U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Public Workshop on Development of Risk Metrics to Support Implementation of Risk-Informed Programs for Advanced Reactors

July 18, 2024

Workshop Overview

- NRC Opening Remarks
- Review Workshop Purpose
- Review Meeting Agenda
  - External stakeholder presentations
  - NRC staff presentations
- Open Discussion
- Public Comments

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Public Workshop on Development of Risk Metrics to Support Implementation of Risk-Informed Programs for Advanced Reactors

Opening Remarks

Division of Advanced Reactors and Non-Power Production and Utilization Facilities (DANU)
of NRC's Office of Nuclear Reactor Regulation (NRR)

Workshop Purpose

- Gather input on strategy for establishing risk metrics for Non-LWRs (NLWRs).
- Focus on technical aspects of risk metric development and use.
- Identify the many risk metric connections to regulatory programs.
- Focus staff ideas for further work on risk metrics for NLWRs.
- Discuss NLWR operating experience data, methods, and tools to support risk estimation.

Project Drivers

Understanding that LWR risk metrics may not be suitable for NLWR designs.

Commission direction to staff on Part 53 rule

SRM-SECY-23-0021 (ADAMS ML24064A039)

- Prepare to assess applicant-proposed comprehensive plant risk metric (or set of metrics) and associated methodology.
- Development of metrics for different plant designs (e.g., LWRs, gas-cooled reactors, molten salt reactors).
- The risk metric(s) and methodology should inform NRC's risk-informed decision making (including applications after initial licensing).

SRM-SECY-23-0021 provides motivation and direction to staff related NLWR risk metrics, but this workshop is *not* part of the Part 53 rulemaking.

NRC Tasks on Evaluating Risk of Advanced Reactors

Task 1

- Development of technology-inclusive risk metrics that can be applied to NLWRs.
  - Output: White paper outlining vision and strategies for risk metrics and tools to support risk-informed licensing and oversight for NLWRs.
  - **Includes topics to be discussed at this workshop**

Task 2

- Developing methods, tools, and processes to collect, analyze, and use data to support RIDM for advanced reactors.
  - **Includes topics to be discussed at this workshop**

NRC Tasks on Evaluating Risk of Advanced Reactors (continued)

Task 3

- Scoping study to evaluate the risk and modeling approaches for a selected advanced reactor design.
  - Effort expected to be focused in fiscal years 2026 – 2028.

Task 4

- Enhancing RIDM guidance and framework for advanced reactors.
  - Effort expected to be focused in fiscal years 2026 – 2029.

Focus of NRC Working Group

Risk metric(s) should be comprehensive in covering all radiological sources, all operating states, and all internal and external hazards.

The Working Group's initial focus:

- Risk metrics that express **plant risk** so they can provide indications of meeting **desired ultimate risk objectives**, such as the Quantitative Health Objectives (QHOs).
- Initial focus on **NLWRs**
  - For example, molten salt reactors, high-temperature gas-cooled reactors.
- Initial focus on radiological sources from reactor's primary system.

Public Workshop Agenda (part 1 of 4)

Time	Topic	Speaker
8:30 am – 8:40 am	NRC Opening Remarks	NRC
8:40 am – 8:50 am	Purpose of Public Workshop	Jeffery Wood, NRC
8:50 am – 9:20 am	Review of Applicant-Proposed Risk Metrics for Commercial Nuclear Power Plants Licensed Under Proposed 10 CFR Part 53 – Development of Interim Staff Guidance	Marty Stutzke, NRC
9:20 am – 10:05 am	NIA Perspectives on Comprehensive Risk Metrics	Patrick White, Nuclear Innovation Alliance (NIA)
10:05 am – 10:35 am	EPRI's Risk Metric Work	Eric Thornsbury, Electric Power Research Institute (EPRI)
10:35 am – 10:45 am	*Break*	

Public Workshop Agenda (part 2 of 4)

Time	Topic	Speaker
10:45 am – 11:15 am	Breakthrough Institute Perspectives on Risk Metrics	Adam Stein, The Breakthrough Institute
11:15 am – 11:45 am	Challenges and Lessons Learned in Applying NEI 18-04 During Active Design: The eVinci™ Microreactor	Kyle Hope, Westinghouse Electric Company
11:45 am – 12:15 pm	Hazard Level Selection for LMP	Jessica Maddocks, X-Energy
12:15 pm – 1:15 pm	*Lunch Break*	

Public Workshop Agenda (part 3 of 4)

Time	Topic	Speaker
1:15 pm – 1:45 pm	UCS Views on Advanced Reactor Risk Metrics	Ed Lyman, Union of Concerned Scientists (UCS)
1:45 pm – 2:15 pm	USNIC Perspectives on Risk Metrics	Cyril Draffin, U.S. Nuclear Industry Council (USNIC)
2:15 pm – 2:30 pm	NRC Plans for Work on Operating Experience, Methods, and Tools to Support Advanced Reactor Risk	John Lane, NRC
2:30 pm – 3:00 pm	NLWR Data Insights and Experience	Dave Grabaskas, Argonne National Laboratory (ANL)
3:00 pm – 3:30 pm	Advanced Reactor Operating Experience Data Analysis to Support Risk Estimation and the Intertwining of Data, Decisions, and Reliability	Sai Zhang and Diego Mandelli, Idaho National Lab. (INL)
3:30 pm – 3:40 pm	*Break*	

Public Workshop Agenda (part 4 of 4)

Time	Topic	Speaker
3:40 pm – 4:10 pm	NRC Preliminary Thoughts on Risk Metrics for NLWRs	Matthew Humberstone and Gerardo Martinez-Guridi, NRC
4:10 pm – 4:50 pm	Open Discussion	All
4:50 pm – 5:00 pm	Public Comments	NRC
5:00 pm	Adjourn	

NRC Working Group on Advanced Reactor Risk Metrics

Matt Humberstone [1]

Gerardo Martinez-Guridi [1]

Hanh Phan [2]

Marty Stutzke [2]

Jeffery Wood [1]

- [1] NRC Office of Nuclear Regulatory Research (RES) / Division of Risk Analysis (DRA)
- [2] NRC Office of Nuclear Reactor Regulation (NRR) / Division of Advanced Reactors and Non-power Production Utilization Facilities (DANU)

Questions?

Comments or questions on workshop purpose?

Acronyms and Abbreviations

- ANL – Argonne National Laboratory
- CFR – Code of Federal Regulations
- EPRI – Electric Power Research Institute
- INL – Idaho National Laboratory
- LMP – Licensing Modernization Project
- NEI – Nuclear Energy Institute
- NIA – Nuclear Innovation Alliance
- NRC – U.S. Nuclear Regulatory Commission
- NLWR – Non-Light-Water Reactor
- QHO – Quantitative Health Objective
- RIDM – Risk-Informed Decision Making
- UCS – Union of Concerned Scientists
- USNIC – U.S. Nuclear Industry Council

Review of Applicant-Proposed Risk Metrics for Commercial Nuclear Plants Licensed Under Proposed 10 CFR Part 53 - Development of Interim Staff Guidance -

Marty Stutzke

Senior Technical Advisor for Probabilistic Risk Assessment

Division of Advanced Reactors and Non-Power Production and Utilization Facilities (DANU)

Office of Nuclear Reactor Regulation (NRR)

July 18, 2024

Agenda

- Review of SRM-SECY-23-0021, Item 2
- Development of interim staff guidance (ISG):
  - ISG applicability
  - Terminology related to risk metrics
  - Review flowchart
  - Change provisions
  - Intellectual property
- Next steps

SRM-SECY-23-0021, Item 2

- Disapproved codification of the QHOs
- Revise draft § 53.220 to specify that applicants must propose a comprehensive plant risk metric (or set of metrics) and a description of the associated methodology:
  - Explain initial and boundary conditions
  - Explain assumptions
- "Cumulative" and "comprehensive" mean that the risk metric(s) should approximate the total overall risk from the facility:
  - Screening tools and bounding or simplified methods may be used for any mode or hazard with an acceptable technical basis
  - Address uncertainties
- NRC's approval of the metric or set of metrics is not, by itself, an indicator of adequate protection
- Ensure that approved metric(s) and methodology cannot be changed without prior NRC approval
- The metric(s) and associated methodology will not constitute a real-time requirement
- Conduct tabletop exercises and widespread public engagement with interested external stakeholders
- Seek comment on whether and how comprehensive plant risk metrics should be codified or otherwise memorialized

Tentative ISG Scope

- Addresses the NRC staff review of applicant-proposed risk metrics for commercial nuclear plants under proposed 10 CFR Part 53:
  - Light-water reactor (LWR) and non-LWR technologies
  - Radiological risks (separate guidance is being developed for the assessment of the risk of permanent injury to the public due to the health effects of the chemical hazards of licensed material)
- Initial applications for:
  - Standard design approvals (SDAs)
  - Standard design certifications (DCs)
  - Manufacturing licenses (MLs)
  - Construction permits (CPs)
  - Operating licenses (OLs)
  - Combined licenses (COLs)
- Changes to risk metrics or risk performance objectives after initial licensing
- Topical reports submitted by:
  - Individual applicants, permit holders, or license holders
  - Third parties, e.g., designers, industry groups
- Industry consensus standards
- White papers

How the proposed risk metric is presented to the staff determines what NRC internal process applies.

- NRC Management Directives
- NRR Office Instructions

Tentative Terminology

Possible terms to be defined in the ISG:

1. Risk metric (RM)
2. Comprehensive risk metric
3. Risk performance objective (RPO)
4. Risk surrogate

Example for Discussion

For all plants, IEFR $\leq 5 \times 10^{-7}$/plant-year

Statement of Applicability

- Technology-inclusive or reactor specific?
- What source(s)?
- What POSs?
- What hazards(s)?

Risk Metric (RM)
Calculated by the PRA

Risk Performance Objective (RPO)
A risk performance objective is a preestablished, indicative value of the risk metric that is used during risk-informed decision making to gauge plant safety.

Tentative Terminology (Continued)

Risk Surrogate – general form

If [risk surrogate is met], then [risk metric is met]

Example

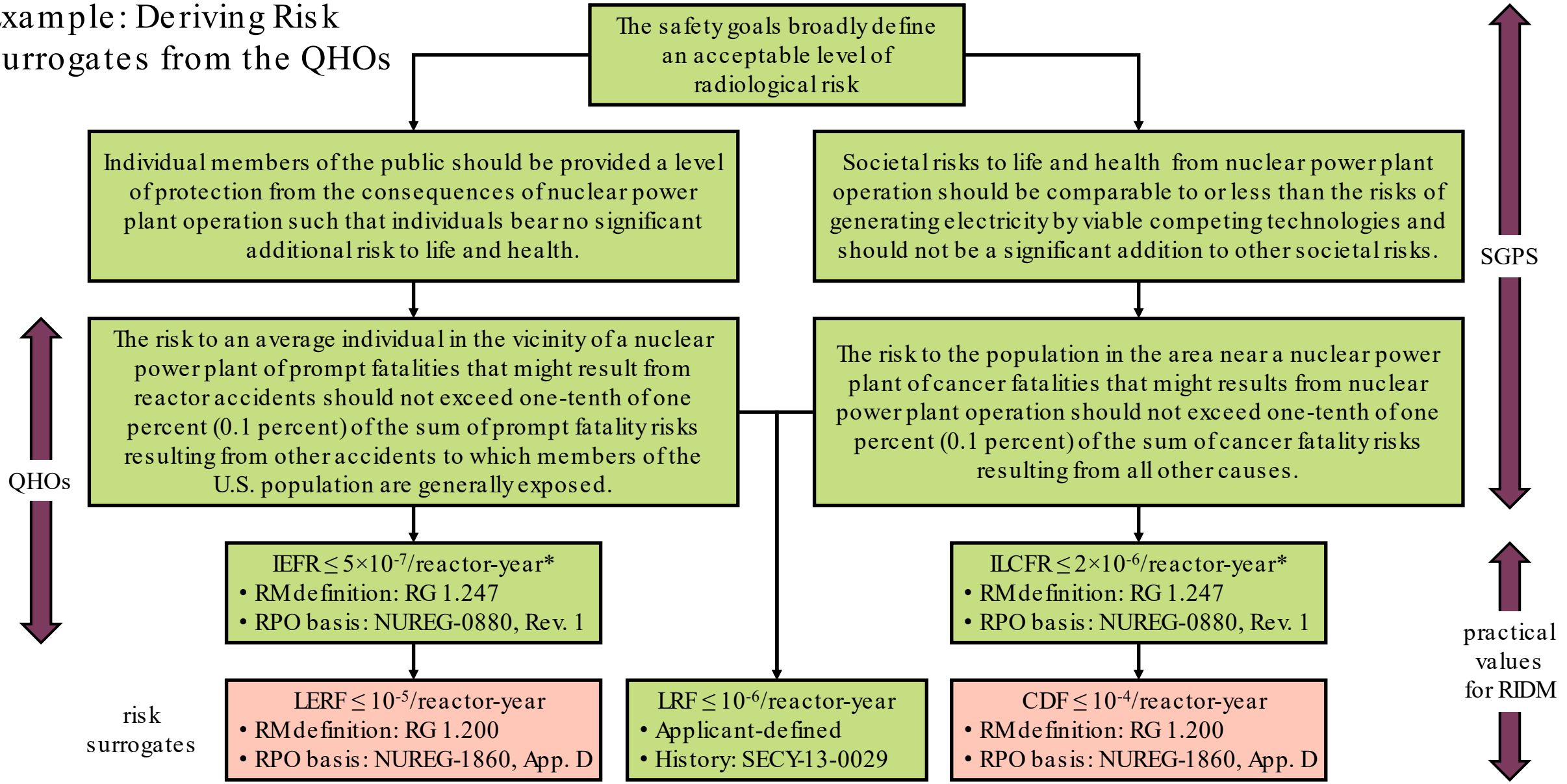
For LWRs, if CDF $\leq 10^{-4}$/r-y, then ILCFR $\leq 2 \times 10^{-6}$/r-y

Question

For LWRs, if HCLPF $\geq$ 1.67 SSE,
then seismic risk is acceptable (SRM-SECY-93-087)

- Is the HCLPF (high confidence of low probability of failure) developed by a PRA-based seismic margins analysis (SMA) a "risk metric" or a "risk surrogate?"
- Note: The 1.67 multiplier has not yet been accepted for non-LWRs

Example: Deriving Risk Surrogates from the QHOs



*LMP (NEI 18-04, Rev. 1, as endorsed in RG 1.233), uses the QHOs on a per plant basis

technology-inclusive

LWR-specific

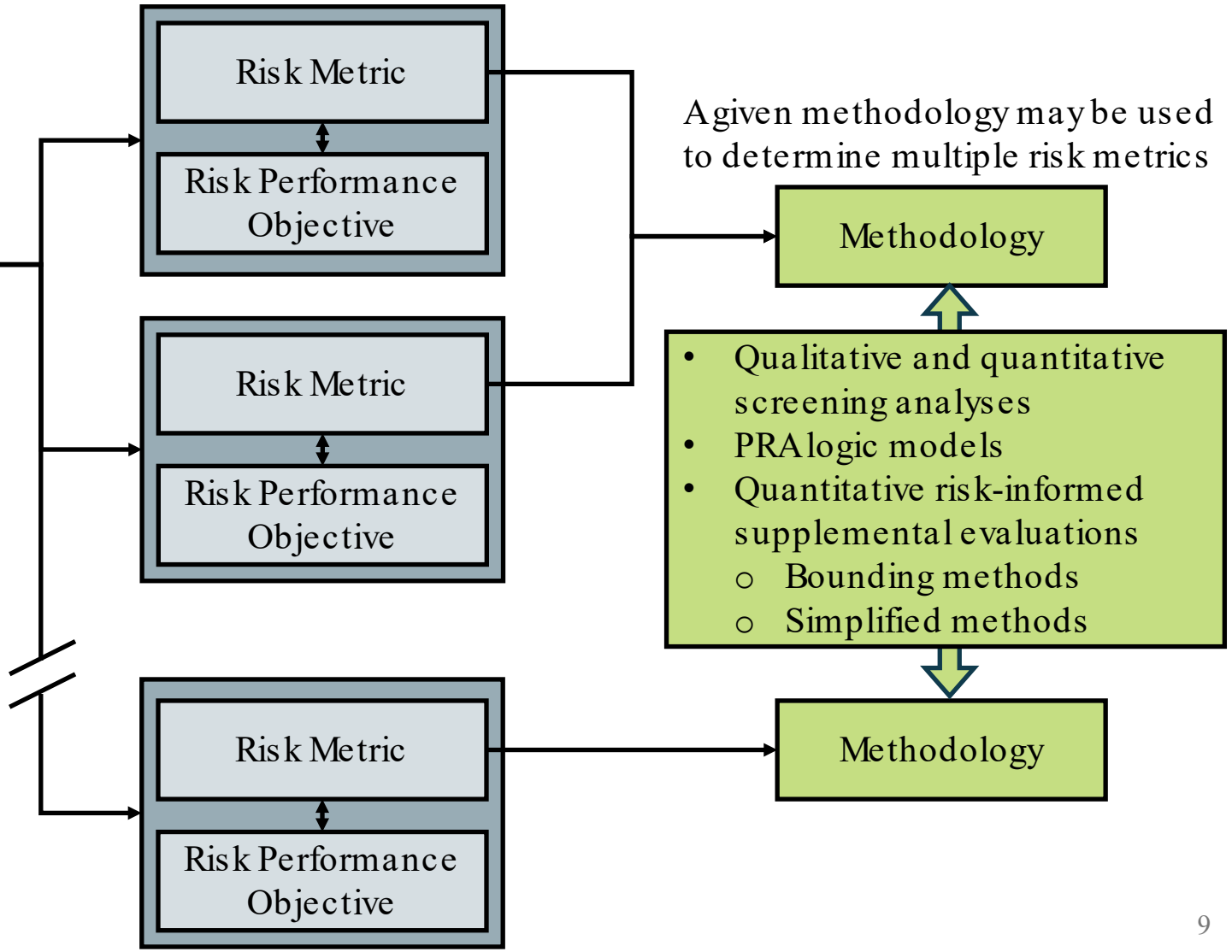
Tentative ISG Overarching Principles

- The ISG provides guidance to NRC staff reviewers
- Review should ensure that the proposed risk metrics and associated risk performance objectives are fit-for-purpose:
  - "Form follows function" - Louis Sullivan
  - "Start with the end in mind" - Stephen Covey
- Review should ensure consistency with Commission policies and previously accepted risk metrics and risk performance objectives to help achieve an equivalent level of safety
- Applicants may use previously accepted risk metrics and risk performance objectives, when applicable, which improves review efficiency

Tentative ISG High-Level Concept

Uses of the PRA
- Meet regulations
- Demonstrate that Commission expectations in policy statements have been achieved
- Support voluntary risk-informed applications

Propose a risk metric (or set of metrics) and associated risk performance target(s) that collectively:
- Approximates the total overall risk
  - All radiological sources
  - All plant operating states
  - All internal and external hazards
- Supports the intended uses of the PRA

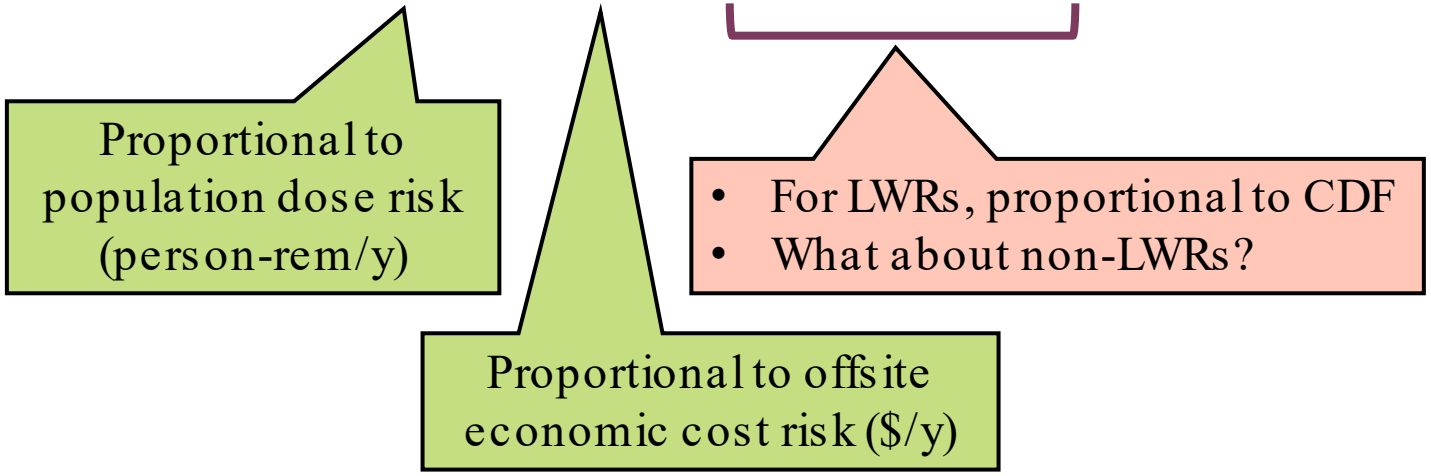


Regulations Related to Risk Metrics

- Proposed § 53.220 - Safety criteria for licensing-basis events other than design-basis accidents
  - Numerous references to proposed § 53.220 throughout proposed Part 53
  - Remember that under Part 53, a commercial nuclear plant means a facility consisting of one or more commercial nuclear reactors and associated co-located support facilities, including the collection of buildings, radionuclide sources, and SSCs. Accordingly, comprehensive risk metrics must include the risks from:
    - Multi-reactor event sequences
    - Non-reactor event sequences
- Proposed § 53.440(k) – Chemical hazards
  - Relation of methods for analyzing the risk of permanent injury to the public due to the health effects of the chemical hazards of licensed material to methods used to calculate radiological risk metrics?
- 10 CFR Part 51 – Severe accident mitigation design alternatives (SAMDAs)
  - Required for DCs, MLs, CPs, OLs, and COLs
  - Not required for SDAs
  - Relation to risk metrics, methods to calculate risk metrics, and risk performance objectives used in the safety analysis?

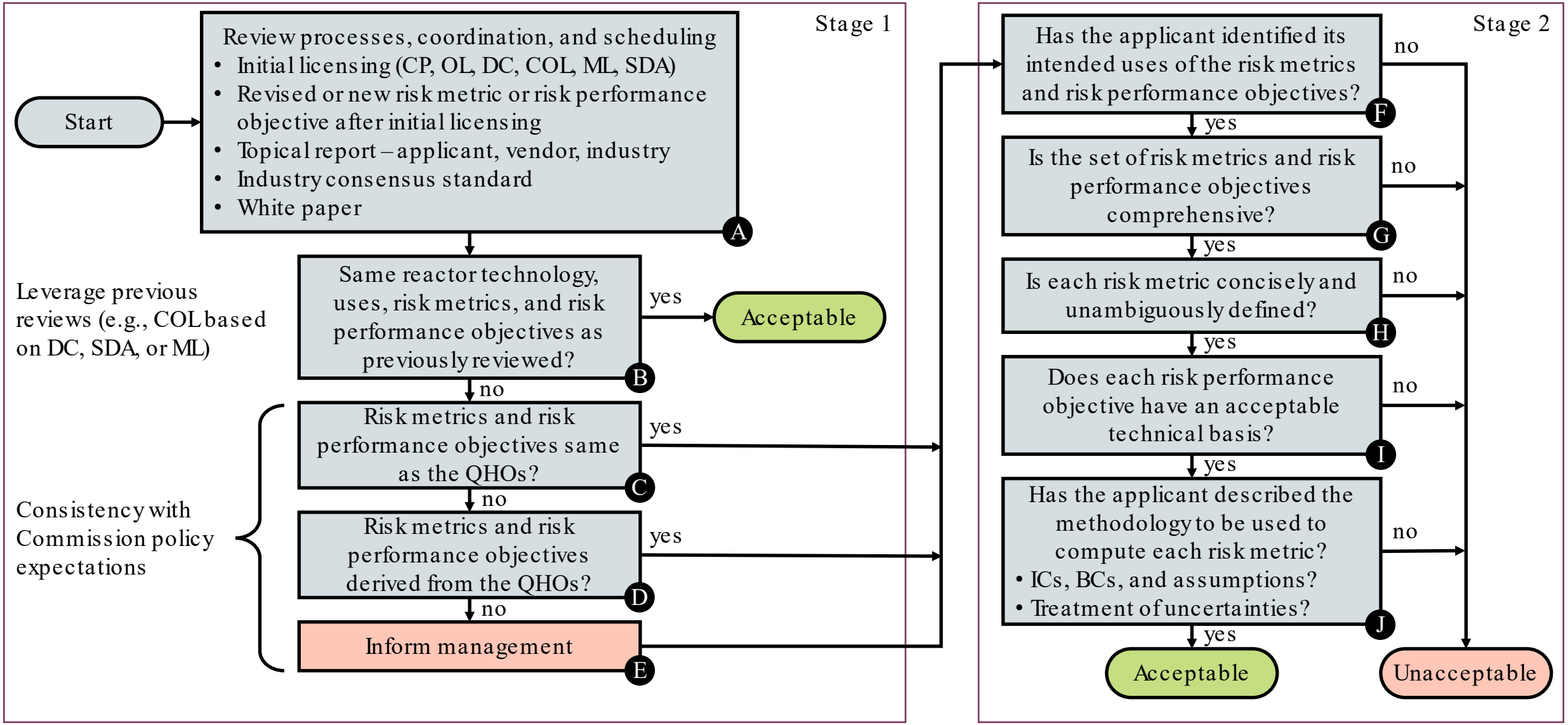
Risk Metrics and SAMDA Analysis

$$NPV = (APE + AOC + AOE + AOSC) - COE$$



NPV	=	Net present value of current risk ($)
APE	=	Present value of averted public exposure ($)
AOC	=	Present value of averted offsite property damage costs ($)
AOE	=	Present value of averted occupational exposure ($)
AOSC	=	Present value of averted onsite costs ($)
COE	=	Cost of any enhancement implemented to reduce risk ($)

Tentative ISG Review Process



Other Topics

- Change Provisions
  - Type of licensing process:
    - CPs – attach as a permit condition
    - MLs, OLs, and COLs – attach as a license condition
    - DCs:
      - Not certification information (analogy: not Tier 1 information under Part 52)
      - Include in the DCD
    - SDAs – Include in the SDA
  - Subject to relevant change provisions in proposed Part 53
- Intellectual Property
  - The NRC staff recognizes that applicants, licensees, and industry organization may invest considerable resources in proposing risk metrics.
  - NRR Office Instruction LIC-204, "Handling Requests to Withhold Proprietary Information from Public Disclosure."
  - The Commission's PRA Policy Statement (60 FR 42622; August 16, 1995): "PRA evaluations in support of regulatory decisions should be as realistic as practicable and appropriate supporting data should be publicly available for review."

Next Steps

- The ISG on staff review of applicant proposed risk metrics is a separate effort (i.e., the ISG will not be not included in the Part 53 rulemaking package).
  - Goal is to issue the ISG when Part 53 is finalized.
- Part 53 rulemaking schedule:
  - September 4, 2024: Send revised proposed Part 53 to the Commission
  - Early October: Publish proposed Part 53 in the Federal Register; start of public comment period
- The ISG will be informed by:
  - Comments and discussion during this workshop
  - Public comments on the proposed Part 53 (late 2024 – early 2025)
  - Future workshops (to be determined)

Acronyms and Initialisms

BC	boundary condition
CDF	core damage frequency
CFR	Code of Federal Regulations
COL	combined license
CP	construction permit
DANU	Division of Advanced Reactors and Non-power Production and Utilization Facilities
DC	standard design certification
FR	Federal Register
HCLPF	high confidence of low probability of failure
IC	initial condition
IEFR	individual early fatality risk
ILCFR	individual latent cancer fatality risk
ISG	interim staff guidance
LERF	large early release frequency
LRF	large release frequency
LWR	light-water reactor
ML	manufacturing license
Non-LWR	non-light-water reactor
NRC	Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation
POS	plant operating state
PRA	probabilistic risk assessment
OL	operating license
QHOs	quantitative health objectives
RM	risk metric
RG	regulatory guide
RIDM	risk-informed decision make
RPO	risk performance objective
SAMDA	severe accident mitigation design alternatives
SDA	standard design approval
SMA	seismic margins analysis
SRM	staff requirements memorandum
SSCs	structures, systems, and components
SSE	safe shutdown earthquake

References

- SRM-SECY-23-0021, "Staff Requirements – SECY-23-0021 – Proposed Rule: Risk-Informed, Technology-Inclusive Regulatory Framework For Advanced Reactors (RIN 3150-AK31)," March 4, 2024, public website.
- SRM-SECY-93-087, "SECY-89-102 - Implementation of the Safety Goals," June 15, 1990, ADAMS Accession No. ML051660712.
- RG 1.200, Rev. 1, "Acceptability of Probabilistic Risk Assessment Results for Risk-Informed Activities," December 2020, public website.
- RG 1.247, "TRIAL - Acceptability of Probabilistic Risk Assessment Results for Non-Light Water Reactor Risk-Informed Activities," March 2022, public website.
- NUREG-0880, Rev. 1, "Safety Goals for Nuclear Power Plant Operation," May 1983, ADAMS Accession No. ML071770230.
- NUREG-1860, "Feasibility Study for a Risk-Informed and Performance-Based Regulatory Structure for Future Plant Licensing," December 2007, public website.
- SECY-13-0029, "History of the Use and Consideration of the Large Release Frequency Metric by the U.S. Nuclear Regulatory Commission," March 22, 2013, public website.

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Reliability & Operational Data Needs For Advanced Reactors

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Division of Risk Analysis
Office of Nuclear Regulatory Research
Workshop on Advanced Reactors Risk Metrics & Data
July 18 2024

Relevance of Research & Operational Data

- Data will inform:
  - Reactor design
  - Reliability assessment
  - Risk modeling
  - NRC licensing
    - Licensing basis event selection
    - Classification of structures, systems and components
  - Conformance with ASME/ANS NLWR PRA Standard data requirements

Component reliability raw data databases

- NaSCoRD-SNL-Sodium System & Component Reliability Database (developed from CREDO data)
- MOSARD-ORNL-Molten Salt Reactor Component Reliability Database (w/ EPRI)
- NDMAS-INL-Nuclear Data Management & Analysis System
- FFTF-PPNL-Passive Safety Testing & Metal Fuel Irradiation Database
- TREXR-ANL-Treat Experimental Relational Database & EBR-II Transient & Fuels DBs

Gateway for Accelerated Innovation in Nuclear

GAIN Gateway for Accelerated Innovation in Nuclear

Database	Lab	Access
ETTD EBR-II Transient Testing Database	ANL	https://ettd.ne.anl.gov/ Access available by application
FFTF Passive Safety Testing & Metal Fuel Irradiation Database	PNNL	https://www.pnnl.gov/projects/fftf Access available via email – see website
FIPD EBR-II Metallic Fuel Irradiation Database Includes data for U-Zr fuel employed in commercial designs; being qualified in accordance with NRC approved QAPP	ANL	https://fipd.ne.anl.gov/ Access available by application
FRDB ART Fast Reactor Databases	ANL	https://frdb.ne.anl.gov/
IMIS (IFR Material Information System) EBR-II and FFTF Metal Fuel Experiment PIE Data	INL/ANL	Supplements the FIPD and FFTF Databases
MOSARD Molten Salt Reactor Component Reliability Database	ORNL/EPRI	Access available via email - yigitoglua@ornl.gov
NaSCoRD Sodium System & Component Reliability Database	SNL	https://www.sandia.gov/nascord/
NDMAS Nuclear Data Management and Analysis System	INL	https://ndmas.inl.gov/SitePages/NDMAS_Pages_Home.aspx
OPTD Out of Pile Transient Testing Database	ANL	https://optd.ne.anl.gov/ Access available by application
TREXR TREAT Experiment Relational Database	ANL	https://www.trexr.anl.gov/ Access available by application

Data Sources & Challenges in Modeling Risk

Early initiatives will likely combine

- Commercial power plant data (INPO-IRIS database)
- Advanced reactor component engineering & operational failure event data
- Expert/engineering judgement
- Simulations

Data challenges for passive system reliability

- Physical failure of components (e.g., pipe breaks, spurious actuation)
- Functional failure (e.g., unexpected, unanalyzed situations)
- Uncertainties in new system design, time-dependent boundary conditions
- Limited testing of operating condition

Planned Data Activities

- Workshop (July 18 2024)
- Examine available existing advanced reactor OpE databases
- Establish database templates, reporting criteria, and data methods/procedures to support risk modeling and regulatory oversight
- Populate the new database with operational data from prominent advanced reactor designs

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NRC Preliminary Thoughts on Risk Metrics for Non-LWRs

NRC Working Group on Technology-Inclusive Risk Metrics

- Matt Humberstone (RES/DRA)
- Gerardo Martinez-Guridi (RES/DRA)
- Hanh Phan (NRR/DANU)
- Marty Stutzke (NRR/DANU Sr. Level Advisor)
- Jeffery Wood (RES/DRA)

Outline

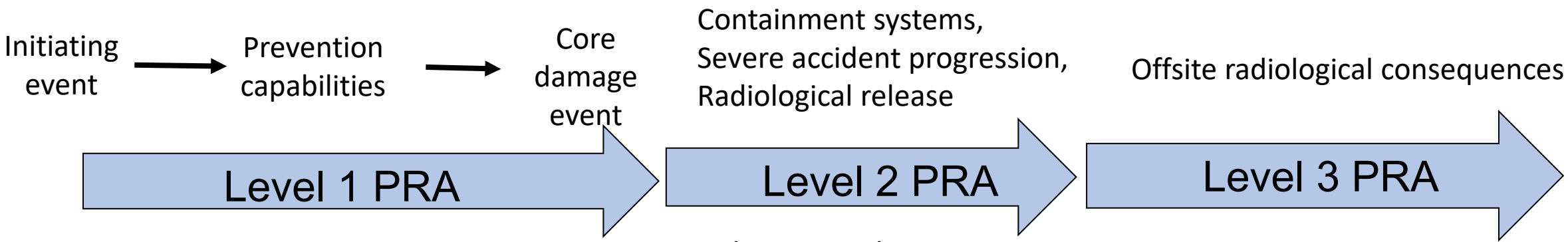
- Structure for Discussing Risk Metrics for NLWRs
- Applicability of Existing Risk Metrics
- Desirable Characteristics for Risk Metrics
- Desirable Characteristics for Using Risk Metrics
- Some Considerations on Other Potential Approaches to Risk Metrics
- Basic Considerations on Risk Metrics Proposed by Industry
- Summary of Initial Thoughts: Proposed Approach to Risk Metrics

Structure for Discussing Risk Metrics for NLWRs

- The current regulatory structure and the three levels of PRA commonly applied to LWRs are used herein as the bases for discussing risk metrics for NLWRs

- Other approaches to developing these metrics are possible and are also briefly addressed

LWR PRA Structure



Reliability and core damage metrics:

- CDF
- Importance measures
- Performance indicators
- Reliability targets

Modeling approach:

- Probabilistic analysis (e.g., SAPHIRE, CAFTA) with probability and frequency-based outputs

Radioactive release metrics:

- LERF, LRF
- Characteristics of release, such as timing and magnitude

Modeling approach:

- Mechanistic analysis (MELCOR, MAAP) for accident progression and source terms
- Frequency-based output

Consequence metrics:

- Early fatalities
- Latent cancer fatalities
- Dose
- Economic impacts

Modeling approach:

- Mechanistic analysis of radionuclide transport and health effects
- Incorporates probabilistic evaluation (e.g., weather)
- MACCS commonly used

Applications of Risk Metrics

Applications Where Regulatory Decision Making is Informed by Applicant/Licensee-Defined Risk Metrics and Models

- Initial licensing (CP, OL, DC, SDA, ML, COL) applications
- 10 CFR 50.69 – Risk-Informed Categorization of SSCs
- 10 CFR 50.65 - Maintenance Rule
- RG 1.178 - Risk-Informed Inservice Inspection
- RG 1.175 - Risk-Informed Inservice Testing
- 10 CFR 50 App J, NEI 94-01, and EPRI TR-1009325 - Risk-Informed Integrated Leak Review Testing
- RG 1.205 - Risk-Informed Fire Protection
- RG 1.177 - Risk-Informed Technical-Specification
- JLD-ISG-2012-01 and NEI 12-06 - Flex Strategies
- Risk-Informing Emergency Planning
- Risk-informing Security
- Mitigating System Performance Indicators (MSPIs)
- RG 1.174 – An Approach for Using PRA in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis
- LR-ISG-2006-03 and NEI 05-01 - SAMDA analysis
- Reliability and Integrity Management Programs
- Etc.

Applications Where Regulatory Decision Making is Informed by Staff-Defined Risk Metrics and Models

- Incidence Investigation Program (MD 8.3)
- Notice of Enforcement Discretion (NOED) (IMC-0410)
- Integrated Risk Informed Decision Making of Emergent Issues (LIC-504)
- Integrated Risk Informed Decision Making for Licensing Reviews (LIC-206)
- Reactor Oversight Process - Significance Determination Process (SDP) (IMC-0609)
- Generic Issues Program – GI screening is heavily informed by the RG 1.174 approach
- Accident Sequence Precursor (ASP) Program
- Etc.

Applicability of LWR Risk Metrics to NLWRs

	CDF	LERF/LRF	Consequence Metrics
LWR	Applicable	Technology inclusive	Technology inclusive
NLWR	Applicable to NLWRs w/CD		
	Not Applicable to Other NLWRs		

For LWRs:

- **CDF** measures **accident prevention** and is a surrogate for the **latent fatality QHO**
- **LERF** measures **accident mitigation** and is a surrogate for the **early fatality QHO**

Challenges with Consequence (Radiological Health-Effects) Metrics

- Technical
  - Health effects metrics are obtained by combining the characteristics of a plant with the conditions of the plant's location, such as the number of people surrounding the plant, the people's spatial distribution, and the weather
  - It is difficult to relate health effects metrics to the elements (e.g., hardware components and human errors) of a Level-1 PRA and a Level-2 PRA to evaluate the importance measures of each element
  - Large uncertainties

Challenges with Consequence (Radiological Health-Effects) Metrics (cont'd)

- Perception
  - Possible perception of additional burden on NLWR applicants compared to LWRs
  - Possible negative perceptions (e.g., results reported in terms of number of fatalities)
  - Increased review times

Desirable Characteristics for Risk Metrics

- A risk metric is a measure that is used to express the risk **quantity** of interest
- A risk metric can be used to illustrate **compliance with safety goals**
- A risk metric can be used in performing **risk characterization**
  - Risk characterization combines the major components of risk (hazards, consequences, frequency, and probability), along with quantitative estimates of risk, to give a combined and integrated risk perspective (i.e., a risk profile)
- A risk metric can be used to **derive risk indicators**
  - An example of a risk indicator is conditional core damage probability (CCDP)
  - Importance measures is an important example because:
    - They provide relative and absolute measures of the importance of PRA elements to plant's risk
    - They are used in many regulatory programs involving RIDM
- Characterization of the **uncertainty of risk metric** is possible

Desirable Characteristics for Using Risk Metrics

- The process for calculating a risk metric is transparent
- Risk metrics for accident prevention and accident mitigation would be useful (as described on SECY-89-102)
- Risk metrics that minimize changes to the current regulatory structure
  - It allows to maximize consistency with current risk metrics (CDF and LERF/LRF)
- Risk metrics that minimize challenges to relate them to safety objectives, such as the QHOs

Desirable Characteristics for Using Risk Metrics (cont'd)

- Risk metrics that can be applied to the lifetime of an NLWR
- Risk metrics that avoid challenges associated with health-effect metrics
- Risk metrics that can be applied to all sizes (i.e., power generation) of reactors

Risk Metrics for Accident Prevention for NLWRs

- **When core damage is applicable** (e.g., for fast reactors cooled by liquid metals)**:**
  - CDF is applicable to these NLWRs
  - Definition of core damage may be specific to each reactor technology
- **When core damage is not applicable:**
  - Core damage for LWRs implies the failure of the LWR fuel cladding, which is the initial confinement of radioactive material
  - Accordingly, our initial tendency is to define a **frequency of failure of initial confinement of radioactive material**
    - Defining failure of initial confinement is specific to each reactor technology
    - It may be somewhat challenging to define this failure for each reactor technology

Some Considerations on Other Potential Approaches to Risk Metrics for NLWRs

- Technology-inclusive risk metrics
  - LERF could be a possibility
  - Risk metrics for accident prevention could be missing since they are technology-specific
  - It would require major modifications to current regulatory structure or developing a new regulatory structure for NLWRs
- "Simplified" approach that is not related to the LWR PRA levels
  - It may be difficult to calculate quantitative risk metrics that can be used to compare with the safety objectives, such as the QHOs
  - It may be difficult to generate derived risk indicators, such as importance measures, which are used in many regulatory programs involving RIDM

Basic Considerations on Risk Metrics Proposed by Industry

- NRC is open to consider the proposed risk metrics

- It also seems desirable to establish:
  - Set of unified metrics between industry and NRC (as much as possible)
  - Set of unified metrics that would be appropriate for use throughout plant lifetime

Summary of Initial Thoughts: Proposed Approach to Risk Metrics for NLWRs

- For accident prevention:
  - Use CDF whenever core damage is applicable
  - Use new metrics when core damage is not applicable (e.g., frequency of failure of initial confinement of radioactive material)
- For accident mitigation, LERF is technology inclusive
- Consequence metrics are technology inclusive, but there are challenges associated with them
- Desirable attributes for risk metrics and for using the metrics are proposed

Acronyms and Abbreviations

Adv.	Advanced
ASP	Accident Sequence Precursor
CCDP	Conditional Core Damage Probability
CDF	Core Damage Frequency
CFR	Code of Federal Regulations
COL	Combined License
CP	Construction Permit
DANU	(NRC) Division of Advanced Reactors and Non-Power Production and Utilization Facilities
DC	Design Certification
EPRI	Electric Power Research Institute
IMC	Inspector Manual Chapter
ISG	Interim Staff Guidance
LERF	Large Early Release Frequency
LRF	Large Release Frequency
LWR	Light-Water Reactor
MACCS	MELCOR Accident Consequence Code System

Acronyms and Abbreviations (cont'd)

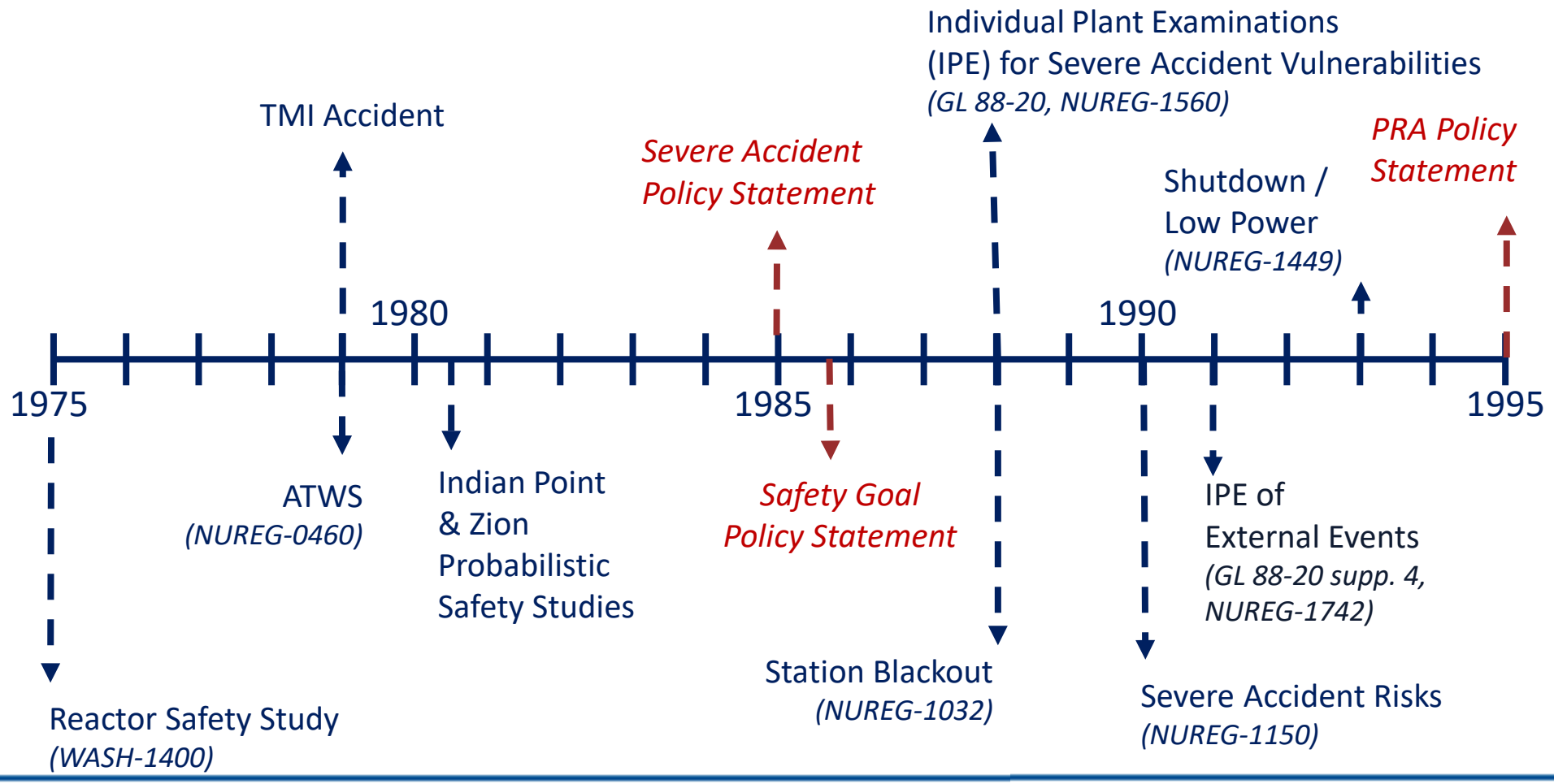
MAAP	Modular Accident Analysis Program
MD	Management Directive
ML	Manufacturing License
NEI	Nuclear Energy Institute
NLWR	Non-Light-Water Reactor
NOED	Notice of Enforcement Discretion
NRC	Nuclear Regulatory Commission
RIDM	Risk-Informed Decision Making
NRR	(NRC) Office of Nuclear Reactor Regulation
OL	Operating License
OpE	Operating Experience
PRA	Probabilistic Risk Assessment
QHO	Qualitative Health Objective
RES	(NRC) Office of Nuclear Regulatory Research
RG	Regulatory Guide

Acronyms and Abbreviations (cont'd)

Rx	Reactor
SAMDA	Severe Accident Mitigation and Design Alternatives
SDA	Standard Design Approval
SSC	Structures, Systems, and Components

Backup Slides

Early Studies, Events, and Policies related to Risk



1986 Policy Statement: *Safety Goals for the Operations of Nuclear Power Plants*

***Qualitative Safety Goals**:*

- *Individual members of the public should be provided a level of protection from the consequences of nuclear power plant operation such that individuals bear no significant additional risk to life and health.*
- *Societal risks to life and health from nuclear power plant operation should be comparable to or less than the risks of generating electricity by viable competing technologies and should not be a significant addition to other societal risks.*

***Quantitative Health Objectives (QHOs)**:*

- *The risk to an average individual in the vicinity[1] of a nuclear power plant of prompt fatalities that might result from reactor accidents should not exceed one-tenth of one percent (0.1 percent) of the sum of **prompt fatality risks** resulting from other accidents to which members of the U.S. population are generally exposed.*
- *The risk to the population in the area[2] near a nuclear power plant of cancer fatalities that might result from nuclear power plant operation should not exceed one-tenth of one percent (0.1 percent) of the sum of **cancer fatality risks** resulting from all other causes.*

[1]Within 1 mile of the nuclear power plant site boundary; [2]Within 10 miles of the plant site

Background on Risk Metrics Policy and History

- NRC has a long history of integrating risk into our decision-making
- Suggested reading:

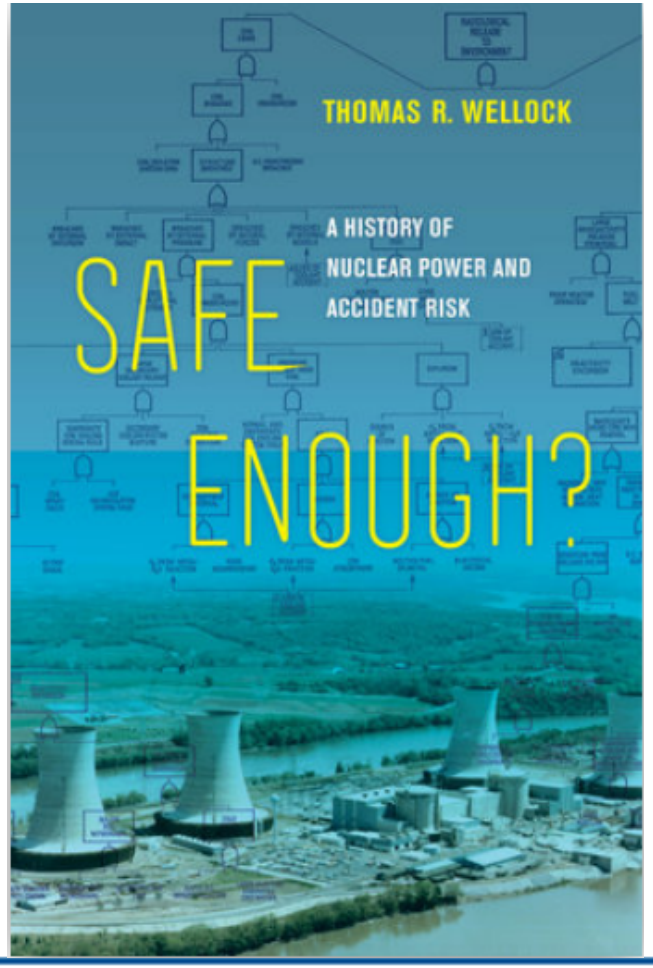
Safe Enough?

A History of Nuclear Power and Accident Risk

by Thomas R. Wellock (Author)

March 2021

First Edition



U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Risk Objective References

- SRM on SECY-89-102, *Implementation of Safety Goals* (ML003707881)
  - Establishes objectives for CDF, LRF, and CCFP
- SECY-93-138, *Recommendation on Large Release Definition* (ML003761015)
  - Recommend terminating further work to develop large release definition
- SECY-10-0121, *Modifying the Risk-Informed Regulatory Guidance for New Reactors* (ML102230076)
  - SRM on SECY-10-0121 (ML110610166) disapproved staff's recommendation, reaffirms existing subsidiary risk goals
- NUREG-1860, *Feasibility Study for a RIPB Regulatory Structure for Future Plant Licensing*
  - See Appendix D – Derivation of Risk Surrogates for LWRs

Risk vs Risk Metrics

- Risk Triplet:
  1. What can go wrong?
  2. How likely is it?
  3. What are the consequences?

- **Risk Metric** – a measure that is used to express the risk quantity of interest (from NUREG-2122 – Glossary of Risk-Related Terms…)
  - For example, for LWRs:
    - Core damage frequency (CDF)
    - Large early release frequency (LERF)
  - Risk metrics could be used to address all parts of the risk triplet.

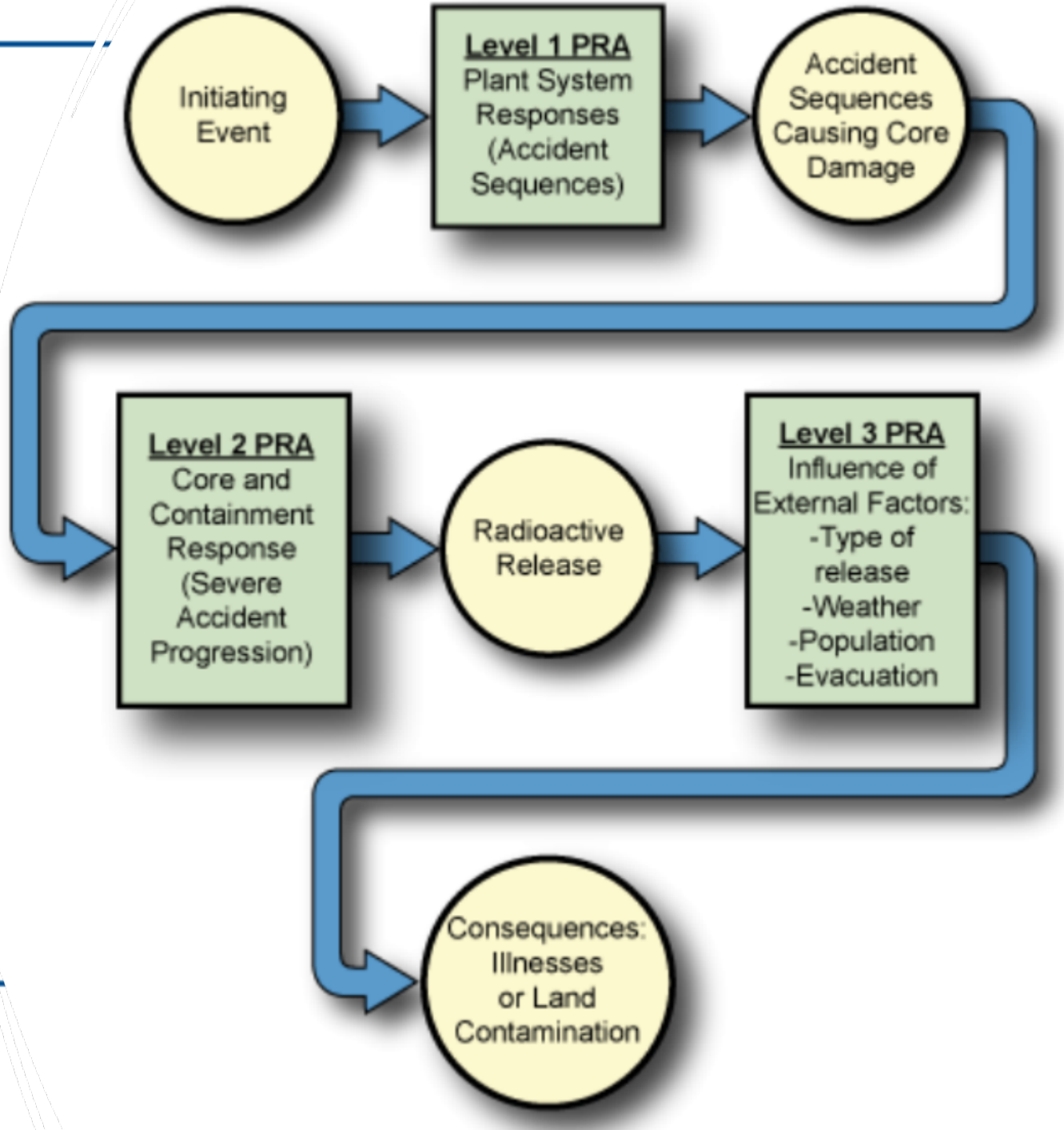
Risk Metric Terms

- **Subsidiary Risk Metric or Surrogate Risk Metric** – an alternative risk metric that can provide indication of meeting a desired ultimate risk objective, e.g., QHOs
  - For example, CDF is a surrogate risk metric for individual latent cancer fatality risk
  - A surrogate is typically developed at a lower modeling level and provides a measure of margin to the desired risk goal
- **Risk Performance Objective** – a preestablished, indicative value that is used during RIDM to gauge plant safety
  - For example, CDF < 1E-4 / year.
  - Provides a reference point for risk metric results.
  - Typically, not a strict acceptance limit.
  - Sometimes also referred to as risk goal or risk criterion.

LWR PRA Levels

- Level 1: Core damage frequency analysis
  - It calculates the core damage frequency given the design and operation of the plant.
- Level 2: Radionuclide release frequency analysis
  - It takes the results of the Level-1 PRA (accident sequences resulting in core damage) as input and produces frequencies of radioactivity releases as output.
- Level 3: Consequence analysis
  - It takes the results of the Level 2 PRA as input and produces offsite consequences (health effects, economic consequences) as output.

Source of text: NUREG-2122



Structure of Level 1, Level 2, Level 3 PRA (for LWRs)

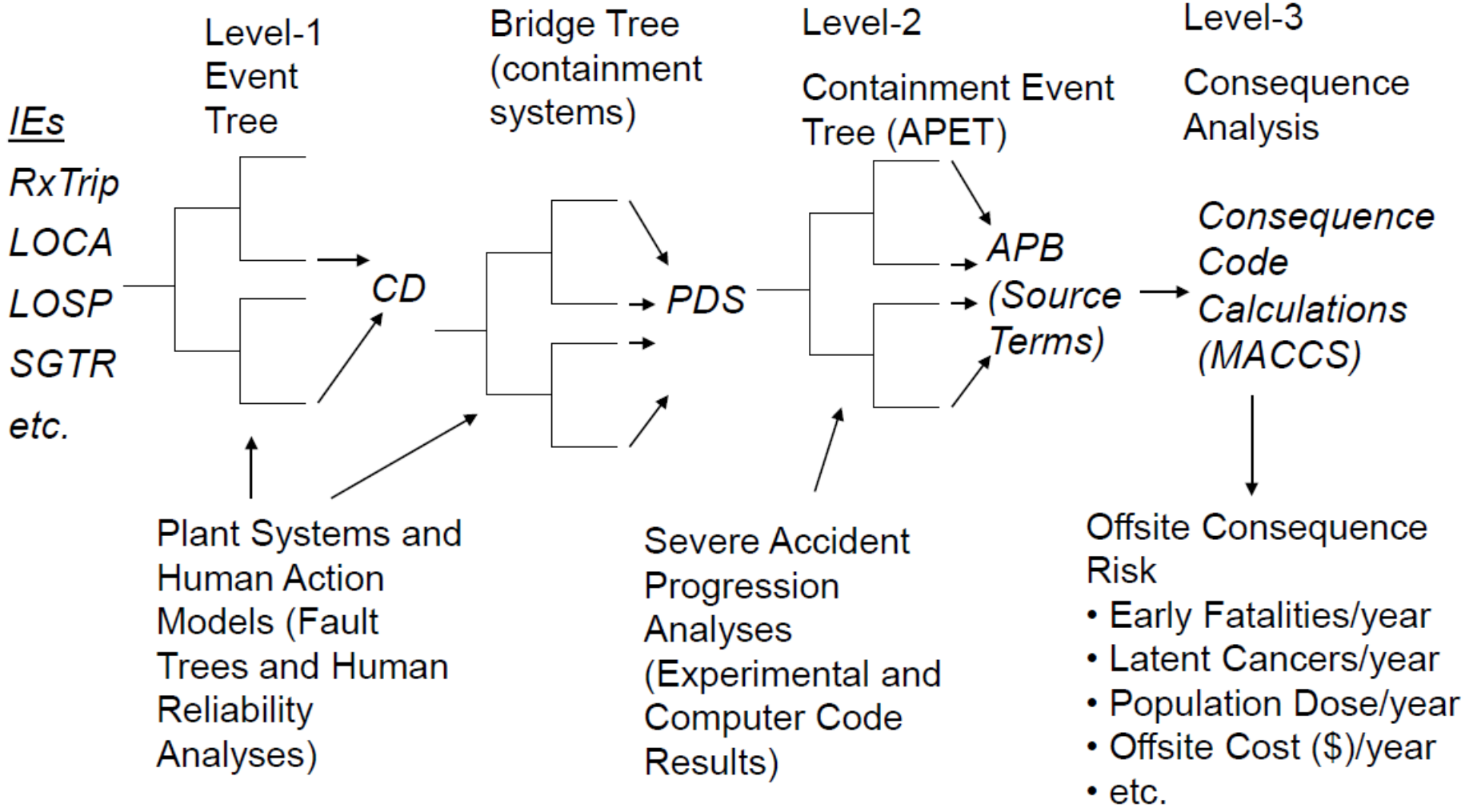


Figure from "System Modeling Techniques for PRA (P-200)" by INL.

Subsidiary Risk Objectives

In NRC's risk-informed decision-making for operating reactors (LWRs):

- A core damage frequency (CDF) of < 10^{-4}/Rx-year is used as a surrogate for the latent cancer fatality QHO.
- A large early release frequency (LERF) of < 10^{-5}/Rx-year is used as a surrogate for the individual prompt fatality QHO.

Subsidiary Risk Objectives (cont'd)

In 1990, the Commission established three risk metrics for new reactors (Advanced LWRs (ALWRs)) and associated quantitative goals:

- **Core Damage Frequency (CDF) < 1×10^{-4}/year** – A measure of overall safety performance in prevention of severe accidents
- **Large Release Frequency (LRF) < 1×10^{-6}/year** – A measure of prevention of significant offsite consequences
- **Conditional Containment Failure Probability (CCFP) < 0.1** – A measure of the capability of design to mitigate a severe accident

Examples of Previously Used Risk Metrics and Associated Performance Objectives.			
Risk Metric and Performance Objective	**Applicability**	**Definition**	**Notes**
IEFR: individual early fatality risk mean* IEFR ≤ 5×10^{-7} /plant-year	Technology Inclusive	RG 1.247	• First quantitative health objective (QHO) in the Commission's safety goal policy statement; NUREG-0880 provides the technical rationale.
ILCFR: individual latent cancer fatality risk mean* ILCFR ≤ 2×10^{-6} /plant-year	Technology Inclusive	RG 1.247	• Second QHO in the Commission's safety goal policy statement; NUREG-0880 provides the technical rationale.
LRF: large release frequency mean* LRF ≤ 10^{-6} /reactor-year	Technology inclusive	Staff has not defined LRF; practice has been to allow Part 52 applicants to define LRF.	• SRM on SECY-90-016 established this performance objective. • LRF applies to all current and future designs (SRM-SECY-98-102). • LWRs transition from LRF to LERF at initial fuel load (SRM-SECY-12-0081) • SECY-13-0029 provides a history of LRF.
CDF: core-damage frequency mean* CDF ≤ 10^{-4} /reactor-year	LWRs and NLWRs susceptible to core damage	RG 1.200	• Surrogate for the ILCFR QHO; NUREG-1860, Vol. 2, App. D provides the technical rationale for LWRs. • Measure of plant's accident prevention capability. • Does not address non-core sources or multi-reactor accidents.
LERF: large early release frequency mean* LERF ≤ 10^{-5} /reactor-year	Technology inclusive	RG 1.200	• Surrogate for the IEFR QHO and LRF; NUREG-1860, Vol. 2, App. D provides the technical rationale for LWRs. • Measure of plant's accident mitigation capability. • Does not address non-core sources or multi-reactor accidents. • LERF sequences have been identified qualitatively for LWRs (e.g., Table 2-2.8-9 in ASME/ANS RA-Sa-2009, as endorsed in RG 1.200).
*The term "mean" refers to the mean of the parametric uncertainty distribution of the risk metric. Modeling uncertainties and completeness uncertainties also should be considered in risk-informed decision making (NUREG-1855).			

Impressions of LMP Approach

Strengths:

- Technology-inclusive
- Useful for initial licensing
- It is being used by applicants and potential applicants

Challenges:

- How will the approach be leveraged for other RI programs?
  - RG 1.174
  - Maintenance rule
  - Significance Determination Process
  - Interface of LMP with industry consensus standards
    - Seismic design process, reliability integrity management, RI fire protection