
  - Common Cause Failures very poorly included
  - HRA poorly included. Data from UKAEA. Stress, training and presence of written procedures and interdependency between human actions as important factors recognized

Seventies (3): PSAs of AGRs Hartlepool, Heysham 1,2 & Thorness

- In the early seventies PSA techniques were used in the design process of AGRs. First Hartlepool and Heysham 1, followed by Heysham 2 and Torness
- Later the PSAs were updated in the PSR process
  - Status 1999: Level 2, only Internal events, only power states limited treatment of internal& external hazards
- PSAs of MAGNOX reactors started in the eighties and nineties
  - Only level 1^{+}, internal events and full power

Late seventies-early eighties: the first post WASH-1400 years (1)

- Large debates after many critiques on RSS and especially after Three Mile Island incident in 1979. First reaction was that RSS was completely wrong. But this critique was based on the description of the TMLQ transient in the Westinghouse plant Surry, and not in a Babcock and Wilcox plant. If done properly WASH-1400 would have given a credible description ($F_{sequence} = 3.3\ 10^{-3}$/year) of the sequence
- Severe Accident Research Program (SARP) by National labs (Battelle, Oak Ridge, Sandia, INEL) and EPRI to get a better understanding of phenomena → MELCOR & MAAP codes
- 1985 Report by APS on "Radionuclide Release from Severe Accidents at Nuclear Power Plants"on results of SARP

Late seventies-early eighties: the first post WASH-1400 years (2)

- 1983 NUREG/CR-2300 "PRA Procedures Guide" by IEEE/ANS (industry)
- 1984 NUREG/CR-2815 "PSA Procedures Guide" by Brookhaven Nat'l Laboratory
  - β-factor model and binominal failure rate model recommended for CCFs

Early to mid eighties - Quantitative Safety Guidelines in The Netherlands (1)

- Risk Criteria developed in the early to mid-eighties as a zoning instrument for conventional hazardous industries ant transport of dangerous substances. They were first published in the 1986-1990 Long Term Programme for Risk Management
- Several years later also valid for NPPs. In 1990 a policy document was published dealing with the risks associated with radiation: “Radiation protection and Risk Management; Dutch Policy on the Protection of the Public and Workers against Ionising Radiation”.

Early to mid eighties - Quantitative Safety Guidelines in The Netherlands (2)

- After Chernobyl, debates in Dutch parliament caused 'deminimis values' in case of nuclear and radiation protection matters to disappear. ALARA up to nil risk.
- In 2003 The Nuclear Installations, Fissionable Materials and Ores Decree (part of Nuclear Energy Act) has been amended to incorporate this risk policy in the licensing Process for nuclear installations. Risk Criteria are explicitly included as assessment principles for licenses to be granted to NPPs. The outcomes of a level-3 PSA must be compared with these risk criteria.

Early to mid eighties - Quantitative Safety Guidelines in The Netherlands (3)

- **Dose Criteria for Design Basis Accidents**

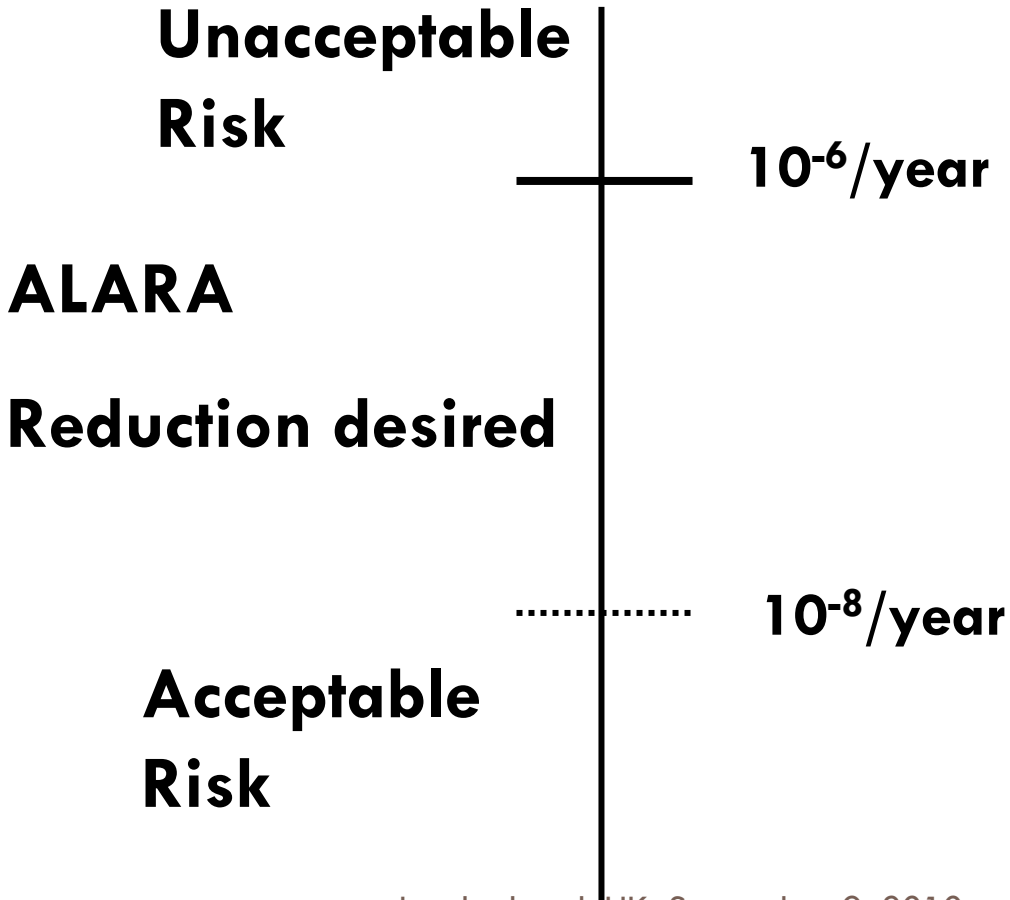
Frequency of Event F per annum	Effective Dose (H_{eff}, 50 years)	
	Adult	Child (1 year old)
$F \geq 10^{-1}$	0,1 mSv	0,04 mSv
$10^{-1} > F \geq 10^{-2}$	1 mSv	0,4 mSv
$10^{-2} > F \geq 10^{-4}$	10 mSv	4 mSv
$F < 10^{-4}$	100 mSv	40 mSv

Early to mid eighties - Quantitative Safety Guidelines in The Netherlands (4)

- **Included in Nuclear Energy Act:**
  - **For the prevention of major accidents, the maximum permissible level for the individual mortality risk (i.e. acute and/or late death) has been set on 10^{-6}/year for a single NPP (hypothetical person staying for 50 years unprotected outside the fence at a place with the highest doses)**
  - **As far as major accidents are concerned, both the individual mortality risk and the societal risk must be taken into account. In order to avoid large scale societal disruptions, the probability of an accident in which at least 10 persons suffer acute death is restricted to 10^{-5}/annum. If the number of fatalities increase with a factor of n, the probability should decrease by a factor of n^2 (Actual demography)**

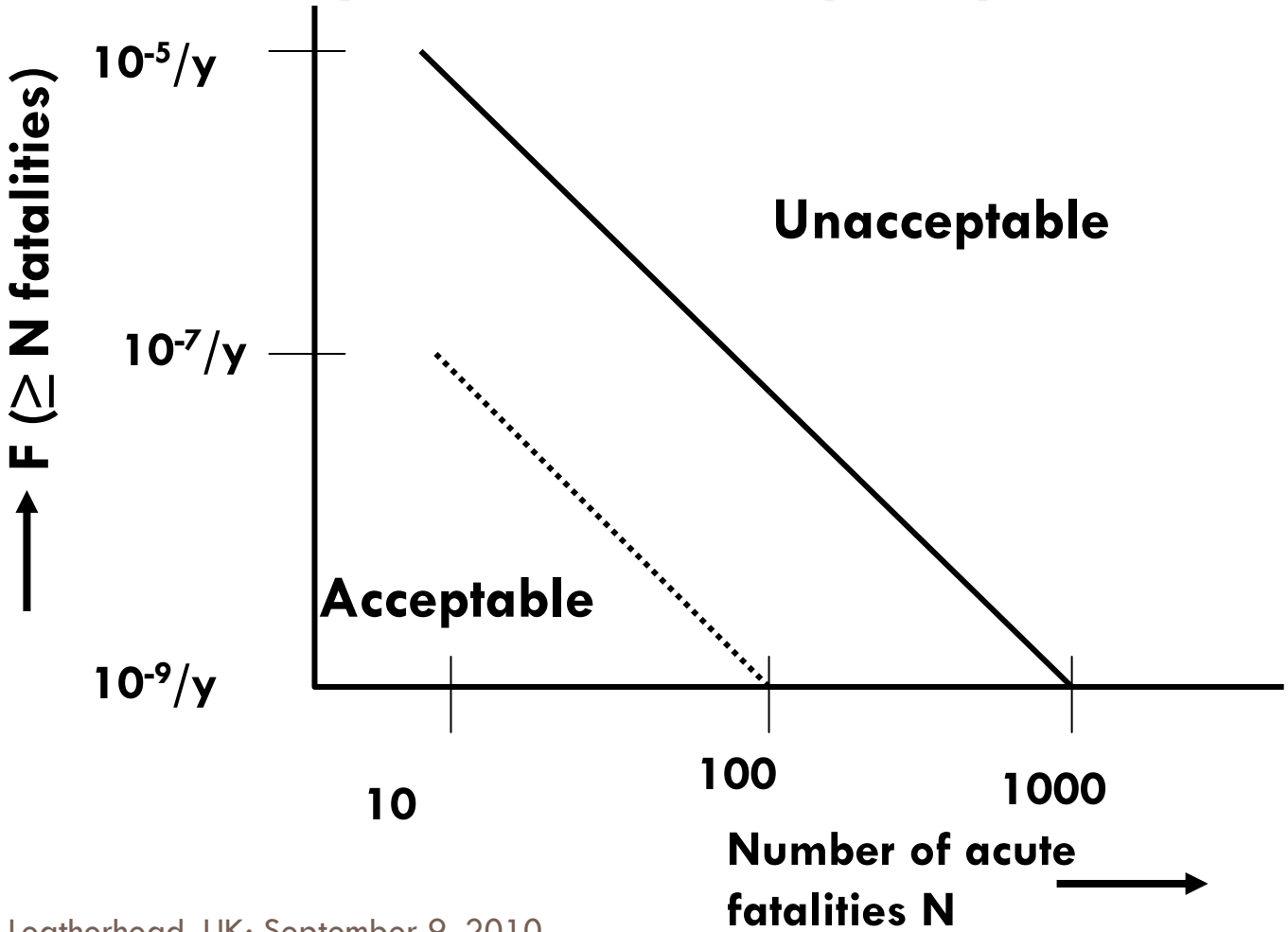
Early to mid eighties - Quantitative Safety Guidelines in The Netherlands (5)

Individual Mortality Risk Criterion (early & late)



Early to mid eighties – Quantitative Safety Guidelines in The Netherlands (6)

Societal Mortality Risk Criterion (prompt fatalities)



Early to mid eighties - Quantitative Safety Guidelines in The Netherlands (7)

Core Damage Frequency Criterion:

CDF < 1.10^{-4}/year old plants, (Used in the eighties by regulatory body.

CDF < 1.10^{-5}/year new plants, (Used in the eighties by regulatory body)

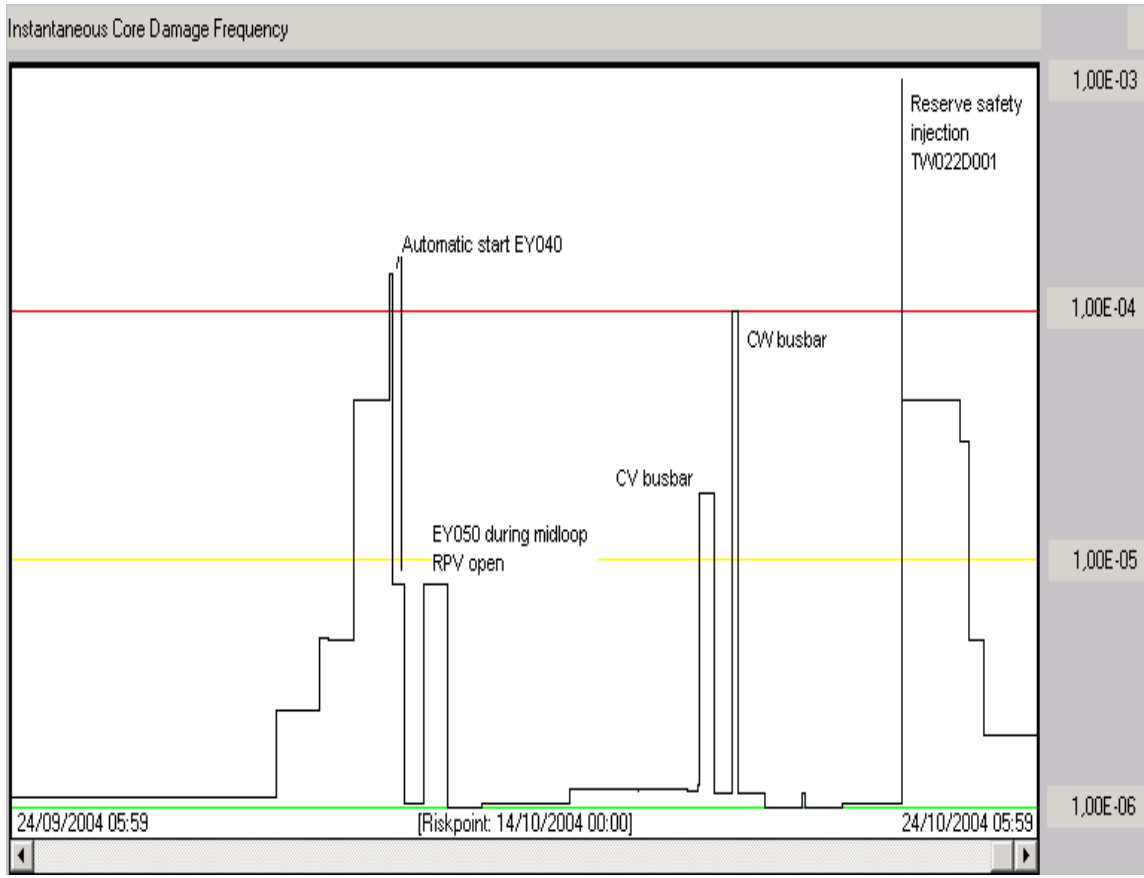
Nowadays 1.10^{-4}/year is used by Borssele NPP as a limit in the Risk Monitor for instantaneous risk due to outages of components.

Late eighties (1) Tolerability of Risk document

- 1988 HSE publishes " The Tolerability of Risk from Nuclear Power Stations" following the recommendation of Sir Frank Layfield in his 1986 report of the Sizewell B Public Inquiry
- Revised in 1992 and combined with the NII Safety assessment Principles .
  - in order to get a better consistency with IAEA Safety Standards, Codes and Guides
  - Implement lessons learned

Mid eighties: First Risk Monitor in Heysham 2 & Thorness

Risk monitors have been in operation at Heysham 2 & Torness since1986. In the next 2 decades almost all plants in the world followed, including Sizewell B. **Not the other UK plants!** Uprated in the nineties to level 2



Late eighties (2): IPEs requested by US-NRC

- In 1988 US-NRC issued generic letter 88-20 requesting that each nuclear perform an Individual Plant Examination (IPE) for severe accident vulnerabilities and report the results to the Commission. It was expected to perform:

  a limited-scope, accident safety analysis designed to discover instances (i.e. outliers) of particular vulnerability to core melt or to unusually poor containment performance, given core melt accidents

- In 1989 NUREG1335 as a submittal guidance was published
- In July 1995, 77 IPEs were submitted representing 115 plants

Early Nineties: NUREG-1150 (2)

- 1991 NUREG-1150: "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants".
- **The NUREG-1150 methodology was more than a decade the standard for a high quality PSA**
  - α-factor method for CCFs
  - Use of advanced level-2 codes such as MELCOR

Mid-nineties: First LPSD PSA

- France produced first Low Power & Shut-Down (LPSD) PSA
  - Effects were enormous: 30%-35% of TCDF due to LPSD operating states. Especially midloop operation prior opening and closing of vessel head of PWR was a large contributor to TCDF. In a few hours 10%- 15% of TCDF

Mid-Nineties: Second Generation HR modeling

- ATHEANA – USA
- MERMOS – France
- EOCA – UK (Barry Kirwan)
- CAHR – Germany
- CODA – Switzerland
- Attempt to model Human Errors of Commission (EOCs)
  - Reliable data still missing

Mid-nineties: Utility applications

- ✓ Tech. Spec optimisation
- ✓ Changes & exemptions to Tech. Spec
  Justification for continued operation
- ✓ Development of EOPs
  Training for Operators & Tech. Staffs
- ✓ Plant changes and back-fitting (part of PSR)
- ✓ Risk informed ISI & IST
  Graded QA
  Maintenance optimization
  Surveillance program planning

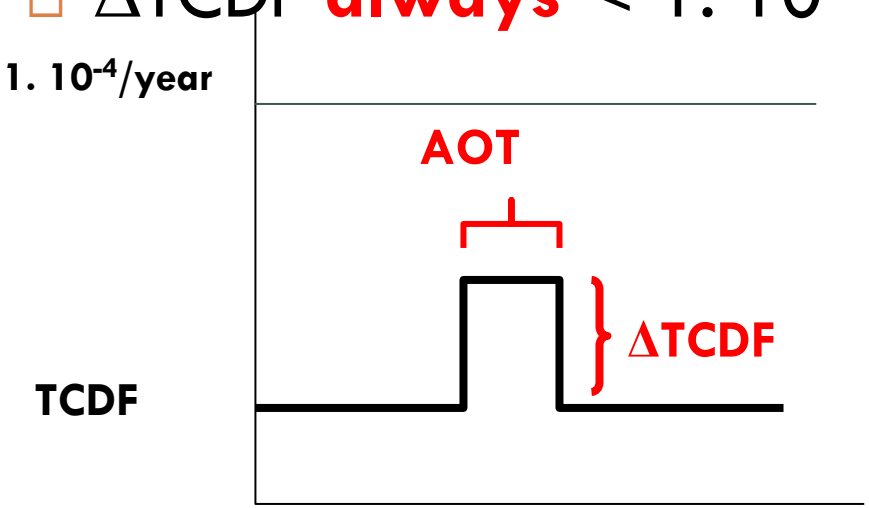
(✓ = Applications in Borssele NPP)

Example PSA application Borssele (Optimisation of AOTs)

- Borssele : ΔTCDF x AOT $\leq 5.\ 10^{-8}$

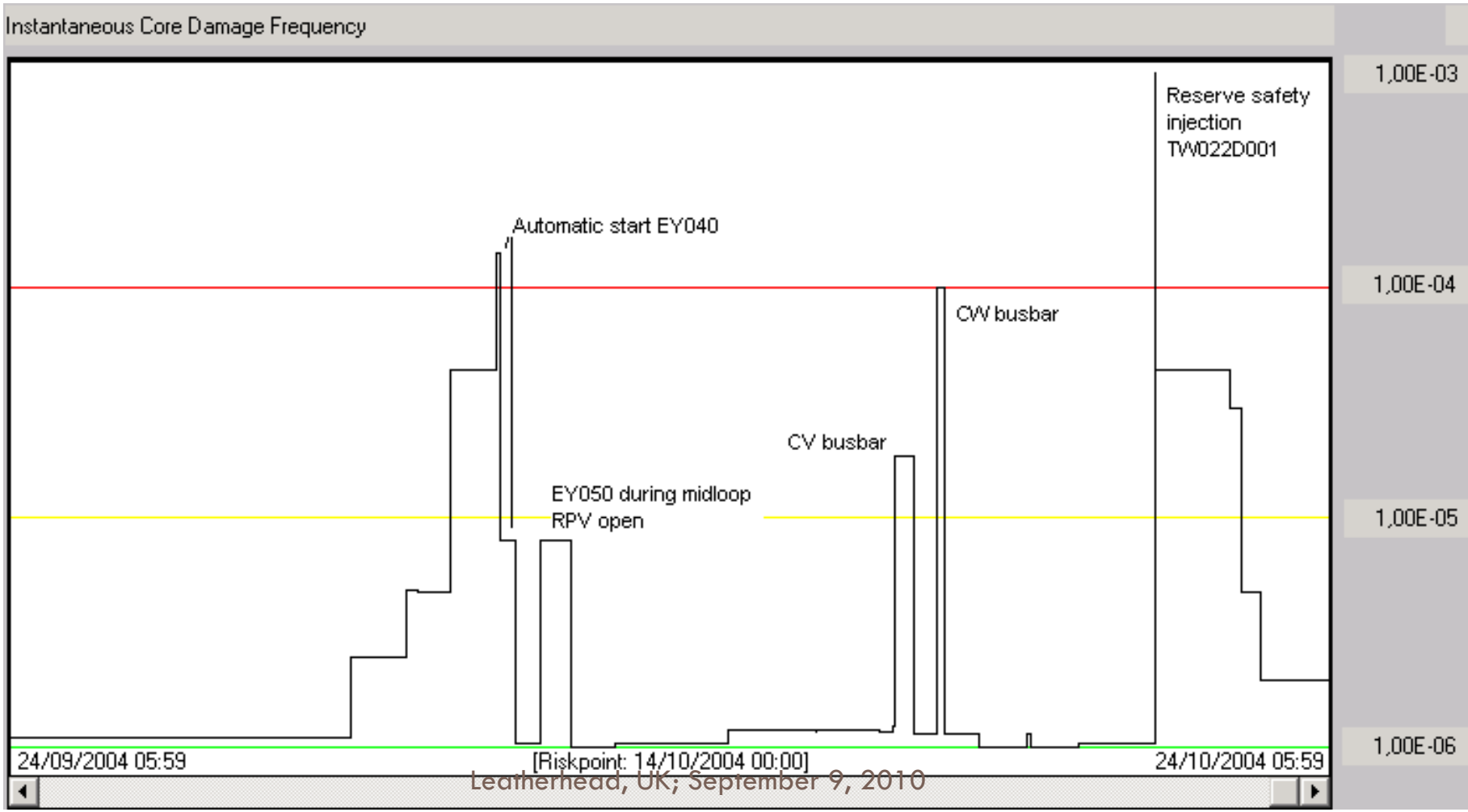
  (Reg. Guide 1.177 $< 5.\ 10^{-7}$)

- ΔTCDF **always** $< 1.\ 10^{-4}$/year



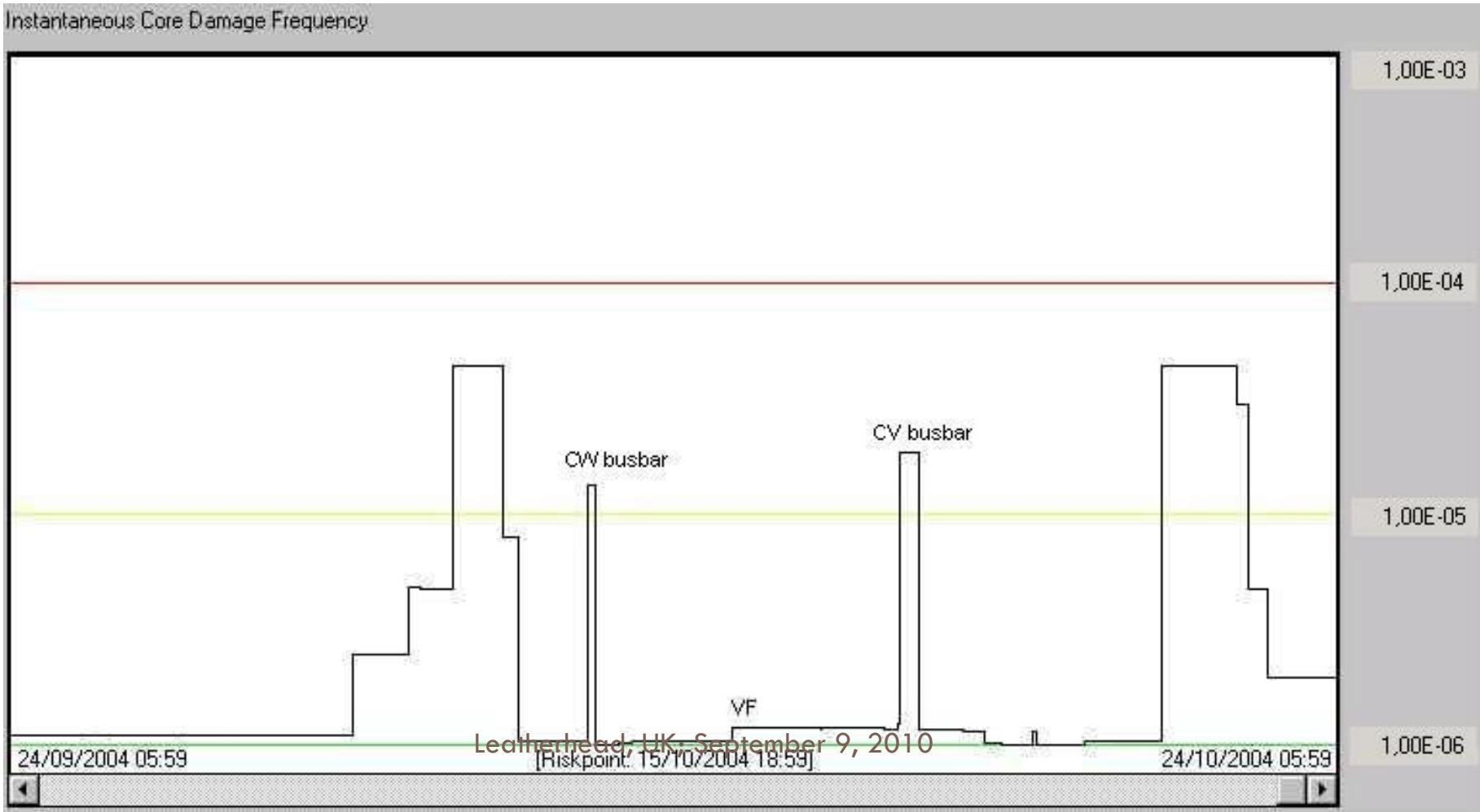
Example PSA application Borssele (Refueling outage planning)

First planning, prior to safety monitor evaluation



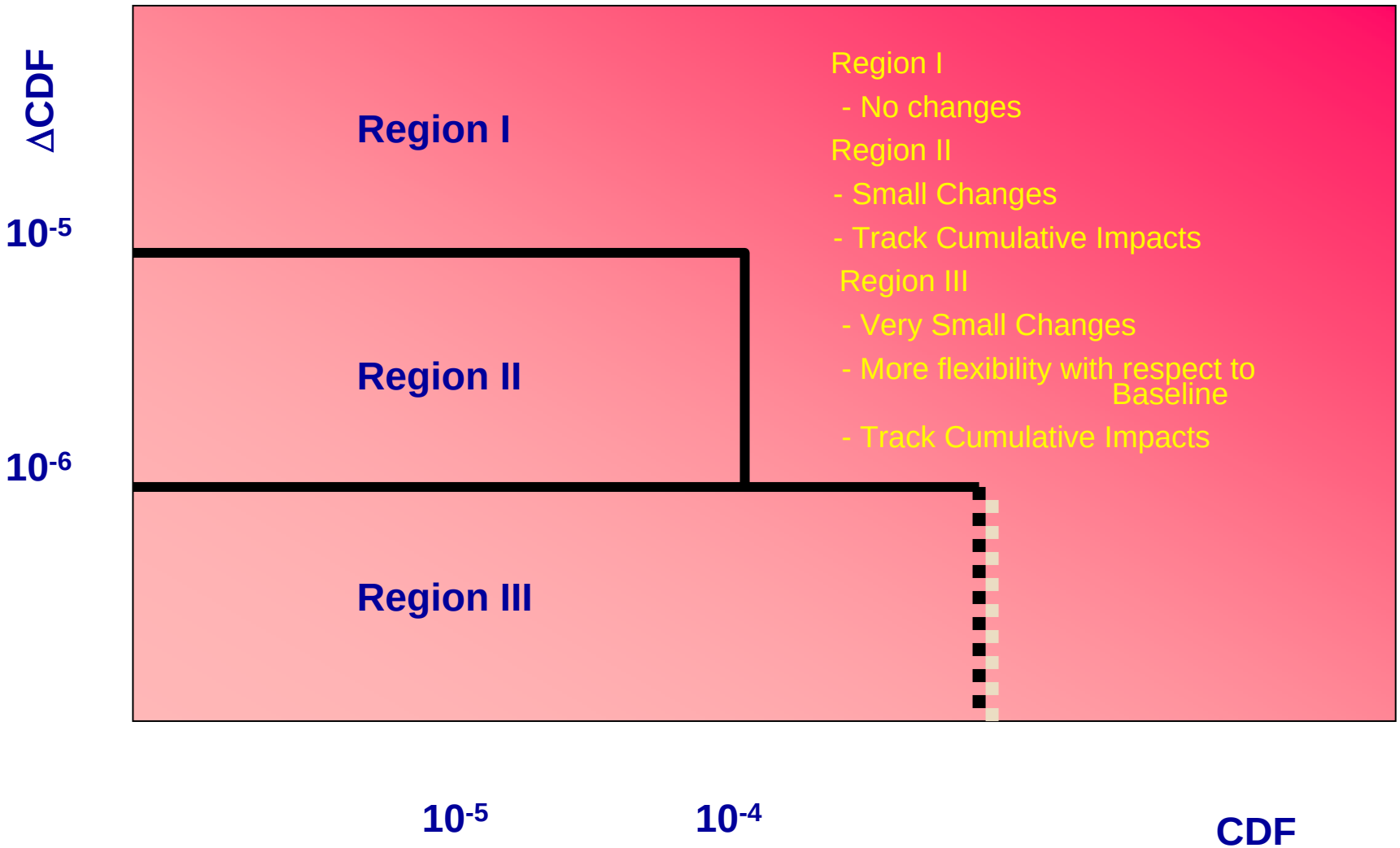
Example PSA application Borssele Refueling outage planning

Second planning, after first safety monitor evaluation



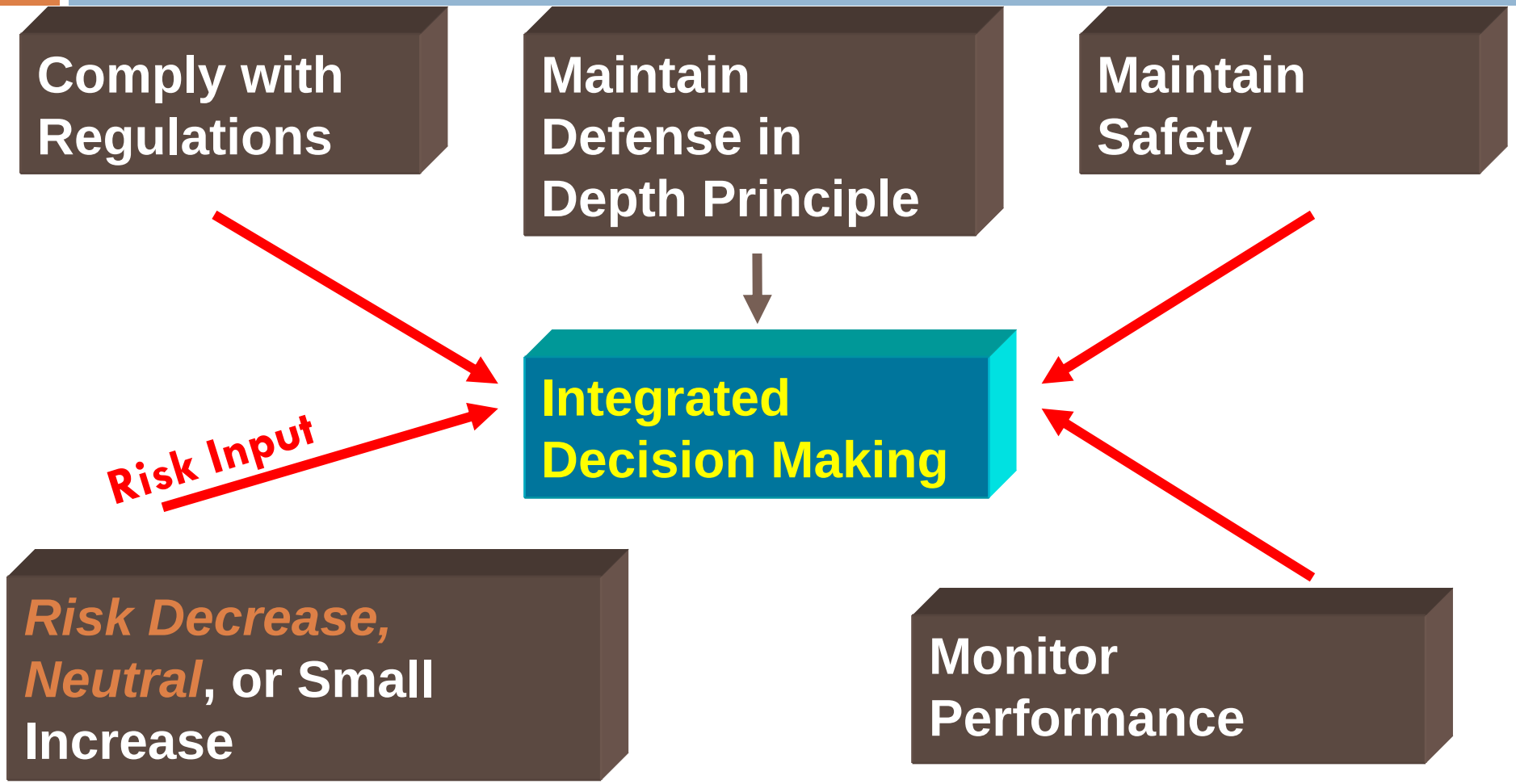
End nineties - Begin of this decade Risk Informed Regulation (1)

- Risk Informed, Performance Based regulation proposed by US-NRC
  - 1998 options for risk informed revisions to 10 CFR 50 (possibility for relaxation of Licensing Basis such as: requirements in QA, TS etc.) SECY-98-132
  - 2000, High level guidelines for Performance Based Activities SECY-00-0191
  - Risk Informed Regulation Implementation Plan in 2000
  - Regulatory Guide 1.175



Acceptance Guidelines for Core Damage Frequency

End nineties - Begin of this decade
Risk Informed Regulation (2)



THIS DECADE (1)

- NUREG/CR 6850 “Fire PRA Methodology for Nuclear Power facilities"
  - Improved Fire PSA methodology
  - Importance of hot shorts leading to premature actuation of components. ***Up to 40% of cable fires can lead to hot shorts!***

THIS DECADE (2)

- Large European Research program on Severe Accidents (SARNET) (such as: CABRI experiments in Cadarache France)
  - Chemical behavior of fission products in the melt is more complex (e.g., formation of Cesium Molybdates). Older versions of MELCOR and MAAP needed to be revised. In-vessel air ingress during some sequences on release of Ruthenium oxides can increase the radiological impact.

Where are we now?

Recommendations for Advancements

Where are we?

1. In general plant safety improved by PSA applications!
2. Risk Informed Decision-making increasingly being applied both by industry and regulatory bodies
3. Most PSA techniques are mature; but not all!!!
4. Still many mistakes in conducting, reviewing and interpretation of results of PSAs
5. Risk Informed decision-making can be a perfect blend of deterministic and probabilistic methods

Some shortcomings (1)

- Ageing effects hardly included
- Insufficient treatment of epistemic uncertainties
- Insufficient use of precursors in Initiating Event analysis (NRC stated that 20% of precursors were not modeled in PSAs)
- Tendency to consider the best-estimate outcomes as a fact, even if scope or level of detail of PSA, etc. is inadequate. Risk Informed → Risk based

Some shortcomings (2)

- Treatment of Common Cause despite improved modeling and data-bases (NEA/ICDE) still cumbersome in too many cases(especially asymmetric component configurations, translation of generic data into plant-specific).

- *This in contrast with the critique on deterministic assessment principles such as: DBAs or Defense in Depth don't include dependencies.*

Some shortcomings (3)

- HRA (treatment of Errors of Commission improved and slowly progressing, but adequate data still missing, effects of error forcing context, effects of organization, inter-dependencies insufficient)

Some shortcomings (4)

- Lack of completeness due to false reasons; initiating events often too easily screened out, no proper uncertainty assessment (no aleatory uncertainty assessment), etc.
- There are still many level 2- PSAs and associated Risk Monitors around which haven't included the severe accident research insights from the last 10 to 15 years. Still based on the insights from the NUREG-1150 period.

Future developments

- HRA!!!
  - In the last 3 PSAM conferences a large portion was devoted to the ongoing developments and plans on HRA
  - Large program on data retrieval from simulators with real operating crews
- Software reliability
  - There is a large need and little knowledge
- Other ??