Atomic Energy Regulatory Board of India

Regulatory Structure for New Plant Licensing, Part 1: Technology-Neutral Framework

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BACKGROUND

- Current regulations developed over 40 years
- Majority of regulations oriented toward or specific to LWR technology
  - For some new reactors, may have limited applicability
  - Design and operational issues different from current LWRs.
- Many are without the benefit of insights from probabilistic risk assessments
  - Risk-informed structure will help ensure the safety of these reactors by focusing the regulations on where the risk is most likely while maintaining basic safety principles
- New regulatory structure that is technology-neutral could enhance the effectiveness, efficiency and stability of new plant licensing
- New regulatory structure could help ensure uniformity, consistency and defensibility in development of the regulations, particularly when addressing the unique design and operational aspects of new reactors

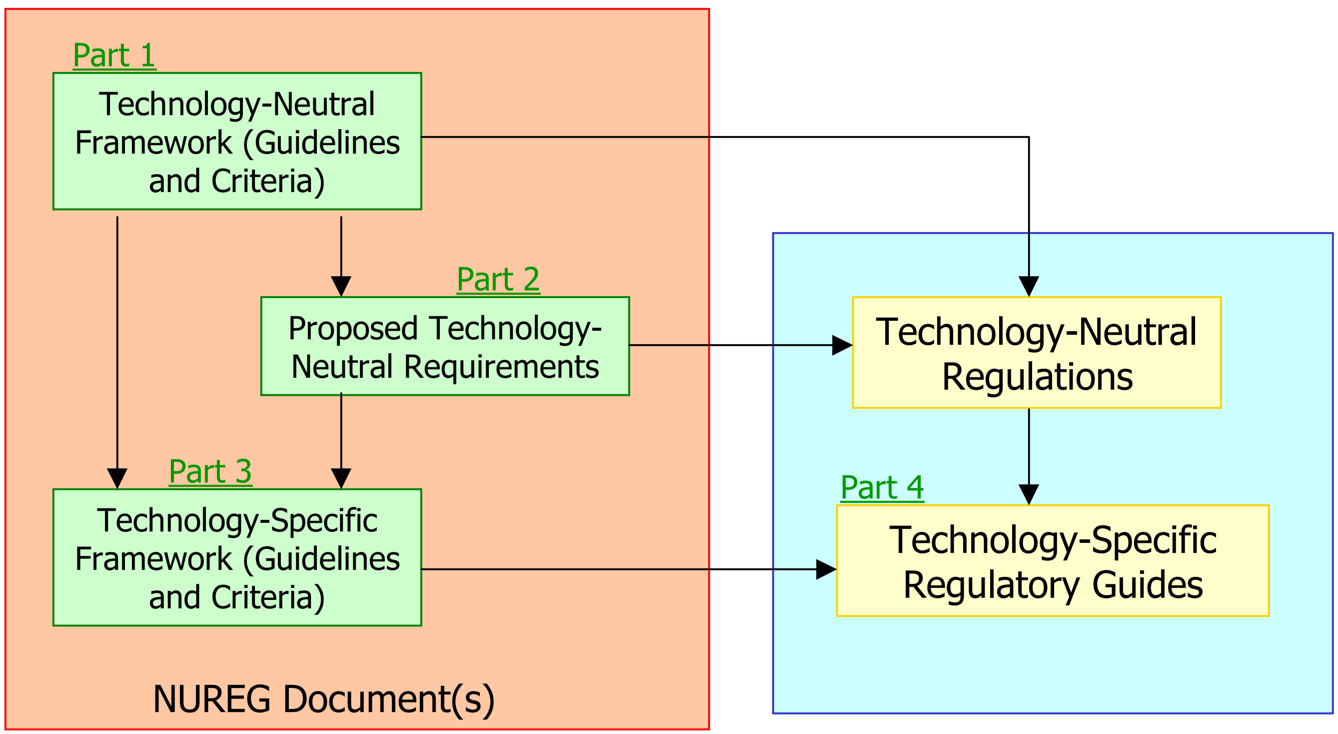
PROGRAM SCOPE

- Applicable to all new plants, all types of reactor designs
  - Non-LWRs (e.g., HTGRs, liquid metal reactors, etc.)
  - Advanced LWRs (e.g., IRIS)
  - The regulatory structure will address risks from reactor full power operation as well as low power and shut down and spent fuel storage, and includes the risk from both internal and external events. Therefore, it includes seismic, fire and (internal and external) flood risks, and risk from high winds and tornados; also included are fuel storage and handling.
- Not intended to be used for designs currently under review
- Ultimately it is envisioned that the new regulatory framework will address safeguards and security; however, the initial focus is on protection of public and worker health and safety and also provides for protection of the environment.

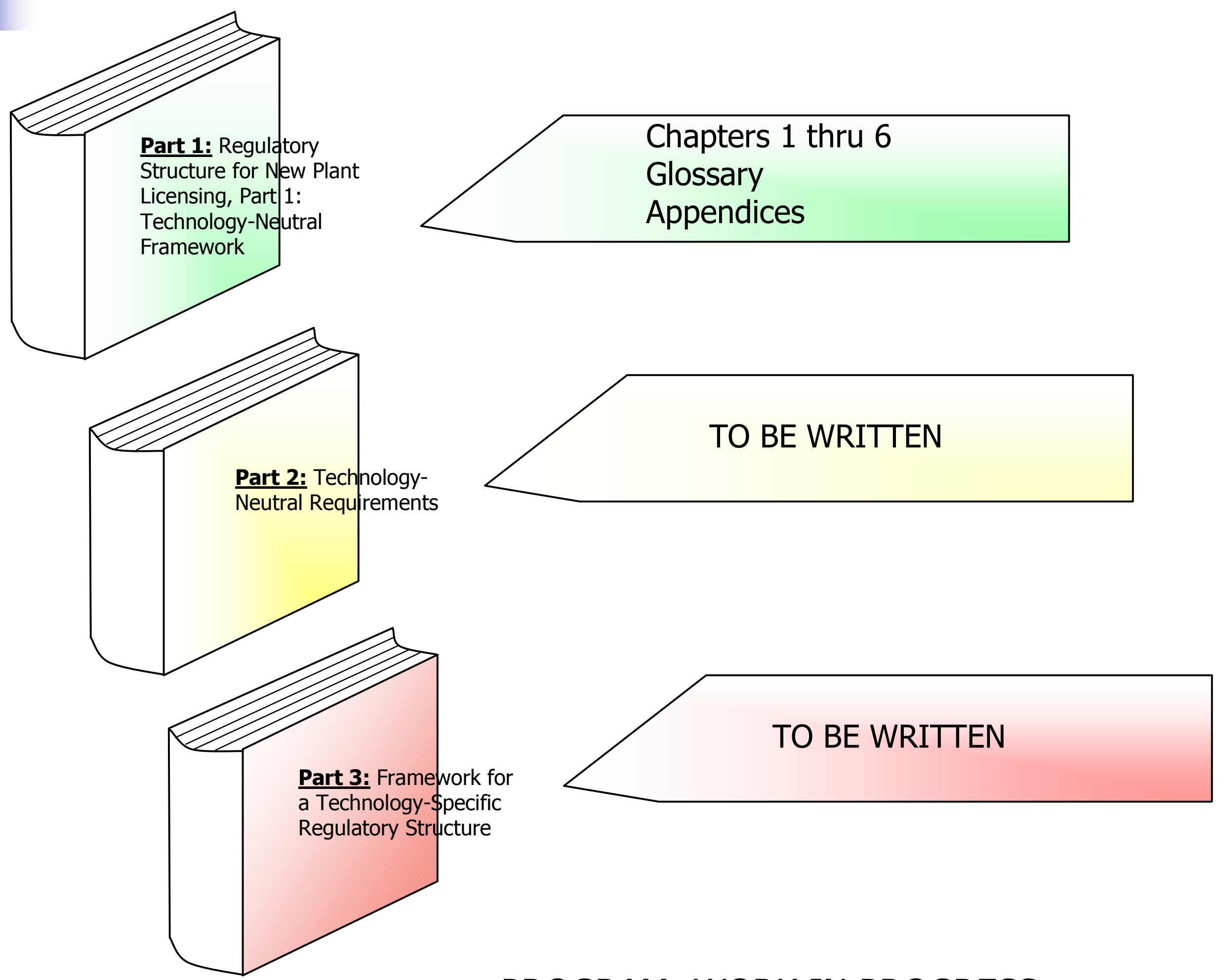
REGULATORY STRUCTURE FOR LICENSING OF NEW REACTORS: FOUR PARTS

- Technology-neutral risk-informed framework (to be documented in a NUREG report) that will provide guidance and criteria to the staff for the development of technology-neutral requirements.
- The content for a set of technology-neutral risk-informed requirements that will be based on the guidance and criteria established in the technology-neutral framework NUREG.
- Technology-specific framework (to be documented in a NUREG report) that will provide guidance and criteria for the staff on how to apply the technology-neutral framework and requirements on a technology-specific basis.
- Technology-specific regulatory guides that will be derived from the implementation of the technology-specific framework that will provide guidance to licensees on how to apply the technology-neutral regulations on a technology-specific basis.

RELATIONSHIP OF THE DIFFERENT PARTS OF THE REGULATORY STRUCTURE



REPORT ORGANIZATION



FRAMEWORK OBJECTIVES

- Develop a technology-neutral framework that provides the necessary guidance and criteria, ***to the NRC staff***, to produce a set of technology-neutral requirements for rule-making consideration
  - Safety expectations defined to establish Commission's expectations
  - Safety fundamentals defined to provide the safety targets
  - Risk objectives defined in quantitative terms that establish the risk acceptance criteria
  - Treatment of uncertainties

DESIRED CHARACTERISTICS

- Characteristics defined for an acceptable framework; how to measure that framework has accomplished its objective; examples
  - Traceable/defensible
  - Flexible
  - Risk-informed
  - Performance-based
  - Completeness
  - Uncertainty
  - Defense-in-depth
  - Consistency

FRAMEWORK

NRC's Overall Safety Mission

Atomic Energy Act and the Statutes that Amended It

Ensure Public Health, Safety and Security as a Result of Nuclear Reactor Operation and the Use of Nuclear Materials

Safety Philosophy

Complementary Approaches

Ch. 3

Protective Strategies

Safety fundamentals for safe NPP Design, Construction, Operation protect against unidentified uncertainties

Ch. 4

Risk Objectives & Design, Construction Operation Objectives

Provide safety requirements, analysis for achieving safety goals

PRA shows how levels of defense support safety goals

Ch. 5

Defense-in-Depth

DID decisions are based on results of PRA and DBA calculations compared with safety/risk objectives and design expectations. PRA evaluates the specific protective strategies against risk objectives and calculates the effects of identified uncertainties.

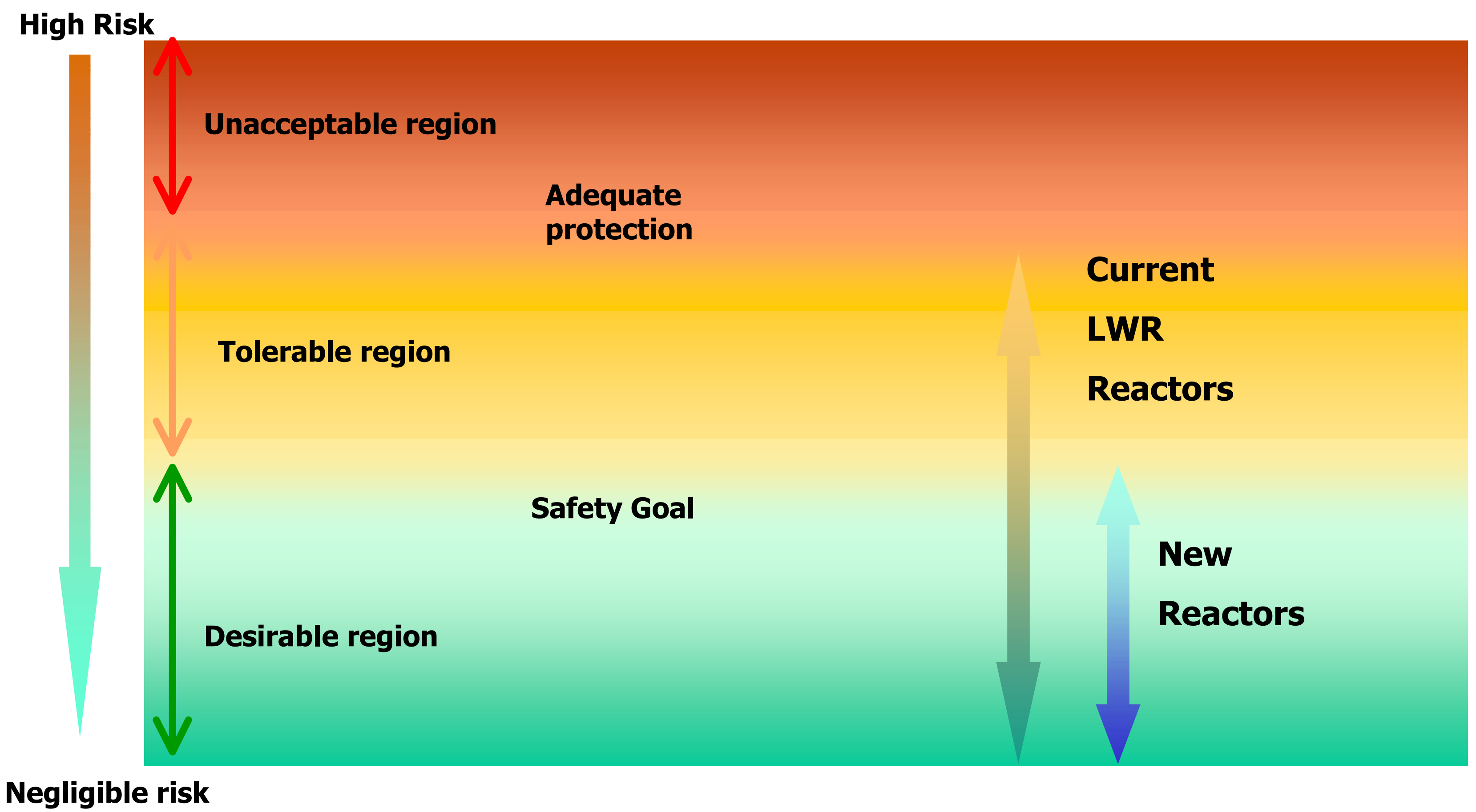
Logic confirming defense-in-depth focuses requirements

Ch. 6

Technology-Neutral Requirements

Technical requirements flow from the Framework; Administrative requirements provide assurance that analyses and plant conditions are maintained as assumed. Both can be performance-based.

FRAMEWORK SAFETY PHILOSOPHY



Safety Philosophy:
Stop events as early as possible

- Prevent
- Mitigate
- Limit
- Contain
- Respond

Safety Philosophy Implementation: Protective Strategies

- ***Protective Strategies:*** Safety fundamentals for safe NPP design, construction and operation
- Protective strategies provide a key element of defense-in-depth to protect against state-of-knowledge (epistemic) uncertainties* in completeness and modeling
- Top-down analysis leads to requirements during design, construction and operation

*While defense-in-depth will occur naturally in any competent design effort, the ***requirements*** for defense-in-depth are a response to uncertainty

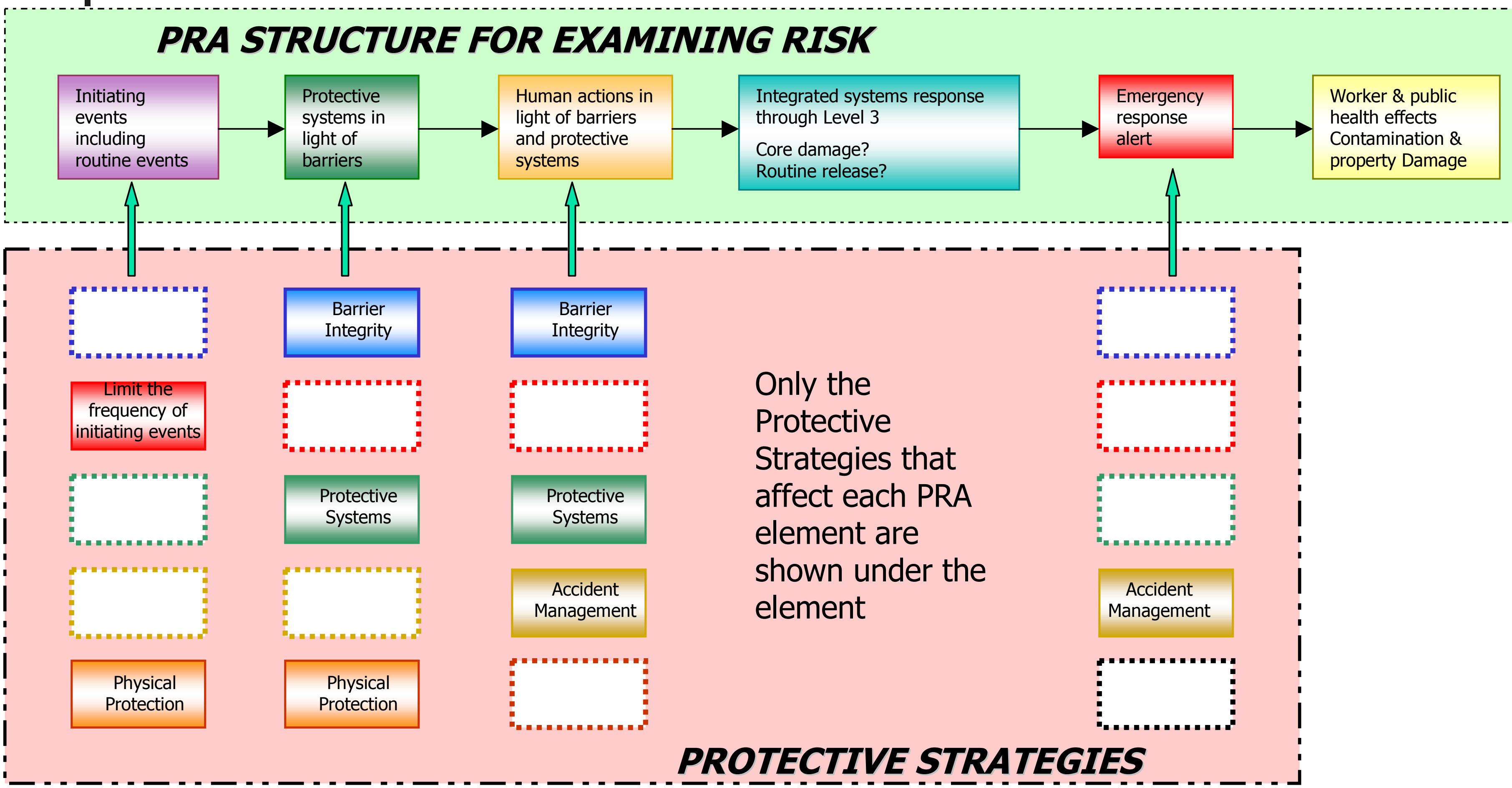
Safety Fundamentals: Protective Strategies

- What are the Protective Strategies?
  - Barrier integrity
  - Limit IE frequency
  - Protective Systems
  - Accident Management
  - (Physical Protection)
- Why are they sufficient?
  - Engineering judgment (defense-in-depth to protect against completeness & modeling uncertainties)
  - Mapping to elements of PRA

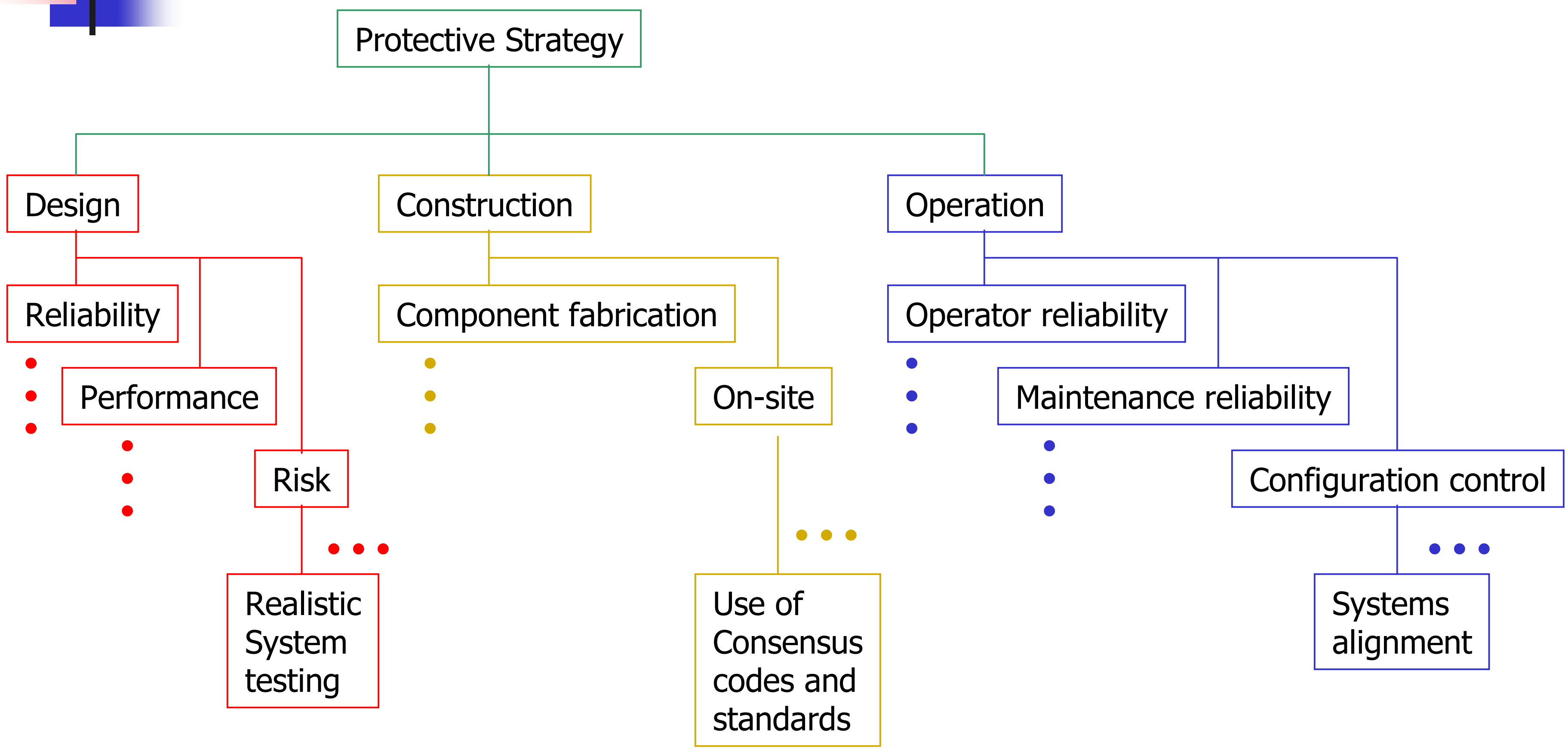
Protective Strategies

- Barrier Integrity
  - Functional barriers to limit the effects of reactor accidents
    - Physical barriers & physico-chemical barriers
  - Adequate to protect public from accidental radionuclide releases in light of uncertainties associated with barrier degradation
- Limit Initiating Event Frequency
  - Events that upset plant stability & challenge critical safety functions
    - All plant operating states
    - Any source of radioactive material on-site in any form
- Protective Systems
  - Adequate design and performance (reliability and capability) to satisfy the design assumptions regarding accident prevention and mitigation during all states of reactor operation
- Accident Management
  - Include emergency procedures, evacuation plans, drills and training

Relationship between Protective Strategies and Elements of PRA



Top-Down Analysis of Protective Strategies (example)



RISK/SAFETY OBJECTIVES

- Protection during normal operation
- Limited risk of accidental exposure
- Frequency–consequence plot used to illustrate overall desired safety
- Risk objectives to be written consistent with Commission Safety Goals (I.e., to achieve the level of safety defined by the safety goals)

RISK OBJECTIVES: PUBLIC RISK

- <u>Protection During Normal Operation</u>
- Provided by system of dose limits in Part 20
- Public dose limit of 100 mrem/year from licensed operation plus ALARA
- Consistent with recommendations of ICRP and NCRP

RISK OBJECTIVES: PUBLIC RISK (cont'd)

- Risk Limits of Accidental Exposure
- Based on ICRP-64 recommendations:

Dose ranges	Frequency ranges
Doses treated as part of normal exposures	1E-1 - 1E-2 per year
Stochastic effects only but above dose limits:	1E-2 - 1E-5 per year
Doses where some radiation effects are deterministic:	1E-5 - 1E-6 per year
Doses where death is the likely result:	< 1E-6 per year

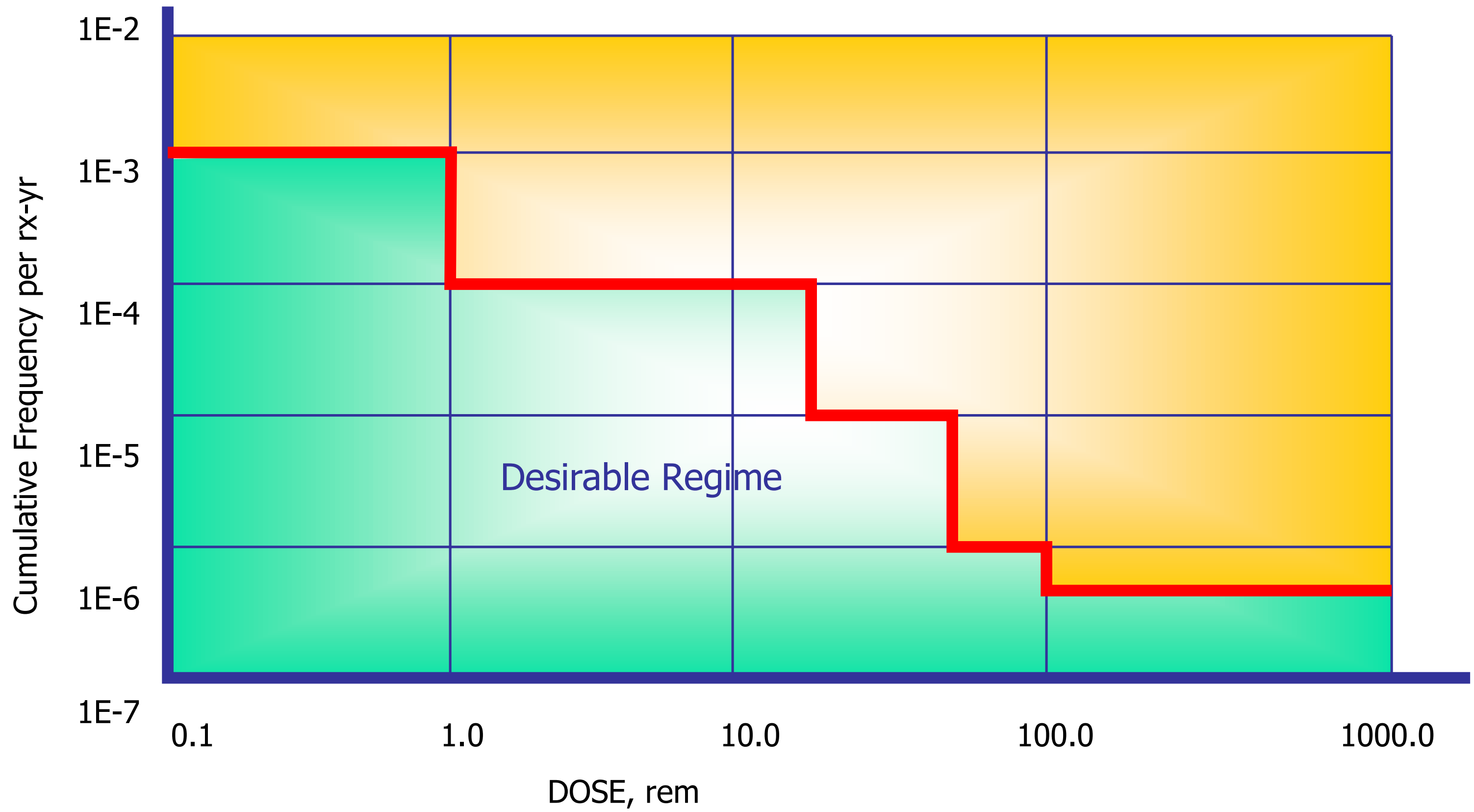
RISK OBJECTIVES: PUBLIC RISK (cont'd)

- Risk Limits of Accidental Exposure
- Proposed dose/frequency ranges for public accidental exposures

Dose Range	Frequency (per year)	Comment
100 mrem - 1 rem	1E-3	1 rem offsite triggers EPA PAGs
1 rem - 25 rem	1E-4	25 rem triggers AO reporting
25 rem - 50 rem	1E-5	50 rem is a trigger for deterministic effects, i.e., some early health effects are possible
50 rem - 100 rem	1E-6	In this range some early radiation health effect is likely
> 100 rem	5E-7	Above 100 rem, early health effects are quite likely and the frequency is based on the early fatality QHO of the reactor safety goal policy

RISK OBJECTIVES: PUBLIC RISK (cont'd)

Frequency-Consequence Curve



RISK OBJECTIVES: OPERATING STAFF

- ***No new risk goals proposed for protection of the operating staff during accidents***

Bases for new plants:

- main control room designed to protect the operating staff during all events which must be considered in the design
- development of procedures and accident management programs consider the environment (e.g., temperature, radiation) in which the local operator action is to take place and ensure the design and procedures provide sufficient protection to all the operators such that those actions can be safely accomplished without serious injury.

In addition:

- For radiation exposure the limits in 10 CFR 20.1206 “Planned Special Exposures” should be used as the measure to prevent serious injury for personnel outside the control room.
- For personnel inside the control room, limits similar to those in GDC-19 could be used. Scenario specific source terms may be used in the assessment, consistent with those used in other accident analyses.
- For other hazards (temperature, chemicals, etc.) other accepted limits should be applied.

RISK OBJECTIVES: LAND CONTAMINATION (ENVIRONMENT)

- Based on ensuring low likelihood of exceeding 10 CFR 140 – ENO criteria for land contamination and cleanup cost
- ENO land contamination value = 20 rem/yr to an individual
  - Keep latent cancer fatality risk below QHO
- ENO cleanup cost values
  - $2.5 million for an individual
  - $5.0 million collectively
  - Keep annualized risk below annualized risk to value of human life used in Regulatory Analysis Guidelines

RISK OBJECTIVES: SURROGATES

- <u>Accident Prevention Criterion</u>
  - Serves as a surrogate for the latent fatality QHO
  - Derived from latent fatality QHO ($2X10^{-6}$/yr) considering only the effects of atmospheric dispersion:
    - No dependence upon reactor size, timing of release, form of source term
    - No dependence upon EP
  - Proposed criterion is – $1X10^{-5}$/ry (mean value)
  - Definition of what constitutes accident prevention will be technology specific
  - Applicant can propose an alternative criterion, taking credit for plant specific characteristics

RISK OBJECTIVES: SURROGATES (cont'd)

- Accident Mitigation Criterion
  - Serves as a surrogate for the early fatality QHO
  - Derived from early fatality QHO ($5x10^{-7}$/ry) considering only the effects of atmospheric dispersion:
    - No dependence upon reactor size, timing of release, form of source term
    - No dependence upon EP
  - Proposed criterion is – $1x10^{-6}$/ry large release frequency (mean value)
  - Large release is that associated with one or more early fatalities offsite
  - Applicant can propose an alternative criterion, taking credit for plant characteristics

DESIGN OBJECTIVES

- Event Selection:
  - Ensures risk assessments consider a sufficient range of events to adequately assess risk consistent with the Safety Goals
  - Provides for categorization of initiating events and event sequences for deterministic treatment
  - Proposed criteria:
    - frequent events $>10^{-2}$/ry (mean value)
    - infrequent events $<10^{-2}$/ry but $>10^{-5}$/ry (mean value)
    - rare events $<10^{-5}$/ry but $>10^{-7}$/ry (mean value)
  - Initiating events less than 10^{-7}/ry (mean value) do not have to be considered for licensing purposes

DESIGN OBJECTIVES (cont'd)

- Selection and Treatment of AOOs/DBAs
  - Based on probabilistic event categorization criteria presented earlier
  - Select event sequences with highest consequences and/or conditionally closest to core damage as AOOs/DBAs
  - Helps ensure risk-informed (not risk-based) approach
  - Helps ensure low consequences for more frequent events
  - Provides for linkage to 10 CFR 100

DESIGN OBJECTIVES (cont'd)

- Proposed deterministic acceptance criteria:
  - Frequent events= AOOs which must
    - not exceed 100 mrem at EAB
    - not result in loss of core cooling or fuel damage
    - maintain at least 2 barriers to the uncontrolled release of radioactive material
  - Infrequent events= DBAs which must
    - meet current siting criteria (or a fraction thereof consistent with F-C curve)
    - not result in sustained loss of core cooling or fuel melting
    - maintain at least one barrier to the uncontrolled release of radioactive material
  - External event DBA selection – use current guidance

DESIGN OBJECTIVES (cont'd)

- Probabilistic Safety Classification Criteria
  - Criteria to be applied to all plant SSCs, not just those used in DBA analysis
  - Use risk importance measures and defense-in-depth considerations to determine safety classification
  - Build upon work done in developing 50.69 rulemaking:
    - Risk importance measures
    - System vs. component

DESIGN OBJECTIVES (cont'd)

- Analysis Guidelines
  - Best estimate analysis with quantification of uncertainties
  - Risk criteria – use mean values
  - AOO/DBA criteria – 95% confidence level
  - Scenario specific equipment failures/human errors (no SFC)*
  - Scenario specific source terms

*will also affect design

CONSTRUCTION OBJECTIVES

- Field fabrication – traditional NRC role (assessing NUREG-1789 for implications)
- Factory fabrication – modular construction – role of NRC?
- Non- U.S. fabrication – how to ensure applicant controls/ensures quality?
- Fuel quality (e.g., HTGR fuel) – how to ensure licensee controls/ensures quality over the life of the plant?
- Role of PRA in identifying key areas for inspection/control?

OPERATIONAL OBJECTIVES

- Normal Operation
  - Training, procedures, technical specifications, etc.

- Accident Management
  - Applicant/licensee must have process and procedures to address beyond design basis accidents
  - Applicant/licensee must have an EP program (discussed further under defense-in-depth)

- Protection of Operating Staff
  - Control room must be designed to remain habitable for events external to the control room (build upon GDC-19)
  - Personnel protection and access must be considered when developing AM program
    - 10 CFR 20.1206 dose criteria for operating staff outside the control room

Treatment of Uncertainties

- Approach
- Types of uncertainties
- Defense-in-depth
  - Principles
  - Model
  - Application

Approach

- Concept of Defense-in-Depth a fundamental part of NRC safety philosophy to treat uncertainties
  - Regulatory Guide 1.174
  - Commission White Paper
  - ACRS papers
- Consists of multiple successive layers of barriers and lines of defense against undesirable consequences
- Builds on past practice, but will result in more consistent and traceable implementation

Types of Uncertainties

- Random or stochastic (aleatory)
- State of knowledge (epistemic)
  - Parameter uncertainty – applies to basic data used in analyses (partially random)
  - Model uncertainty – applies to data limitations, analytical physical models, acceptance criteria
  - Completeness uncertainty – applies to
    - risk contributors not thought of
    - Considerations for which adequate analysis methods do not exist
    - Risk contributors deliberately excluded from analysis

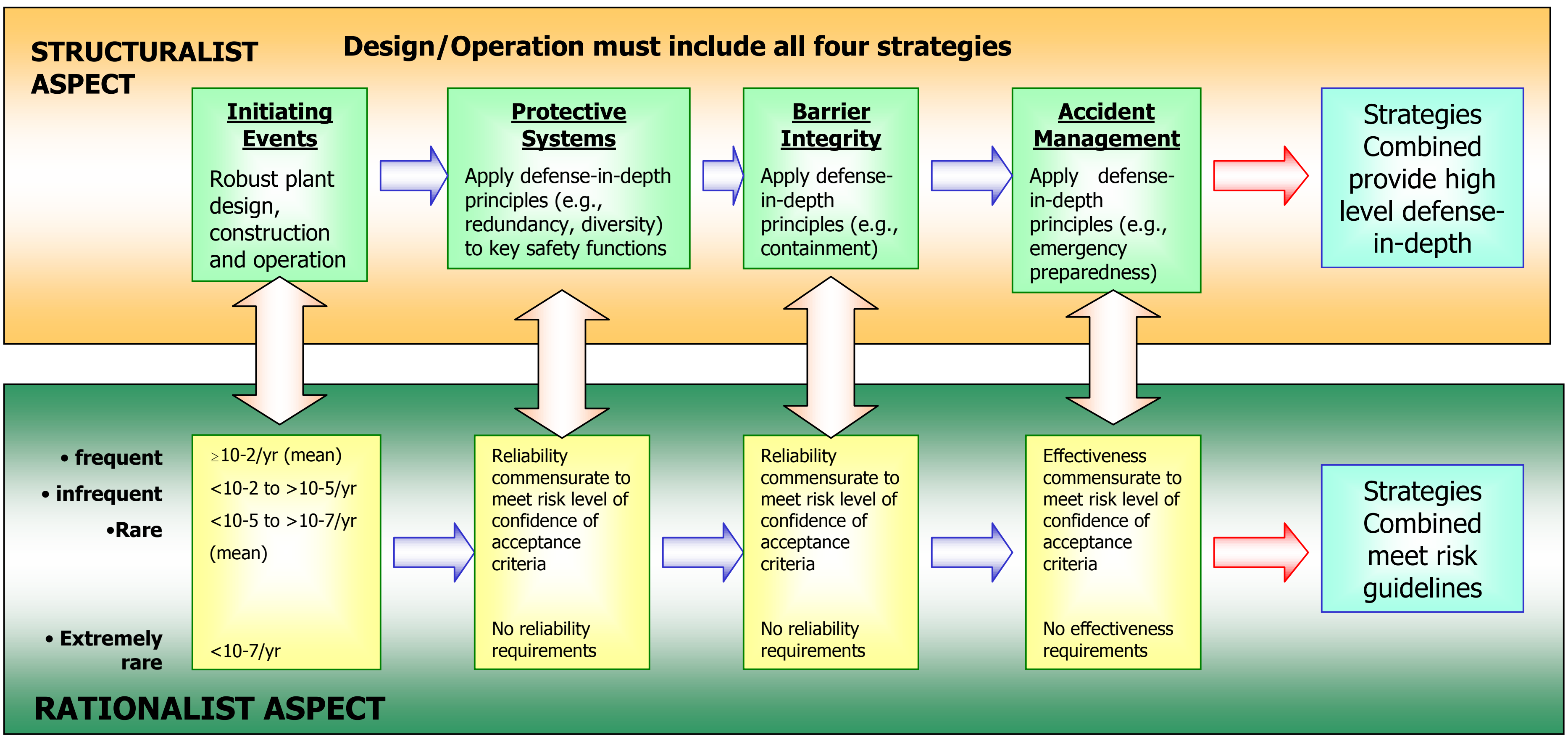
Defense-in-Depth Principles

- Incorporates both accident prevention and mitigation measures
- Key safety functions not dependent on a single element of design, construction, or operation
- Uncertainties in SSCs and human performance accounted for in reliability goals and calculations
- Siting consistent with intent of Part 100 and Regulatory Guide 4.7

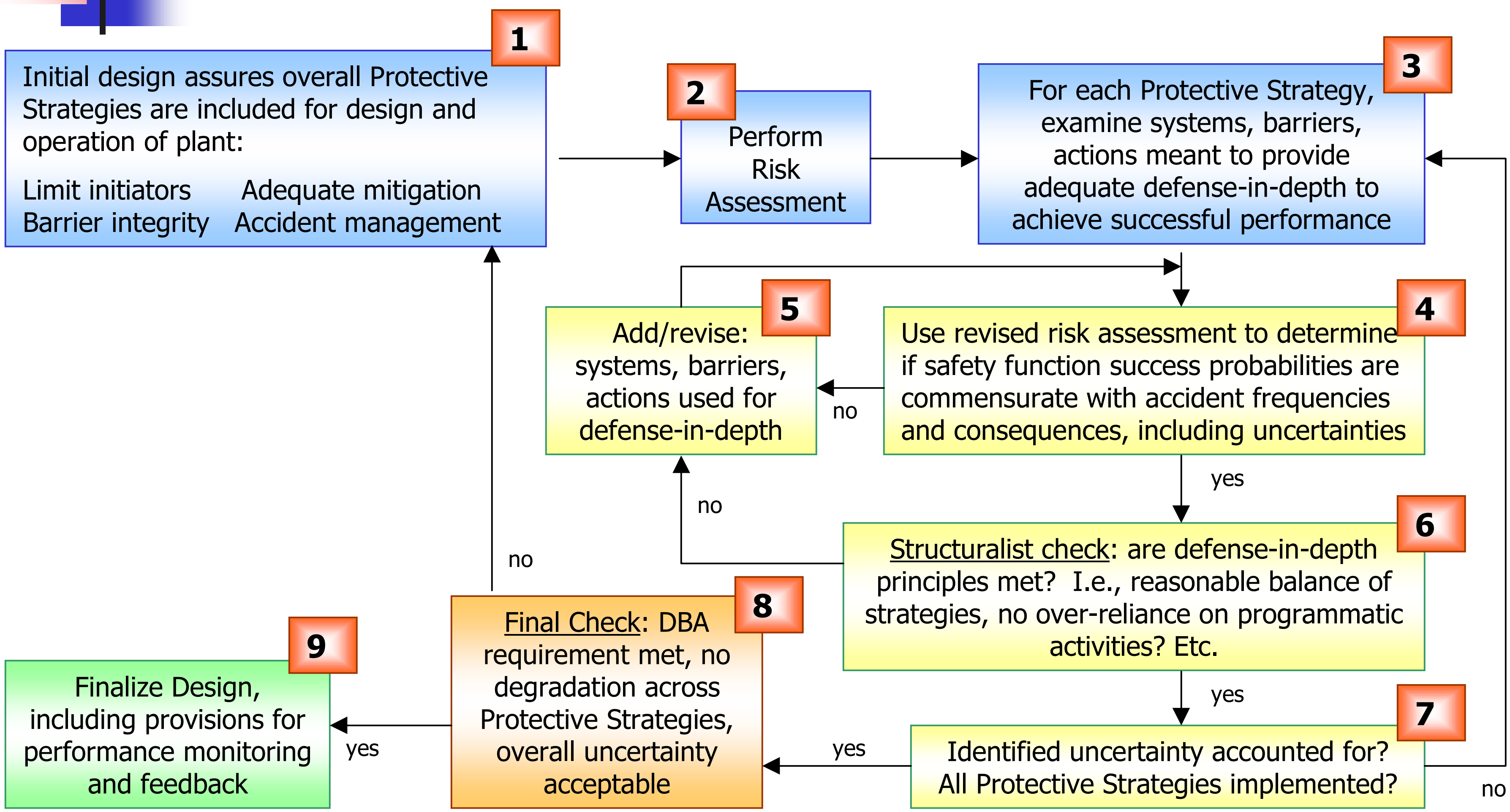
Defense-in-Depth Model

- Combination of structuralist and rationalist
  - Structuralist at high level
    - Qualitative (deterministic) requirements to assure accomplishment of protective strategies and their key safety functions
    - Addresses primarily completeness uncertainty
  - Rationalist at lower levels
    - Quantitative (probabilistic) performance goals to assure achievement of each protective strategy at required confidence
    - Specific requirements to ensure uncertainties are accounted for (safety margins, level of confidence, monitoring and feedback)
    - Addresses primarily modeling and parameter uncertainties

Defense-in-Depth Model



Defense-in-Depth Application



How DID addresses uncertainties

- Completeness uncertainty addressed by structuralist elements: barrier integrity, limit initiating events, reliable mitigating systems, accident management
- Parameter uncertainties remaining after research and testing programs addressed mainly by rationalist elements
- Model uncertainties addressed by both rationalist and structuralist elements
- Monitoring and feedback important for ensuring all uncertainties were adequately met (embodies concepts of living PRA)

How DID addresses uncertainties (cont'd)

- Structuralist Elements:
  - Redundancy and diversity for key safety functions (Reactor shutdown, decay heat removal, barriers to release of large quantities of radioactive material)
  - Containment versus confinement (policy decision)
  - Accident management and emergency preparedness
- Rationalist Element:
  - Reliability goals
  - Overall risk goals
  - Monitoring and feedback

DEVELOPMENT OF TECHNOLOGY-NEUTRAL REQUIREMENTS

- The framework describes the overall objectives, scope, criteria and technical basis to support the development of a set of technology neutral, risk-informed and performance-based requirements for future plant licensing.

- The final step in the framework is to define the scope and content of the requirements using a systematic process based upon the approach and criteria in the framework.
  - Technical and administrative requirements
  - Requirements for design, construction and operation
  - Full power, shutdown, refueling

- This step will identify topics only – writing the requirements is Part 2

DEVELOPMENT OF TECHNOLOGY-NEUTRAL REQUIREMENTS (cont'd)

- The process to define the scope and content of the requirements consists of the following steps:
  - Identify what needs to be done to ensure the protective strategies are accomplished (key questions)
  - Use the risk and defense-in-depth criteria and processes to help define how to accomplish what needs to be done.
  - Identify topics for administrative requirements to ensure structure for future plant licensing is self contained. Example topics include:
    - PRA scope and quality
    - Analysis methods
    - Research and development
    - License-by-test
    - Change control (recognizing reality of living PRA versus finality of design certification)

DEVELOPMENT OF TECHNOLOGY-NEUTRAL REQUIREMENTS (cont'd)

Structure for key questions:

- Design
  - What performance is needed?
  - What reliability is needed?
  - What good design practices should be used?
  - What confirmation of design features is needed?
- Construction
  - What good construction practices should be used?
  - How is construction to be confirmed?
- Operation
  - How is reliable operation ensured?
  - How is the plant configuration controlled?
  - How is the performance to be monitored?

DEVELOPMENT OF TECHNOLOGY-NEUTRAL REQUIREMENTS (cont'd)

- Conduct a final check for completeness, practicality, implications
  - Completeness
    - check against Commission Policy Statements, 10 CFR 50, IAEA Safety documents, etc.
  - Practicality
    - check against future plant designs (VHTR via DOE; ACR-700)
  - Implications
    - check to see if problem areas of the past are prevented (e.g., DCH, MK-I containment shell melt thru)
    - Check against current LWR

DEVELOPMENT OF TECHNOLOGY-NEUTRAL REQUIREMENTS (cont'd)

PRA Scope and Quality

- Full-scope PRA will be required
- What is meant by "full-scope" may need to be revisited
- Living PRA will be required
- Uncertainties will need to be addressed
- Current standards will need to be reviewed and modified as appropriate for new designs

Glossary and Appendices

- Glossary: Provide a consistent and common understanding of key terms

<u>Appendices</u>:

- A – Current Quantitative Guidelines
- B – Safety Characteristics of the New Reactors
- C – PRA Quality Needs for New Reactors
- D – Assessment of Part 50 for New Reactors
- E -- Guidance for the Formulation of Performance-Based Requirements

Next Steps -- Schedule

- Part 1 (Draft): December 2004, SECY paper to Commission
  - release NUREG (Part 1) for public review and comment
- Part 1 (Final): 2005 (Technology-Neutral Framework)
- Part 2: 2005 (technology neutral requirements)
- Part 3: 2006 (technology specific framework)