# The Use of Risk Concepts in Regulation

Report of the IRCC Workshop
San Francisco, CA, USA
17-18 October 2006

IRCC

Arup

# NOTICE

## Foreword

Building regulations are legal instruments intended to ensure that buildings, when constructed in accordance with the regulations, provide socially acceptable levels of health, safety, welfare and amenity for building occupants and for the community in which the buildings are located. This is typically accomplished through regulatory controls on the design, construction and operation of buildings, covering such diverse areas as structural stability, fire safety, heating, lighting, ventilation, plumbing, sanitary facilities, indoor air quality, and energy.

Historically, these regulatory controls have generally been highly prescriptive in nature (e.g., the maximum travel distance to an exit shall not exceed 30 meters), allowing limited flexibility in alternative compliance options, and have often been based on reaction to significant events (e.g., fires, earthquakes, hurricanes, etc.). In the last 20 years, however, there has been a growing transition to objective-, functional- and performance-based building regulations. In these regulations, the focus has shifted from prescribing solutions to identifying objectives, functional requirements, and performance expectations (e.g., design the building so that occupants not intimate with the fire source can safely exit the building before untenable conditions are reached in egress paths), and allowing for a wider selection of compliance options. However, with this new form of building regulation come several challenges, including:

- What are society's expectations for building performance: how are these being met?
- How does one define and measure performance: what are appropriate bases?
- What happens when broader societal expectations and technical capability do not intersect?
- Can risk be used as a basis for establishing tolerable performance of buildings: how?
- What risks should be addressed by building regulation versus by the market?
- Is it possible, feasible or practicable to establish levels of tolerable risk in building regulation?

To help the IRCC learn more about issues associated with the use of risk in regulations, specifically within a performance-based regulatory environment, a workshop was held at the Sheraton Fisherman's Wharf Hotel in San Francisco, CA, on 17-18 October 2006. The intent of the workshop was to provide a forum for IRCC members to ask questions of, and gain insight from, invited experts with experience and expertise in the use of risk and performance concepts in regulation. The aim was for IRCC members to leave the workshop with an increased understanding of the uses, applications, challenges, limitations, and benefits of risk concepts as bases for regulatory policy, and to the extent practicable, guidance for incorporating risk concepts into performance-based building regulation.

The Workshop presentations and discussions were necessarily wide-ranging, yet proved to be extremely insightful and beneficial to the IRCC members. Although it is impossible to capture the full extent of discussions and perspectives, the following provides a summary of some of the key issues that were discussed. As performance-based building regulations become more risk-informed in the future, the discussions and professional connections made at this workshop will help set the foundation for facilitating global cooperation and advancement in this area.

Brian J. Meacham, Ph.D., P.E.
Editor

## Acknowledgments

The success of any workshop is due ultimately to the participants, and this workshop is no exception. The core of the workshop participants – the source of issues to be addressed and factors to be considered – were the members of the IRCC. As representatives of organizations responsible for the development and support of nationally-adopted building regulations in ten countries, the challenges you face and the experience you bring shaped the breadth and depth of discussion around risk and performance issues in buildings.

To help the IRCC expand their knowledge of risk and performance issues in regulation, consider new and different approaches to use of risk concepts in performance regulation, and learn from a broader cross-section of regulated areas, a small group of invited experts participated in the workshop, sharing their insights and experience, and making the workshop an incredibly valuable experience for all:

Prof. Ann Bostrom, Georgia Institute of Technology, School of Public Policy

Prof. Cary Coglianese, University of Pennsylvania Law School

Dr. Paul Croce, FMGlobal (retired)

Prof. Greg Deierlein, Stanford University, Department of Civil & Environmental Engineering

Prof. Peter May, University of Washington, Center for American Politics and Public Policy

Dr. Gareth Parry, U.S. Nuclear Regulatory Agency, Office of Nuclear Reactor Regulation

We sincerely thank each of you for your generosity in sharing your time, experience and expertise with the IRCC – your participation is deeply appreciated.

Finally, no workshop happens without planning, organization and administrative support. We extend our sincere appreciation to Arup for providing financial support, administrative support via Jason Prodoehl, and organizational support via Brian Meacham, and to IRCC for financial support for our invited speakers.

## Executive Summary

The use of risk in regulation is a challenging issue. Who or what is at risk, how is the risk calculated, how is the risk perceived, what should we do to mitigate risk and how much will that cost are just a handful of considerations that need to be addressed. As building regulations around the world look to incorporate risk concepts – particularly into performance-based building regulations – gaining input and perspectives from other regulated areas is not only desirable but is essential. To help facilitate the process of knowledge transfer, and to open lines of communication with experts in risk and performance regulation, the Inter-jurisdictional Regulatory Collaboration Committee (IRCC) convened a workshop on the use of risk in regulation. Over the course of the workshop, a variety of perspectives were voiced and a wide range of issues were discussed. Although there was no preconception that the workshop would answer all the open questions and provide solutions in a nice, neat package, the workshop did result in identifying some key issues and potential paths for the future.

### Approaches Discussed

A major impetus for the workshop was to capture different approaches for the use of risk concepts in regulation. Through the presentations and discussions, three primary approaches were raised:

1) The use of risk-informed decisions about what to regulate or what aspects of existing regulations to emphasize in enforcement (e.g., see presentation by Dr. Gareth Parry on the USNRC approach);
2) A focus on risk (hazard) management through regulation by quantifying hazards, impacts and uncertainties (and therefore risks) as a basis for deciding about regulatory actions and standards (e.g., see presentation from Dr. Gregory Deierlein and associated discussions related to the PEER approach to performance-based seismic design); and
3) Establishing "tolerable" levels of risk (damage/loss), "acceptable risk," or other risk-related standards as minimum standards for safety.

### Key Issues

***"Acceptable risk"*** is a value-judgment about what levels of loss/damage are willing to be "accepted" in the case of damaging incident or event. The use of the term "acceptable risk" implies that someone understands the risk and actively accepts it. This is often not the case in a regulated environment. Sometimes the term ***"tolerable risk"*** is used as an alternative, with the implication that instead of understanding and actively "accepting" a risk, the recipient "tolerates" the risk imposed upon them. However, the concept of "tolerable risk" is also a value-judgment regarding what levels of loss/damage/impact are willing to be "tolerated" in the case of a damaging event.

***"Acceptable risk' is a problematic concept*** – framing of the decision makes a difference. Consider "safety" versus "risk" – the latter forces attention to zero risk, which is an unrealistic concept. Acceptance is not automatic – it depends on who is bearing the risks, what the benefits are, what the costs of reducing the risks are, who bears the cost, and much more.

***As with any decision, acceptable risk decisions involve choices between alternatives.*** For acceptable risk decisions in the policy arena, the decision process requires consideration of values as well as technical data. However, this adds complexity, since preferences are often constructed, and how a risk problem is framed will have an influence on subsequent judgments of acceptability. As a result, the consequences of an acceptable risk decision are sometimes judged acceptable only by virtue of the processes that produce them. If the process is lacking, the decision may not be as fully considered as desired.

***"Acceptable risk" is the residual of other choices and is a moving target*** (e.g., searching for safety in a poorly defined environment). Most public discussions about risks are about the costs of addressing those risks. As a consequence, the decisions are more often based on what costs (in terms of mitigating the risk) can be borne for which the residual is the risk that remains. These decisions are revisited after "learning" from disasters about the consequences of earlier choices.

***Elected officials do not like to talk about "acceptable risk."*** For the most part, they do not like to talk about "probabilities" and "uncertainty," especially when it comes to issues such as deaths and injuries.

***If developing such a standard for defining "acceptable risk" is deemed necessary, creating a credible process for establishing relevant metrics, standards or goals is critical.*** However, this applies to any metric, standard- or goal-setting process, not just "acceptable" risks.

***Effective performance-based regulations depend on the ability of government agencies to specify, measure, and monitor performance, and reliable and appropriate information about performance may sometimes be difficult if not impossible to obtain.*** If implemented incorrectly or under the wrong circumstances, performance-based regulation will function poorly, as will any regulatory instrument that is ineffectually deployed. A critical concern is the risk associated with 'full compliance sub-optimality' – getting what is called for in the regulation, but having that falling short of what was intended or needed. To assess the success of any regulatory system, three fundamental questions should be considered:

- Is it effective: does it work?
- Is it cost effective: does it deliver benefit at the least cost practicable?
- Is it efficient: do benefits outweigh costs?

***It is important to distinguish between risk of a failure and risk of occurrence, and to distinguish societal risk from individual risk***. The risk of failure is important in estimating overall risk, but is likely a bigger concern for risk analysts than it is for the public (e.g., people have some sense of how "risky" driving is and the potential consequences of an accident, but probably do not think much about the likelihood of brake failure leading to the accident – what "risk" one is talking about affects the perception of that risk).

***When looking at broad regulatory change, society needs to be ready for the change or they will not buy into the process.*** Societal risk perception involves much more than probability: human behavior, attitudes and perceptions are critical, and it must be remembered that building regulation operates within a political environment: often times the squeaky wheel gets the grease.

## A Path Forward

***A performance-based approach is characterized and recognized by the occurrence of five defined attributes:***

- A framework exists or can be developed to show that performance, as indicated by identified parameters, will serve to accomplish desired goals and objectives.
- Measurable, calculable, or constructable parameters to monitor acceptable performance exist or can be developed.
- Objective criteria to assess performance exist or can be developed.
- Margins of performance exist such that if performance criteria are not met, an immediate safety concern will not result.
- Flexibility in meeting the established performance criteria exists or can be developed.

***Performance-based design*** can work effectively when expectations/ outcomes are defined in terms of decision variables, specific damage measures are defined to measure these outcomes, and damage measures and performance outcomes are assessed based on evaluation of specific engineering demand parameters for events of defined magnitude.

***A performance-based framework should closely link loss objectives, performance metrics, and design approaches with probabilistic representations of hazards and expected losses***. Such linking of risk and performance clarifies stakeholder expectations and engineering analysis, and opens the door for benefit-cost analysis and other mechanisms to be introduced to help decision-making, which in many cases, results in design strategies that go beyond current code requirements.

Often, building safety objectives are currently defined in terms of safety to life, with objectives for property in some cases (most often adjacent property). As a result, the focus is on building occupants and not necessarily the public well being. ***By refocusing the objective on public well being, it may be possible to address several of the current gaps in performance-based building regulation.***

***To get to a new framework***, there should be a shift in language from "risk avoidance" to "safety goals," the system needs to allow or consideration of different dimensions of safety (e.g. public safety, repairability and usability of structure), and safety improvements should be expressed in relative terms (e.g., the relative risk notion of health risks).

## Background and Introduction

Performance-, functional- or objective-based building regulatory systems are in use or under development in numerous countries world-wide. In some instances, such as in England and Wales, functional-based building regulations have been in use for more than 20 years, while in Canada, objective-based codes are just being promulgated. In New Zealand and Australia, major modifications are underway to the performance-based regulations, including a focus on better quantifying performance criteria, exploring different levels of performance which might be expected for different types of buildings, and investigating how risk might be used as a basis for establishing performance levels and criteria.

The fact that so many countries are developing and promulgating performance-, functional- or objective-based codes, that the various countries can learn from one another and take advantage of joint research and learning opportunities, and can help transfer this knowledge to others are just some of the issues that led to the formation of the Inter-jurisdictional Regulatory Collaboration Committee (IRCC).

The IRCC, formed in 1996, is an unaffiliated committee of eleven of the lead building regulatory agencies and organizations of ten countries (http://www.ircc.gov.au):

- The Austrian Institute of Construction Engineering, Austria
- The Australian Building Codes Board, Australia
- The Department of Building and Housing, New Zealand
- The Department for Communities and Local Government, England and Wales
- The Institute for Research in Construction, National Research Council, Canada
- The International Code Council, USA
- The Ministry of Housing, Spain
- The Ministry of Land, Infrastructure and Transport, Japan
- The National Institute for Land and Infrastructure Management, Japan
- The National Office of Building Technology and Administration, Norway
- The Scottish Building Standards Agency, Scotland

Over the past ten years, the IRCC has developed guidelines for the introduction of performance-based building regulations (1998 - used by code developers in Spain, the USA and elsewhere in the drafting of their performance-based building codes), has held global summits on issues in performance-based building regulation (Washington, DC, 2003) and sustainability (Gold Coast, Australia, 2005), in addition to meeting at least twice annually to discuss issues and share experiences.

Recently, issues such as changing demographics, global warming, sustainability, terrorism, extreme events and unexpected building failures has led to discussion of if and how the concept of tolerable risk might be used as a basis for establishing building performance levels, in addition to the ongoing challenges related to establishment of performance metrics that can be measured, calculated and verified as part of the overall regulatory system. To help IRCC members further explore these issues, and to learn from other regulated areas which have adopted risk and performance concepts, it was decided to hold a small workshop, with a handful of invited experts whose backgrounds included chemical process safety, nuclear power, seismic hazards, tolerable risk, insurance, performance regulation, and public policy.

## Invited Speakers

### Professor Ann Bostrom

Ann Bostrom is an Associate Professor in the School of Public Policy and Associate Dean for Research in the Ivan Allen College at the Georgia Institute of Technology. Her research focuses on mental models of hazardous processes (how people understand and make decisions about risks), and is currently funded by the National Science Foundation, and the U.S. Environmental Protection Agency in the areas of air pollution, children's environmental health, and seismic risk. She co-authored Risk Communication: A Mental Models Approach (Cambridge University Press, 2001), with M. Granger Morgan, Baruch Fischhoff, and Cynthia J. Atman. Prof. Bostrom served as program director for the Decision Risk and Management Science Program at the National Science Foundation from 1999-2001, is on the editorial board of Risk Analysis, and is an associate editor for the Journal of Risk Research, and for Human and Ecological Risk Assessment. She is a former Councilor of the international Society for Risk Analysis, a past Chair of its Risk Communication Specialty group, and received its Chauncey Starr award for a young risk analyst in 1997. Prof. Bostrom is a member of the U.S. EPA Science Advisory Board Committee on Valuing the Protection of Ecological Systems and Services, a past member of the executive committee of the U.S. EPA Board of Scientific Counselors, has served on National Research Council, Transportation Research Board, and Institute of Medicine committees, and has consulted for other organizations on risk communication.

### Professor Cary Coglianese

Cary Coglianese is Edward B. Shils Professor of Law and Professor of Political Science, and Director, Penn Program on Regulation, at the University of Pennsylvania Law School. He comes to Penn Law from Harvard, where he spent twelve years on the faculty of the John F Kennedy School of Government and served as faculty chair of the school's Regulatory Policy Program and director of its Politics Research Group. His research focuses on issues of regulation and administrative law, with a particular emphasis on the empirical evaluation of alternative regulatory strategies and the role of disputing and negotiation in regulatory policy making. His work has appeared in, among other journals, the *Administrative Law Review*, *Duke Law Journal*, *Law & Society Review*, *Michigan Law Review*, *University of Pennsylvania Law Review*, and *Stanford Law Review*. Prof. Coglianese is the founder and co-chair of the Law & Society Association's international collaborative research network on regulatory governance, Vice Chair of E-Rulemaking Committee of the American Bar Association's section on Administrative Law and Regulatory Practice, and Vice Chair of the Innovation, Management Systems, and Trading Committee of the American Bar Association's section on Environment, Energy, and Resources. He has been a visiting professor of law at Stanford and Vanderbilt, and is a founding editor of the new international, peer-reviewed journal, *Regulation & Governance*.

**Dr. Paul Croce**

Paul Croce recently retired as Vice President and Manager of Research for FM Global. In this capacity, he oversaw the entire scientific research operation for the world's largest property insurer, covering all aspects of loss prevention research. This work covered both the phenomena that can cause loss as well as technical solutions to assess risk and to prevent or reduce loss. In his prior technical work, he addressed a variety of safety, security and protection problems in his research, including the effects of fluid stress in blood flow (biomedical) applications, fire and explosion hazards in industrial and residential settings, quantitative risk assessments for various process and computer system technologies, transportation of hazardous materials and the evaluation of security and business interruption risk in the financial industry. Dr. Croce is a founder and former Chair of the ASME Safety Engineering and Risk Analysis Division, served five years as Chair of the International FORUM of Fire Research Directors, was a Member of the two-year US Commission on Fire Safety and Preparedness of the DOE Complex and was an invited participant to the White House Conference on Critical Infrastructure Protection Priorities. He is a Life Fellow of the ASME, a Life Member of the FORUM, a Senior Member of the AIChE and a Member of the NFPA. He has published numerous technical papers and reports, and contributed to several books.

**Professor Gregory Deierlein**

Gregory Deierlein is Professor of Civil Engineering and Director of the John A. Blume Earthquake Engineering Center, Stanford University. His research and professional interests focus on improving the structural design of buildings, bridges, and other constructed facilities. His research includes both computational and experimental techniques with emphasis on the development and application of nonlinear analysis of structural limit states, characterization of structural material and component behavior, performance-based engineering for earthquake and fire hazards, finite element simulation of ductile crack initiation in steel structures, design and behavior of composite steel-concrete structures. Prof. Deierlein is active in several national technical and specification committees, including the American Institute of Steel Construction's Specification Committee, the Structural Stability Research Council, the Earthquake Engineering Research Institute, and the ASCE and ACI Committees on Composite Construction. Deierlein presently serves as Deputy Director for Research of the Pacific Earthquake Engineering Research (PEER) center, whose mission is to develop a comprehensive methodology and enabling technologies for performance-based earthquake engineering. Prior to joining Stanford University in 1998, Deierlein was on the faculty at Cornell University and worked as a structural engineer with the firm of Leslie E. Robertson and Associates in New York.

## Professor Peter J. May

Peter J. May is a professor of political science at the University of Washington where he is affiliated with the Center for American Politics and Public Policy. His research and teaching address various facets of policy design and implementation with particular emphasis on regulatory policy implementation. Prof. May has had extensive research involvement for various projects in Australia, Denmark, New Zealand, and the United States with funding from sources that include the National Science Foundation and the Environmental Protection Agency. He has served on National Research Council panels, as a member of the policy analysis staff of the U.S. Department of Interior, and on various boards of professional organizations. He was a recipient of a Fulbright senior scholar grant for research in Australia in 1991 and was a visiting scholar at University of Aarhus, Denmark in 1998.

## Dr. Gareth W. Parry

Gareth W. Parry is a Senior Advisor on probabilistic risk assessment (PRA) in the Office of Nuclear Reactor Regulation of the U.S. Nuclear Regulatory Commission. His principal activities have been in the development of the infrastructure for risk-informing the regulatory structure, and in methods for assuring that PRAs used to support risk-informed decisions are of sufficient quality. Dr. Parry has over thirty years experience in probabilistic risk assessment of nuclear power reactors. Early in his career he worked for five years at the Safety and reliability Directorate of the United Kingdom Atomic Energy Authority. Subsequently, he worked for 16 years at NUS Corporation, a U.S. consulting company, developing probabilistic risk assessments of nuclear power plants for a number of clients worldwide, where he specialized in developing methods for human reliability analysis, common cause failure analysis, and uncertainty analysis. He has been a Senior Advisor on probabilistic risk assessment (PRA) in the Office of Nuclear Reactor Regulation of the U.S. Nuclear Regulatory Commission for the last 10 years.

## IRCC Background Issues and Questions

IRCC members were asked to provide some thoughts, issues and questions, which were sent to the invited speakers in advance of the workshop, to provide context for the presentations and discussions. The following reflects material submitted by IRCC members in advance of the workshop.

### Australia

Within the context of regulation and standard setting, the Council of Australian Government Guidelines suggested the use of risk analysis in addressing the threshold issue of whether or not to regulate. We are most interested in policy type issues such as:

- What types of risks that should or should not be regulated, e.g., should we regulate for amenity or durability?
- What kind of risk do we expose the community, governments and business to if we decide to regulate or not regulate?
- Can we use risk analysis to prioritize the issues to be considered?

Our government directive is to reduce the regulatory burden on business but in doing so we might expose the community and business to new risks that have not been foreseen. Different sectors of the community also have different scales of values, how to balance these different interests could be a subject worth exploring.

Specific to estimation and expression of risk, following are three questions / issues for the risk workshop:

- How do we establish the tolerable level of risk? Can we calibrate against the current level inherent in the regulations? Do we have one level for safety, or a level for different hazards? How do we account for the community's perception to different hazards? Do we need to have a tolerable level for individual and societal risks? Can we use F-N curves?
- Do practitioners have the skills, methodologies, data etc. to evaluate risk? Are these techniques currently being used?
- How do we communicate the concept of a tolerable risk level (given that it is tolerable to have consequences as a result of certain events) to the public and politicians?

I believe the development and adoption of risk informed building regulations is a necessary progression. I believe we need to quantify the minimum level of heath and safety.

### New Zealand

We are working to define the outcomes for use of buildings and the metrics for outcomes based on risk. We have prepared "Outcome Statements" under four main headings: Safety, Health, Wellbeing and Sustainable Development. In effect these relate to the risks that we consider important. We have also identified the "events" that, for the purpose of regulation in the Building Code, contribute to those risks (i.e., hazards). A number of questions arise, including prioritizing, etc., that have already been submitted:

- What risk metrics might be used for sustainable development? We have defined metrics for safety (probability of injury), health (probability of illness or disease), wellbeing (percentage of affected population satisfied) but a metric (or metrics) for sustainable development is still eluding us.
- How do we properly balance what appears to be an inconsistent tolerance for risk in different situations? For example, value of life in fire in a commercial building vs. value of life in fire in a stand-alone house, or probability of death due to earthquake vs. probability of death due to fire.
- Given that the code is essentially a societal consensus on risk outcomes, and that the code is setting performance requirements for buildings that will last for many years, how do we not only reflect current society expectations but also anticipate them so they remain valid for the life of the building? How do we determine the long-run risk that is acceptable to society, and avoid the knee-jerk "flavor of the month" syndrome, e.g., currently tsunami, but also perception of flood immediately after an event when it might be a 1 in 100 year event?
- How can we establish the connection between the occurrence of an event - say the collapse of a building, for which we can calculate the probability of it happening - and the outcome in terms of the critical metric such as probability of serious injury or death?

### Norway

The verification of building designs to fulfil the functional requirements of the building regulations constitutes a major problem in practicing regulations based on functional requirements. In Norway today, comparative analysis using qualitative evaluations is the dominating verification method. The qualitative analysis is compulsory and will always be the most important part of the verification. In many projects, a qualitative analysis is adequate. However, in more complex buildings/situations, quantitative methods may be warranted to support the qualitative analysis.

In comparative analysis quantification is possible by, using an appropriate tool (if existing?), quantifying both a "pre-accepted design" (in Norway described in the Guideline to the building code) and an alternative design. If an appropriate tool for comparative quantitative analysis does not exist, or is not possible to use, the designer has to 1) choose his tool(s) and 2) define his own acceptance criteria based on the functional requirements. This is causing conflicts between the fire safety designer, the 3rd party reviewer and the authorities. In order to make the regulations based on functional requirements work, and in order to reduce the extent of conflicts, some fire safety engineers think that the authorities should define quantitative acceptance criteria. Since method/tool and acceptance criteria are strongly linked, this also means that the authorities have to describe the appropriate verification method/tool.

Others claim that predefined, sharp limits of risk acceptance will require an accuracy of the verification methods/tools that is unreasonable or not possible to achieve. It will also be a problem that the engineer may manipulate the analysis and put too much effort in meeting the defined risk limit. The analysis itself should be focused, not the effort to meet the acceptance criteria. (However, this is of course a problem because one of the tasks of the engineer is to verify the fulfilment of the regulations).

There is an obvious need to improve the specification of functional requirements (and building performance) in order to simplify the verification of the requirements. Based on experiences from other regulated areas, should (if possible?) the authorities define quantitative acceptance criteria and verification methods?

### Scotland

In each jurisdiction we are continually having to determine which issues pose a risk of sufficient magnitude to include within our regulations or codes. Traditionally this was relatively easy as we dealt with those which were considered to pose the highest risk to either the life or health of people in, or around, a specific building. In terms of life safety we considered issues such as fire escape and structural collapse. In terms of health we considered the risks related to sanitation, air quality and possibly excessive noise. In some parts of the world there are also specific geographical risks, possibly seismic or cyclonic.

For the last three decades we have come under increasing political/societal pressures to include other issues in the building regulations/codes which reflect the desire that buildings should play a part in wider risk issues. For example we have been concerned about the conservation of fuel and power for thirty years and about ensuring access and facilities for people with disabilities for about twenty years. In Scotland the list of issues which politicians/society wants to see included is growing ever faster. Sustainability is the catch all term we are continually encountering (it is now enshrined in our primary legislation) and we are being asked to deal with issues as diverse as security, access to public transport, space standards, security, property protection, water conservation, flood resilience, reuse of demolition materials, embodied energy and flexibility in buildings under this heading.

What I would be very keen to explore at the autumn meeting is how it is possible to consider the comparative importance of building related risk issues. How can we try and introduce some rigour into the decisions on which issues should be covered by building regulations/codes.

This is a very real question for us as it goes to heart of how we allocate resources and of how far building regulations/codes can be used for ever wider objectives. I do not imagine we can solve everything in a day, but I would be very interested to hear in some depth about, perhaps, four specific fields. It would be valuable to see how they have attempted to quantify risk and balance the relatively comprehensible issues of health and safety with those with a wider political or societal interest.

### USA

There are many issues that I could raise, but I think a few critical issues that we can gain insight from other regulated areas include the following:

- To what extent do risk data need to be 'validated' for use as the basis for policy decisions, and who 'validates' the data, who maintains the data, and who sets the guidelines for how the data are used?
- In the face of significant uncertainty, variability and unknowns regarding the risk data and associated impacts (i.e., not just the magnitude and consequence of an

event, but of the impacts on people, the economy, etc), what tools, methods, and processes exist in order to gain agreement on risk assessment approaches, acceptable data, and suitable risk management approaches?

- What are some of the key issues that must be addressed in benefit-risk-cost analyses?

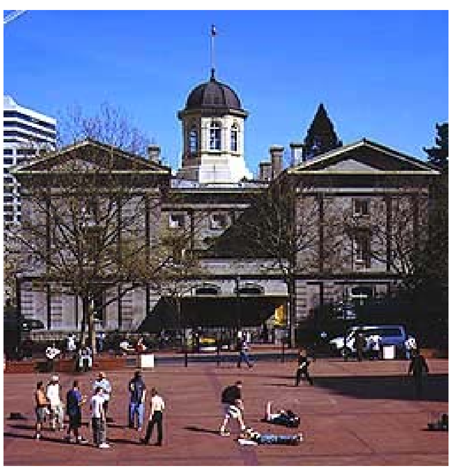
## Presentation Summaries

### Professor Ann Bostrom

Professor Bostrom focused her presentation on acceptable risk decisions and the benefits of using dynamic decision support as a mechanism for facilitating complex decisions related to issues of acceptable risk.

As with any decision, acceptable risk decisions involve choices between alternatives. For acceptable risk decisions in the policy arena, the decision process requires consideration of values as well as technical data. However, this adds complexity, since preferences are often constructed, and how a risk problem is framed will have an influence on subsequent judgments of acceptability. As a result, the consequences of an acceptable risk decision are sometimes judged acceptable only by virtue of the processes that produce them. If the process is lacking, the decision may not be as fully considered as desired.

In sociotechnical systems, such as those which earthquake risk mitigation entail, risk management decisions are contextually complex with hierarchical structures. Different risk mitigation decisions imply different levels of acceptable consequences, and acceptable consequences in earthquake mitigation cannot typically be derived analytically by a single decision maker. Often the public perceptions of earthquake risk are low, the upfront cost for mitigation is high, the benefits of mitigation actions are uncertain, technical and financial resources are limited, and there are competing interests among stakeholders, whose values can be quite diverse. If these issues are not well managed in the decision process, it can be difficult to gain agreement amongst stakeholders.



To highlight the need to look at approaches which do a better job at incorporating a broader spectrum of stakeholders and issues, two case studies were noted.

The first involved a seismic retrofit decision for a federally owned building, the Pioneer Courthouse in Portland, Oregon. In this case, the public was not consulted, the historical properties of building not taken into account by the U.S. General Services Administration, and the result was a decision which produced controversy and conflict.

In Palo Alto, California, the situation was a bit different, as it involved a local government ordinance for seismic retrofit of privately owned buildings. As with the situation in Portland, OR, however, the spectrum of stakeholders was not sufficiently engaged, and the ordinance met with widespread opposition from building owners. In the end, the decision was overturned and a voluntary approach adopted (Berke and Beatley, 1992).

To address the challenges of acceptable risk decisions within complex sociotechnical systems, a decision-making process which addresses the above issues can be quite helpful. Dynamic decision support can do this, as it provides a framework for iterative definition of decision attributes (e.g., death, dollars and downtime) and decision alternatives, while providing a platform for interaction between technical experts and other stakeholders to translate, apply and assess relevant science and technical information, including risk assessment, to have value-focused deliberations, and to increase transparency and access to risk assessment and mitigation option information. Professor Bostrom provided some case studies where dynamic a decision support process has been used in earthquake mitigation decisions with success, and suggested that the process might be helpful in other acceptable risk decision areas within the building regulatory environment.

## Professor Cary Coglianese

Professor Coglianese focused his presentation around issues associated with performance regulations, providing insights on appropriate application and areas of concern.

Recent research has shown that in many areas of regulation, the use of performance-based instruments has remained less frequent than might be expected, with many areas still specifying particular behaviors, technologies, procedures, or processes, rather than setting performance targets and allowing regulated entities the flexibility to achieve that goal (Coglianese et al., 2002).

Effective performance-based regulations depend on the ability of government agencies to specify, measure, and monitor performance, and reliable and appropriate information about performance may sometimes be difficult if not impossible to obtain. If implemented incorrectly or under the wrong circumstances, performance-based regulation will function poorly, as will any regulatory instrument that is ineffectually deployed.

A critical concern identified by Professor Coglianese is the risk associated with 'full compliance sub-optimality' – getting what is called for in the regulation, but having that falling short of what was intended or needed. To assess the success of any regulatory system, three fundamental questions should be considered:

- Is it effective: does it work?
- Is it cost effective: does it deliver benefit at the least cost practicable?
- Is it efficient: do benefits outweigh costs?

For a cost-effectiveness perspective, performance-based regulation is inherently more optimal than prescriptive regulation, as a variety of choices are available at a wide range of costs, which allows for an acceptable low-cost solution. However, although cost-effectiveness may be achieved, there may be situations where efficiency is sub-optimal or unintended outcomes arise. Professor Coglianese outlined three examples which illustrate situations where such situations have been seen.

When the National Highway Transportation Safety Administration (NHSTA) was looking for ways to regulate passive restraints such that passengers where not subject to unacceptable forces on vehicle impact, they set a performance metric wherein crash test dummies would not be subjected to forces above a certain limit. Given the challenges associated with meeting this criterion, the airbag soon became an option of choice. Although this was good, the initial criteria for acceptable performance of airbags were based primarily on middle-aged male drivers. As a result, forces associated with airbag deployment had the unintended consequence of having the potential for causing injury to shorter and less massive persons, particularly women, children and the elderly.

Another example cited was the effort by the Consumer Products Safety Commission (CPSC) to set performance criteria for child safety lids for medication. The well-meaning intent was to reduce the ability for children to open medicine containers, ingest contents and injure themselves. With this in mind, children were used to test the ability to open containers, and if a defined percentage were unable to open the container it passed the test. However, a key subject group was not considered in the test: the elderly. This was unfortunate because the elderly could not open a large percentage of the 'child safe' packages. As a result, elderly people were found to be asking younger people – sometimes children – to help them open their medicine. The behavior-changing outcome therefore defeated the intent of the regulation.

More recently, emission limits from diesel engines were recently changed by the Environmental Protection Agency (EPA) with the intent to reduce $NO_2$ released into the air. However, the test which was devised to measure the emissions was designed as a factory test. The unintended consequence of such a test was the manufacturers could program the engines to recalibrate after testing, thus meeting the test in the factory but not when in use.

These cases illustrate issues that could arise from the implementation of performance-based regulation. However, they are not meant as an argument against the use of performance-based regulation. Rather, they highlight issues that should be considered when faced with the choice of implementing performance-based regulation, specifically:

- Does the promulgating entity really understand the problem and how the regulation will address it?
- Has the full range of societal concerns been captured by the regulation and associated tests, standards and guidelines?
- How might regulated entities adapt to the flexibility provided under performance-based regulation, and what are the potential implications?
- What mechanisms are in place to access how things are actually working in practice?

Performance-based regulation holds promise for achieving societal goals at reasonable cost in a way that accommodates technological innovation. However, the potential for full-compliance sub-optimality can result if the performance-based regulation fails to address the true underlying problem, addresses one problem but creates new ones (perhaps worse than the problem), or addresses the problem but results in adaptive behaviors that introduces new problems. By asking questions such as outlined above, the robustness of the performance-based regulation can be increased.

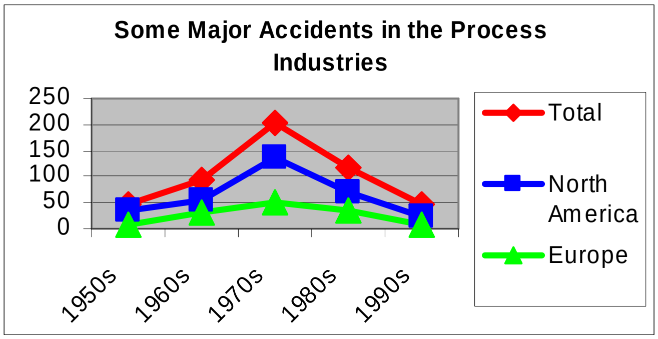
## Dr. Paul Croce

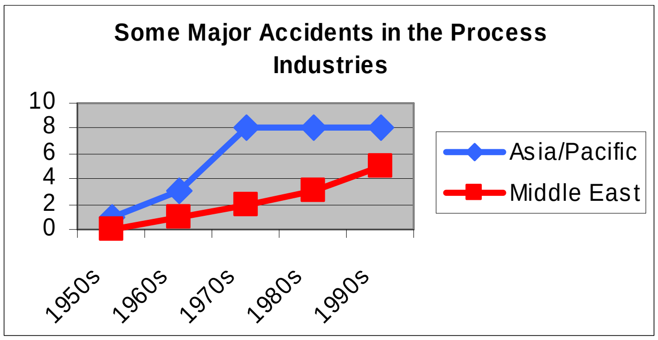
Dr. Croce began with a perspective from the insurance industry, specifically the engineering-based approach of FMGlobal, and focused his presentation on a comparison of performance-based building and fire regulation to process safety management, with particular emphasis on risk and hazard management, maturity of approaches, and regulatory focus.

With respect to process safety management, a timeline was presented which illustrated that early process operations were quite dangerous, with control measures ranging from punishment of operators to repairing and replacing parts after an event. It was not until the

1970's, with the development and application of quantitative risk assessment techniques, that a systemic approach was applied to trying to identify the likely failures and associated consequences. By the 1980's, the systemic approach gained credibility, being accepted by leading industries and government agencies (post Bhopal), with a focus on management systems. By the 1990's, process safety could be characterized by broadened acceptance, regulations, international standardization.

At present, there is an integrated approach to safety management in the process industry which combines requirements of good industry practices, regulations and directives, and international standards, which result in the benefits of meeting all relevant requirements, providing internal consistency, eliminating duplication and overlap, and is cost-effective. Overall, this seems to provide a strong rationale for success. However, it is fair to ask the question: does the system work? To answer this question, one can gain some insight from loss data in the process industry, which shows an increase in process safety industry loss until the development and implementation of risk-informed control systems in North America and Europe, where such safety management systems are in place, with no reduction in the Asia Pacific and Middle East regions, where such measures are not as widely implemented.




From the data, one can conclude that the resulting process improvements are real. The safety management systems, which are based on a reasonable approach to scenario development, including most probable, worst case, and likely worst case scenarios, a full risk profile and a strong corporate safety culture, work well and are readily available from such organizations as the Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE).

Looking at building fire safety, it is interesting to see if any parallels exist, or where lessons can be learned. Performance-based building regulations have been adopted by several countries, and the use is expanding, including the use of risk as a performance criterion.

This is good. However, each country implements performance-based regulation differently and has different approaches to performance-based analysis and design. Although there is some commonality, such as earthquake resistance for critical or essential facilities, and efforts are being focused on fire events, there remain several problems and inconsistencies, and in many cases, practice appears to be outdistancing science. It part, the challenge is that process systems can be more tightly standardized than building design, which allows for better standardized analysis methods and data. In addition, there is more experience in the process industry sector, which means there are more people with the experience and qualifications to address complex hazard issues. Comparing process industries and building regulation side by side, a picture of the key differences quickly emerges:

| Process Industries | Building Regulation |
|---|---|
| Standardized process elements | Large variety of building designs, construction |
| Risk quantification methods well defined | Risk more difficult to quantify |
| Risk assessment approach accepted | No set general method to assess / quantify risk |
| Full risk profile | Design scenario approach (few scenarios) |
| Fewer, more experienced practitioners | Many, less experienced practitioners |
| Cost effective | Cost effectiveness unknown |
| Hazard expertise with process industries | Hazard expertise with practitioners |

In addition to the above, there is also a question on the focus of fire safety objectives. For the most part, fire safety objectives are currently defined in terms of safety to life, with objectives for property in some cases (most often adjacent property). As a result, the focus is on building occupants and not necessarily the public well being. By refocusing the objective on public well being, it may be possible to address several of the current gaps in performance-based building regulation. For example, with such a focus, the immediate design result will be protection of the building of origin and critical infrastructure, but concomitantly, life safety is achieved, the measurement of risk may not be so important, it may be easier to test and assure adequacy and to achieve consistency, and such an approach seems to fit well with existing approaches that work, such as for seismic protection of essential facilities. Work is needed to test this hypothesis, but testing such an approach could be relatively quickly achieved, and the IRCC could play a significant role in assuring consistency of implementation worldwide.

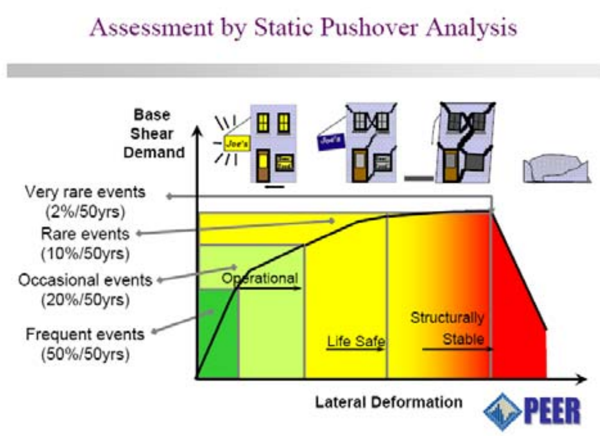
## Professor Gregory Deierlein

Professor Deierlein provided a comprehensive presentation on performance-based seismic design, and how the performance-based approach can be used to better quantify and address risk and uncertainty issues.

To place the discussion in context, a comparison was made between the current, traditional approach to seismic analysis and to a performance-based approach. Key differences are noted below. These parallel quite closely the differences between process safety management and performance building regulation as identified by Paul Croce.

| Traditional Approach | Performance-Based Approach |
|---|---|
| Non-scientifically defined seismic hazard | Scientifically-defined seismic hazard |
| Indirect design approaches | Direct design approaches |
| Undefined and uncertain outcomes | Defined outcomes with probabilities of attainment |

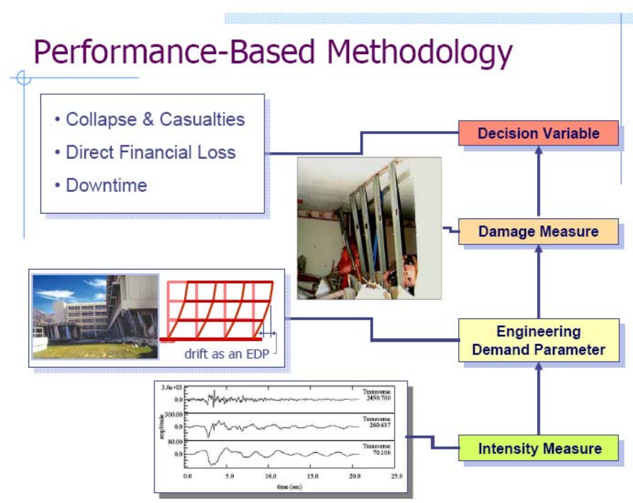
In brief, the current approach considers the magnitude of earthquake events in terms of percent likelihood of exceedence within a 50 year period (e.g., an earthquake categorized as 50% likely in a 50 year period is considered a small, frequent event, whereas one categorized as 2% likely in a 50 year period would be considered quite large and rare). For the various earthquake levels, a set of damage thresholds are defined – operational, life safe and structurally stable – which qualitatively describe the expected level of damage to a building given an earthquake event. This is illustrated below.

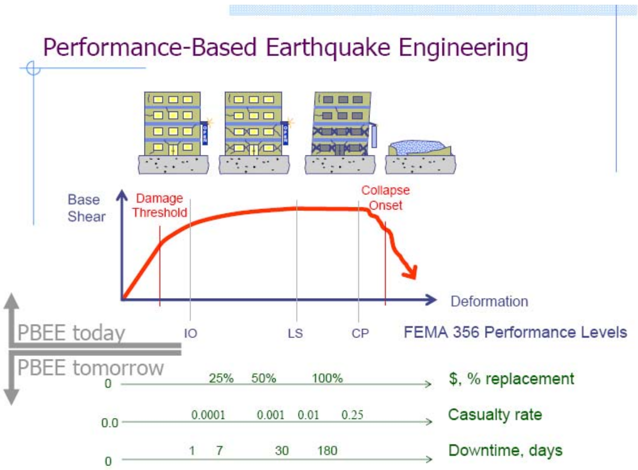



As indicated above, although performance-oriented, this approach does not require a scientifically defined seismic hazard and is not able to define specific outcomes should an earthquake occur, but rather, provides a somewhat broad characterization of damage potential for a few specific design-basis events. It has served to be a good first step in the evolution of performance-based seismic design, but more is desired.

Current thinking for a more performance-based approach aims to better quantify the hazard and expected outcomes, and enable the design specific mitigation measures to meet well-defined performance expectations using specific design methods. This is illustrated below.

In this approach, the performance expectations are defined in terms of decision variables, illustrated here as collapse, casualties, direct financial losses and downtime. To measure these outcomes, specific damage measures are defined. These damage measures and performance outcomes are assessed based on evaluation of specific engineering demand parameters for events of defined intensity.






The net result is the ability to create hazard curves and loss exceedence probability curves which better characterize the expected performance of a facility over the range of earthquake hazard events which could be expected to occur. As illustrated here, the intent is to enable better quantification of key decision variables such as collapse potential, direct damage and downtime, which can inform risk mitigation decisions.

## Professor Peter May

Professor May offered extremely valuable insights regarding how individuals, organizations and society in general think about and respond to the myriad risks faced every day, challenged the notion that risks need to be quantified to be addressed, and offered suggestions for a revised regulatory framework for considering these issues.

The tone for the presentation was set with a number of examples from daily life: from balancing inputs from different perspectives regarding whether a house is sufficiently robust against earthquakes, to the deciding whether the potential for being involved in an accident on a bridge is motivation enough to find another route home. The point of the examples was to highlight that we accept many risks without explicit evaluation of the risk: we "take" risks because benefits are attractive and more easily observed than the risks, which in turn means our attention is often focused on benefits not the risks, and to the extent that there are decisions about lowering risk, cost often dominates over other risk or benefit contributors. In short, discussion about "acceptable risks" is essentially nonexistent in daily life.

At the societal level, the public perception of risk is somewhat more complicated, with scale, externalities and interdependencies playing roles in perception and expected responses. Scale is a factor when dealing with risks that could impact large numbers of people or have impacts across a large geographic area. Externalities, such as fire following earthquake, point to the need to think beyond the initial event to understand the totality of possible impacts. Likewise, interdependencies become critical in thinking about regional disruptions (e.g., loss of critical infrastructure can have ripple effects on the local economy).

To help the IRCC think about the concept of acceptable risk from a societal perspective, Prof. May posed, and spoke to, three key questions.

**Societal Perspectives and Acceptable Risk**

Question 1: *Is the concept meaningful?*

Question 2: *Can a standard be established?*

Question3: *Are public officials willing to talk about it?*

To begin, "acceptable risk' is a problematic concept. As noted by Prof. Bostrom, framing of the decision makes a difference. For example, think about "safety" versus "risk" – the latter forces attention to zero risk, which is an unrealistic concept – a point made by Dr. Croce as well. Also, acceptance is not automatic – it depends on who is bearing the risks, what the benefits are, what the costs of reducing the risks are, who bears the cost, and much more.

Regarding whether a standard for "acceptable risk" can be developed, Prof. May noted that "acceptable risk" is the residual of other choices and that "acceptable risk" is a moving target (e.g., searching for safety in a poorly defined environment). Most public discussions about risks are about the costs of addressing those risks. As a consequence, the decisions are more often based on what costs (in terms of mitigating the risk) can be borne for which the residual is the risk that remains. These decisions are revisited after "learning" from disasters about the consequences of earlier choices. Finally, there is a significant challenge in that elected officials do not like to talk about "acceptable risk." For the most part, they do not like to talk about "probabilities" and "uncertainty," especially when it comes to issues such as deaths and injuries.

So what do we do? In short: Don't Ask, Don't Tell, let people ignore the risks. Instead of trying to make things clearer for the purpose of establishing clear thresholds, obfuscate – stick to vague terms and standards (e.g., life safety), and formulate – keep it technical with unclear implications. To help get where we need to, consider changing the regulatory framework to emphasize consequences and safety goals rather than risks (a point made by Dr. Croce as well).

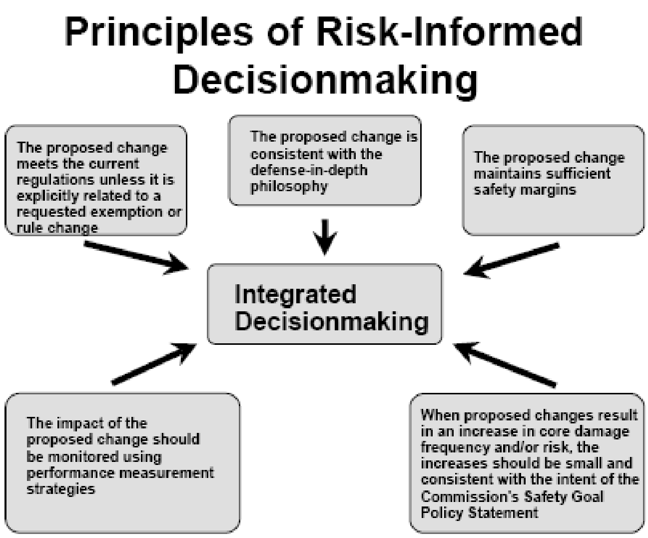
To get to a new framework, there should be a shift in language from "risk avoidance" to "safety goals," the system needs to allow or consideration of different dimensions of safety (e.g. public safety, repairability and usability of structure, and safety improvements should be expressed in relative terms (e.g., the relative risk notion of health risks). Along the way there will several challenges, since multiple decision considerations will be involved (relevant consequences will differ among decision makers and decision situations) and the level of desired information will be varied, by stage of education in the decision process, and by desire for refined estimates of impacts (moving from vague notions about loss of life to more refined probabilistic statements and moving from scenario-based results to probabilistic results). In the end, to be successful the framework needs to include deliberative, transparent processes that allow for wide participation in setting goals/standards, it must have the ability to inspire confidence in the goal/standard-setting process and results, and it needs to produce a regulatory system that is robust enough to adapt to changing societal goals and gaps in regulatory provisions.

## Dr. Gareth Parry

Dr. Parry provided an overview on risk-informing regulatory decisions, using the approach taken by the U.S. Nuclear Regulatory Commission (USNRC) as the basis for his presentation.

The existing regulations are, for the most part, highly prescriptive with considerable focus on defense-in-depth, and in some areas, the provisions are rather difficult to comply with. The latter issue is of some concern, since the USNRC does not want to see such a strong focus on compliance with the letter of the regulations that insufficient focus is given to areas of safety importance.

Over time, this has led to increased consideration of risk assessment as a means to increase efficiency and effectiveness, and to provide focus on those aspects of plant design and operation most significant to safety. The focus on risk assessment had its own set of concerns, however, particularly related to breadth of issues to be addressed, the availability of data, the lack of a uniform approach to creating risk assessment models, and variability in the application of the models and in the abilities of the analysts. With 103 nuclear reactors, the potential existed for 103 different risk assessment models and associated analyses. The recognition of these issues, together with the understanding that models are, by their very nature, incomplete, has led the USNRC in the direction of a risk-informed approach, which uses the risk results from application of Probabilistic Risk Assessments (PRAs) in the regulatory decision-making process, but does not necessarily rely on the PRA output as the only decision variable(s). This is illustrated below.




In this context, the USNRC is less concerned with the quality of the PRA in its own right than with the quality of the decisions made. Clearly, the PRA must be capable of supporting the results used in the application (new facility, change to a facility) in terms of scope and level of detail, but different applications require use of different PRA elements. As such, the focus is on the competency of the application more so than the outcome.

Use of PRAs involves establishing scenarios (what can go wrong), estimating how likely the scenarios are, and estimating their consequences. Specific to PRA formulation for use in the risk-informed decision process, one needs to identify those systems, structures and components (SSCs), operator actions, and plant operational characteristics affected by the application. One must then describe the impact of the proposed application on SSCs, etc. (cause-effect relationship), map the impact onto elements of the PRA model, and evaluate the impact on the risk. It is also necessary to define the acceptance guidelines and criteria (both the risk metrics and the method of comparison). In the case of the U.S. NRC, the acceptance guidelines are based on and consistent with existing guidelines, such as safety goals and subsidiary objectives as established in a Commission's Safety Goal Policy Statement or from specific regulatory acceptance guidelines.

Within the decision-making process, there are a variety of issues that can impact the value of PRA input, including the "quality" of the PRA model (see comment above), the treatment of uncertainty (parameter and model uncertainty), and completeness (e.g., missing initiating events or modes of operation, errors of commission). It is worth noting that incompleteness from unknown sources is one of the main reasons why the USNRC has adopted a risk-informed rather than a risk-based approach.

The NRC approach to establishing the quality of the analysis is to rely on the use of industry consensus PRA standards. However, as with the use of any model, there remain uncertainties due to lack of perfect knowledge. A key objective is to provide assurance that the conclusion drawn from the PRA analysis is robust in light of the uncertainties. This requires characterizing and addressing sources of uncertainty.

Parameter uncertainty can be *characterized* by probability distributions representing state of knowledge about "true" value, whereas model uncertainty may be represented as a discrete probability distribution over several models, with the probabilities representing the analysts' relative degrees of belief in the validity of the models. By definition, incompleteness is not addressed in the model structure, but the scope of model needs to be understood. Parameter uncertainty can be *addressed* by propagating uncertainties and using resulting mean value for comparison with acceptance guidelines. Model uncertainties can be addressed by developing an understanding of whether there are plausible, alternative assumptions that would impact the result of the comparison with the acceptance guidelines. The incompleteness that is known about can be addressed by providing qualitative arguments or bounding analyses; in other words, by designing the application so that it does not impact the unmodeled contribution to risk, by making conservative decisions to compensate for missing contributions, or by perform a full scope PRA.

As the next step in risk-informed decision-making for the USNRC, the concept of performance has entered the picture – a topic of great interest to the IRCC. As viewed by the USNRC:[1] "A risk-informed and performance-based approach is one in which the risk insights, engineering analysis and judgment, and performance history are used to: (1) focus attention on the most important activities; (2) establish objective criteria based upon risk insights for evaluating performance; (3) develop measurable or calculable parameters for monitoring system and licensee performance; and (4) focus on the results as the primary basis of regulatory decision-making.

Accordingly, whenever possible, a performance-based approach should be used. A performance-based approach brings about a focus on results as the primary basis for regulatory decision making, whether PRA information is available or not. A performance-based approach is characterized and recognized by the occurrence of five defined attributes. These attributes are:

1) A framework exists or can be developed to show that performance, as indicated by identified parameters, will serve to accomplish desired goals and objectives.
2) Measurable, calculable, or constructable parameters to monitor acceptable plant and licensee performance exist or can be developed.
3) Objective criteria to assess performance exist or can be developed.
4) Margins of performance exist such that if performance criteria are not met, an immediate safety concern will not result.
5) Licensee flexibility in meeting the established performance criteria exists or can be developed."

In many ways, this approach can be applied directly in the building regulatory environment.

[1] Revised Working Draft: Framework for Development of a Risk-Informed, Performance-Based Alternative to 10 CFR Part 50, Section 8.8.3., http://ruleforum.llnl.gov/cgi-bin/downloader/Approaches_to_requirements_for_reactors_lib/1715-0005.pdf

## Discussion

Following presentations by the invited speakers, IRCC members and guests engaged in a wide-ranging discussion with the invited speakers on topics of risk, performance, and regulation. With the IRCC focus on performance-building regulatory systems, the focus of discussion was on use of risk concepts in building regulation and design, and how lessons from the other regulated areas could be helpful.

At the outset of the discussion, Dr. John Hall noted that historically some regulators have seen risk assessment as a stalking horse for eliminating or reducing regulation, which resulted in a cautious approach when risk assessment was used as an argument for a deviation from the code. He also echoed Prof. May's comments about the challenge that regulatory officials have with concepts of probability and the resultant impact on any risk estimation. This is a particular concern given the large number of issues associated with safety in buildings, which translates to a large number of scenarios to be considered, each with associated probabilities of occurrence. In addition, Dr. John Hall noted that reliability is a major concern: the probability of an event occurring, and the expected performance of measures designed to mitigate the risk, can change over time if the reliability of protection measures degrades.

Dr. Paul Stollard followed with questions regarding the metrics used to determine whether risks – however assessed – are tolerable. Is it regulator's duty to set the parameters, or should engineers be allowed to take more responsibility? Either way, who bears the burden of proof? Dr. Rainer Mikulits added by noting that it is equally important to ask who makes decision to regulate at a particular risk level?

In response, Dr. Parry noted that the US Nuclear Regulatory Commission (USNRC) attempts to address questions such as these through the regulatory process, which includes input from various stakeholders addressed during the rule-making process. He noted the current rule-making activities on the topic of risk-informing and performance-basing requirements for nuclear reactors, which is tackling many of these issues head-on (see summary principles on following page).[2]

In response, Dr. John Hall noted that in the built environment, since application of risk concepts in design and regulation is somewhat new, perhaps we ought to look to crawl before we walk, and walk before we run. Maybe we should be looking at the data to see where the biggest problems are and focusing there. Perhaps we could develop some sort of rating systems for buildings to help in this process. Ms Suzanne Townsend raised the issue that perhaps the biggest challenge we currently have, and why we are having difficulty making progress, is that we are having difficulty defining the problem. In the case of the 'leaky building' problems in New Zealand, for example, the issue was more of a regulatory system failure than a risk or performance issue. Although the knee-jerk reaction was that the performance code needed to be fixed, perhaps that is not the problem at all?

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[2] http://ruleforum.llnl.gov/cgi-bin/library?source=*&library=Approaches_to_requirements_for_reactors_lib&file=*&st=anpr

**1.4 Desired Principles of the Overall Framework**[2]

As the regulatory structure is developed and implemented, it should adhere to certain principles that are based on and consistent with the NRC's mission of protecting the public health and safety and the environment and the common defense and security as outlined in the NRC's Strategic Plan. These principles essentially define the acceptance criteria of the technology-neutral framework and the technology-neutral and technology-specific requirements:

**Safety.** The requirements will ensure protection of public health and safety and the environment.
**Security.** The secure use and management of radioactive materials will be ensured.
**Openness.** Openness in the regulatory process will be maintained.
**Effectiveness.** The structure will ensure that NRC actions are effective, efficient, realistic and timely.

In addition, the framework must also ensure that it is:

**Risk-informed.** Risk information and risk insights are integrated into the decision making process such that there is a blended approach using both probabilistic and deterministic information.
**Performance-based.** When implemented, the guidance and criteria will produce a set of safety requirements that will not contain prescriptive means for achieving its goals, and therefore be performance oriented to the extent practical.
**Incorporates Uncertainty.** The guidance and criteria have to address the uncertainties, identification of key uncertainties, the impact of the uncertainties, and their treatment in the development of the requirements.
**Maintains Defense-in-depth.** Defense-in-depth is maintained and is an integral part of the framework.
**Technology-neutral.** The framework is developed in such manner that, as new information, knowledge, etc is gained, changes and modifications to the regulatory structure can be adapted to any technology-specific reactor design in an effective and efficient manner.

Prof. Coglianese, referring back to his presentation, noted that as part of defining the problem, one really has to ask 'what does performance mean' in the context of the regulatory system. While performance approaches give flexibility to those being regulated, it may not always be the most appropriate outcome. Back to the question Dr. Stollard asked earlier, who should bear the burden, rule-makers or industry?

In the discussion that followed, Prof. May and Prof. Bostrom reinforced the themes of their presentations, noting the difficulty in addressing issues such as 'the right level' to regulate at, how challenging it is to establishing tolerable risk or performance levels, and that getting the right decision-making systems and participants is critical, as there are no simple answers to these issues.

Dr. Mikulits followed the performance thread and brought the discussion around to whether all aspects of buildings should be regulated from a performance basis. In particular, he noted concerns for adaptive behavior in the design community, where perception of a particular performance attribute could bias the behavior of a designer, for example, a focus on travel distance in a shopping mall may inadvertently result in other of the complex issues in a mall to be missed. In addition he noted that there are cost-effectiveness issues associated with the use of performance analysis and design approaches, which may influence their use. In a complex facility, such as a shopping mall, a performance-based approach may be appropriate for assessing and design for life safety, but such an approach may not be practical for acoustical design or other design features. In simple structures, such as single family homes, performance concepts may not have much of a role at all.

Mr. Armin Wolski, reflecting on the presentations by Dr. Parry and Prof. Bostrom, responded that probabilistic risk assessment (PRA) can be useful for the complex design situations, even though the tools themselves are complex, as they can incorporate a wide range of factors to be considered. Also, the use of decision tools can be helpful when trying to determine when, where and how to apply performance approaches. As an example, he noted the current discussion and debate in the United States, which although is focused around the specific topic of height and area restrictions in the code, the issue is really about what level of fire safety is appropriate. In this case, both PRA and decision tools could be helpful. Dr. Stollard noted that, although there is promise for risk-informed performance-based approaches to fire safety engineering, the entire discipline of fire engineering is still quite young, and echoing comments of Dr. John Hall, noted that perhaps baby steps are appropriate, as we need to take a systems approach to the problem, and that integration of the many issues needs to be addressed.

To Dr. Mikulits' comment on performance concepts in single family homes, Dr. John Hall noted that although we might not engage in performance-based design for one-off single family home designs, it may well be appropriate for design for common templates (e.g., a single family home design that would be applied in many locations), much in the way it can be appropriate for whole classes of buildings, since it becomes more cost effective. In this way, performance concepts for new buildings have merit, but may not have much traction with respect to regulation of existing buildings.

In response to the latter point, Dr. Deierlein noted that performance-based design for earthquake has been driven far more from the perspective of upgrading existing buildings than for new building design, since the existing building stock is quite large, as is the associated loss exposure without upgrades. The application of performance-based concepts helps to provide a structure to identify loss objectives and designing to meet the desired performance. Mr. Mike Stannard noted that the situation is similar in New Zealand, where seismic upgrade of existing buildings is a significant issue, and that there is a lot of focus currently on identifying those buildings most at risk in a seismic event. Recent legislation calls for action on buildings that would be likely to collapse in an earthquake one third as strong as used to design a new building. Local councils have been required to develop policies which cover all buildings except small residential. Guidelines for the assessment and improvement of earthquake performance have been developed and published. Ms. Townsend added that much of the focus is a result of communities not realizing the level of risk they were 'accepting,' and when it became better understood, chose to increase the seismic performance requirements.

Mr. Tariq Nawaz pointed out that application of performance concepts to existing buildings can be challenging, since data are incomplete and imperfect, and it can be difficult to go back and fix past problems without supporting data. Fire safety is an old problem, for which we have methods that work. For example, we may have 50 deaths per year from fire in apartments, while there may also be 500 deaths from slips, trips and falls, yet the focus is often on fire safety and it is not clear where real reductions can be made. Perhaps more gains can be realized by focusing risk and performance concepts on health and safety issues that go beyond fire, such as noise, indoor air quality, and other building requirements.

Still on the topic of existing buildings, Dr. John Hall noted that some codes are trying to use risk-informed concepts, such as the ICC Performance Code, but in that case, a large portion of the code seems to be focused on seismic issues, does not seem to address other risks as well, and does not necessarily provide enough information to the user to make good decisions. Dr. Mamoru Kohno noted that in Japan, the Building Standard Law provisions for seismic design had not changed since 1981, but that recent events were causing the provisions to be reassessed, and that a new law was recently passed to require upgrades for all houses to meet more stringent seismic requirements. Dr. Parry noted that the risk-informed performance-based approach of the USNRC is built around trying to address issues with 103 existing facilities, and that risk information helps identify areas of concern and guide solutions. He pointed out, however, that the role of oversight and enforcement cannot be overlooked. The near accident at the Davis-Besse facility was oversight and maintenance related, and that strong management procedures are needed to help assure performance expectations are continuously being addressed.

Picking up on Mr. Nawaz' earlier comment related to looking at the data and seeing where that leads, Prof. Coglianese asked whether ex-post risk assessment is ever undertaken in the built environment to support ex-ante risk assessments? Dr. Stollard responded that ex-post analysis is undertaken, and pointed to the issue of requirements for sprinklers in buildings as an example. Dr. John Hall added that ex-post assessment is not done very often for individual buildings, but is undertaken with respect to large-impact issues, of which fire may not qualify in some peoples' eyes. It can be helpful to look at the data, though, to understand drivers. For example, floods do not drive water damage losses, and large fires do not drive fire deaths, although in both cases the large events get the most attention. With respect to slips, trips and falls, we know there are a lot of injuries, but it is not clear what the causes are, and therefore what if anything can be done to significantly change the situation.

Following the discussion on ex-post risk assessment, Dr. Mikulits asked a fundamental question: should risk and performance issues separated. He noted that he was hearing a mixture of risk assessment and performance design and regulation issues that were not necessarily linked, and which could have very different paths for resolution. Dr. Deierlein responded that, in the seismic engineering community, there is a strong linkage between risk and performance concepts, and that the Applied Technology Council (ATC) project 58 on developing performance-based seismic design guidance is developing around the use of establishing performance objectives in terms of risk-related objectives, such as direct losses, casualties, and facility downtime (http://www.atcouncil.org/atc-58.shtml). In this effort, the performance-based framework closely links loss objectives, performance metrics, and design approaches with probabilistic representations of hazards and expected losses. Such linking of risk and performance clarifies stakeholder expectations and engineering analysis, and opens the door for benefit-cost analysis and other mechanisms to be introduced to help decision-making, which in many cases, results in design strategies that go beyond current code requirements. In response, Prof. May noted that quantification is a tricky issue to address, since it is a 'value of information' issue. What are the benefits of increased precision in the risk assessment or performance quantification? Environmental economists spend a lot of time looking at willingness to pay and contingent valuation to help resolve benefit-cost issues relative to mitigation decisions – how is this addressed in the seismic arena, is there something to be learned? Mr. Stannard added that uncertainty is a significant challenge in the performance-based design process, noting material properties as an example – if you do not have the data on materials, how well can one predict performance under different conditions?

After considerable discussion around seismic, fire and existing building issues, the participants were asked what other risk and performance issues were becoming significant issues in their countries. Mr. Stannard noted that climate change and sustainability are big issues in New Zealand. There is currently considerable emphasis on improving the energy efficiency performance of buildings and sustainability is being placed at the heart of the review of the Building Code. This is not simply a technical issue. There will inevitably be gaps between what is technically feasible, what is cost effective and what is politically acceptable. Mr. Javier Serra noted that energy issues are increasingly important in Spain, and that the new building regulations have significant requirements for energy efficiency and renewable energy sources, including requirements for the use of photovoltaic cells in some new commercial buildings. Dr. Stollard noted that the issues facing him and his agency directly are fire safety, disabled access and energy, with challenges in the fire safety area relating to licensing and differing levels of risk based on occupant characteristics, with care homes being a significant focus at the moment.

At the workshop neared its end, participants were asked how the issues of societal risk perception and managing performance expectations were being, or could be addressed.

Mr. Denis Bergeron noted that in Canada, societal risk acceptance needs to be built into the process, but not in an overt manner. If you ask people directly what risks they would choose to face, they will not likely be able to provide helpful information. A better approach might be to maintain a high level of stakeholder interaction and keep ongoing dialog, which helps to address issues as they arise. In general, there is a focus on understanding the risks and benefits of regulating, with some strong feedback indicating that the government should do as little as needed in regulation, and allow the market to help find solutions.

Similar feedback is being heard by stakeholders in Australia. Recent studies by the government, including by the Productivity Commission, raised the issue of what should be regulated, to what level, and what the resultant implications might be. As pointed out by Dr. Lam Pham, it is important to look at what risks are being imposed on society as a result of what is regulated, in addition to looking at which risks are purposely being mitigated.

Mr. Nawaz echoed other representatives of other countries in noting that care should be taken to minimize unnecessary regulation. Building regulation operates in a political climate, and sometimes science and engineering takes a back seat. Human behavior, attitudes and perceptions are critical, and need to be addressed in the regulatory decision-making process.

Dr. Mikulits suggested that it is important to distinguish between risk of a failure (e.g., a fire protection system failure) and risk of occurrence (e.g., probability of a magnitude 8.0 earthquake), and to distinguish societal risk from individual risk. The risk of failure is important in estimating overall risk, but is likely a bigger concern for risk analysts than it is for the public (e.g., people have some sense of how "risky" driving is and the potential consequences of an accident, but probably do not think much about the likelihood of brake failure leading to the accident – what "risk" one is talking about affects the perception of that risk). Dr. Mikulits also noted that when looking at broad regulatory change, society needs to be ready for the change or they will not buy into the process. Societal risk perception involves much more than probability, and as Mr. Nawaz noted, human behavior, attitudes and perceptions are critical, as is the fact that building regulation operates within a political environment.

Dr. John Hall voiced his support for the issues identified by Dr. Mikulits. He also noted that rationality is not an issue that regulation can assume or control for, and as Dr. Parry noted earlier, focus on oversight and enforcement to help assure controls remain in place is critical to meeting public expectations should an event occur (The Station nightclub tragedy might not have occurred if the maintenance and enforcement parts of the regulatory system worked as intended).

Ms Townsend observed that societal expectations often have nothing to do with risk from a regulatory performance perspective, and that often the squeaky wheel get the grease.

Going forward, Dr. Paul Croce suggested that a focus on public well being would be far more encompassing that a focus on life safety, and will help address some of the societal expectation issues. Prof. May noted that often perceived failures in the regulatory system come after events. Without an event, the public is not marching on government demanding a change, but going with the flow because nothing is perceived to be amiss. To help address potential issues down the road, professional communities can do more to study and address issues, even to the point of lobbying or being more involved in the political process.

## Summary

The use of risk in regulation is a challenging issue. Who or what is at risk, how is the risk calculated, how is the risk perceived, what should we do to mitigate risk and how much will that cost are just a handful of considerations that need to be addressed. As building regulations around the world look to incorporate risk concepts – particularly into performance-based building regulations – gaining input and perspectives from other regulated areas is not only desirable but is essential. To help facilitate the process of knowledge transfer, and to open lines of communication with experts in risk and performance regulation, the Inter-jurisdictional Regulatory Collaboration Committee (IRCC) convened a workshop on the use of risk in regulation. Over the course of the workshop, a variety of perspectives were voiced and a wide range of issues were discussed. Although there was no preconception that the workshop would answer all the open questions and provide solutions in a nice, neat package, the workshop did result in identifying some key issues and potential paths for the future.

### Approaches Discussed

A major impetus for the workshop was to capture different approaches for the use of risk concepts in regulation. Through the presentations and discussions, three primary approaches were raised:

1) The use of risk-informed decisions about what to regulate or what aspects of existing regulations to emphasize in enforcement (e.g., see presentation by Dr. Gareth Parry on the USNRC approach);
2) A focus on risk (hazard) management through regulation by quantifying hazards, impacts and uncertainties (and therefore risks) as a basis for deciding about regulatory actions and standards (e.g., see presentation from Dr. Gregory Deierlein and associated discussions related to the PEER approach to performance-based seismic design); and
3) Establishing "tolerable" levels of risk (damage/loss), "acceptable risk," or other risk-related standards as minimum standards for safety.

### Key Issues

***"Acceptable risk"*** is a value-judgment about what levels of loss/damage are willing to be “accepted” in the case of damaging incident or event. The use of the term “acceptable risk” implies that someone understands the risk and actively accepts it. This is often not the case in a regulated environment. Sometimes the term ***“tolerable risk”*** is used as an alternative, with the implication that instead of understanding and actively “accepting” a risk, the recipient “tolerates” the risk imposed upon them. However, the concept of “tolerable risk” is also a value-judgment regarding what levels of loss/damage/impact are willing to be “tolerated” in the case of a damaging event.

***“Acceptable risk’ is a problematic concept*** – framing of the decision makes a difference. Consider “safety” versus “risk” – the latter forces attention to zero risk, which is an unrealistic concept. Acceptance is not automatic – it depends on who is bearing the risks, what the benefits are, what the costs of reducing the risks are, who bears the cost, and much more.

***As with any decision, acceptable risk decisions involve choices between alternatives.*** For acceptable risk decisions in the policy arena, the decision process requires consideration of values as well as technical data. However, this adds complexity, since preferences are often constructed, and how a risk problem is framed will have an influence on subsequent judgments of acceptability. As a result, the consequences of an acceptable risk decision are sometimes judged acceptable only by virtue of the processes that produce them. If the process is lacking, the decision may not be as fully considered as desired.

***"Acceptable risk" is the residual of other choices and is a moving target*** (e.g., searching for safety in a poorly defined environment). Most public discussions about risks are about the costs of addressing those risks. As a consequence, the decisions are more often based on what costs (in terms of mitigating the risk) can be borne for which the residual is the risk that remains. These decisions are revisited after "learning" from disasters about the consequences of earlier choices.

***Elected officials do not like to talk about "acceptable risk."*** For the most part, they do not like to talk about "probabilities" and "uncertainty," especially when it comes to issues such as deaths and injuries.

***If developing such a standard for defining "acceptable risk" is deemed necessary, creating a credible process for establishing relevant metrics, standards or goals is critical.*** However, this applies to any metric, standard- or goal-setting process, not just "acceptable" risks.

***Effective performance-based regulations depend on the ability of government agencies to specify, measure, and monitor performance, and reliable and appropriate information about performance may sometimes be difficult if not impossible to obtain.*** If implemented incorrectly or under the wrong circumstances, performance-based regulation will function poorly, as will any regulatory instrument that is ineffectually deployed. A critical concern is the risk associated with 'full compliance sub-optimality' – getting what is called for in the regulation, but having that falling short of what was intended or needed. To assess the success of any regulatory system, three fundamental questions should be considered:

- Is it effective: does it work?
- Is it cost effective: does it deliver benefit at the least cost practicable?
- Is it efficient: do benefits outweigh costs?

***It is important to distinguish between risk of a failure and risk of occurrence, and to distinguish societal risk from individual risk***. The risk of failure is important in estimating overall risk, but is likely a bigger concern for risk analysts than it is for the public (e.g., people have some sense of how "risky" driving is and the potential consequences of an accident, but probably do not think much about the likelihood of brake failure leading to the accident – what "risk" one is talking about affects the perception of that risk).

***When looking at broad regulatory change, society needs to be ready for the change or they will not buy into the process.*** Societal risk perception involves much more than probability: human behavior, attitudes and perceptions are critical, and it must be remembered that building regulation operates within a political environment: often times the squeaky wheel gets the grease.

### A Path Forward

***A performance-based approach is characterized and recognized by the occurrence of five defined attributes:***

- A framework exists or can be developed to show that performance, as indicated by identified parameters, will serve to accomplish desired goals and objectives.
- Measurable, calculable, or constructable parameters to monitor acceptable performance exist or can be developed.
- Objective criteria to assess performance exist or can be developed.
- Margins of performance exist such that if performance criteria are not met, an immediate safety concern will not result.
- Flexibility in meeting the established performance criteria exists or can be developed.

***Performance-based design*** can work effectively when expectations/ outcomes are defined in terms of decision variables, specific damage measures are defined to measure these outcomes, and damage measures and performance outcomes are assessed based on evaluation of specific engineering demand parameters for events of defined magnitude.

***A performance-based framework should closely link loss objectives, performance metrics, and design approaches with probabilistic representations of hazards and expected losses***. Such linking of risk and performance clarifies stakeholder expectations and engineering analysis, and opens the door for benefit-cost analysis and other mechanisms to be introduced to help decision-making, which in many cases, results in design strategies that go beyond current code requirements.

Often, building safety objectives are currently defined in terms of safety to life, with objectives for property in some cases (most often adjacent property). As a result, the focus is on building occupants and not necessarily the public well being. ***By refocusing the objective on public well being, it may be possible to address several of the current gaps in performance-based building regulation.***

***To get to a new framework***, there should be a shift in language from "risk avoidance" to "safety goals," the system needs to allow or consideration of different dimensions of safety (e.g. public safety, repairability and usability of structure), and safety improvements should be expressed in relative terms (e.g., the relative risk notion of health risks).

## Participants

### Invited Speakers

Prof. Ann Bostrom, Georgia Institute of Technology, School of Public Policy

Prof. Cary Coglianese, University of Pennsylvania Law School

Dr. Paul Croce, FMGlobal (retired)

Prof. Greg Deierlein, Stanford University, Department of Civil & Environmental Engineering

Prof. Peter May, University of Washington, Center for American Politics and Public Policy

Dr. Gareth Parry, U.S. Nuclear Regulatory Agency, Office of Nuclear Reactor Regulation

### IRCC Members

Mr. Mike Balch, Australian Building Codes Board, Australia

Mr. Denis Bergeron, Institute for Research in Construction, National Research Council, Canada

Ms Megumi Hata, Australian Building Codes Board, Australia

Dr. Mamoru Kohno, National Institute for Land and Infrastructure Management, Japan

Ms Lisbet Landfald, National Office of Building Technology and Administration, Norway

Dr. Brian Meacham, Arup, USA

Dr. Rainer Mikulits, Austrian Institute of Construction Engineering, Austria

Mr. Tariq Nawaz, Department for Communities and Local Government, England and Wales

Mr. Richard Okawa, International Code Council, USA

Dr. Lam Pham, CSIRO / Australian Building Codes Board, Australia

Mr. Javier Serra, Ministry of Housing, Spain

Mr. Mike Stannard, Department of Building and Housing, New Zealand

Dr. Paul Stollard, Scottish Building Standards Agency, Scotland

Mr. Jon Traw, Traw Associates, USA

### Guests

Mr. Wayne Bretherton, WSP Fire Engineering, UK

Dr. John Hall, National Fire Protection Association, USA

Ms Abbie Liel, Stanford University, Department of Civil & Environmental Engineering, USA

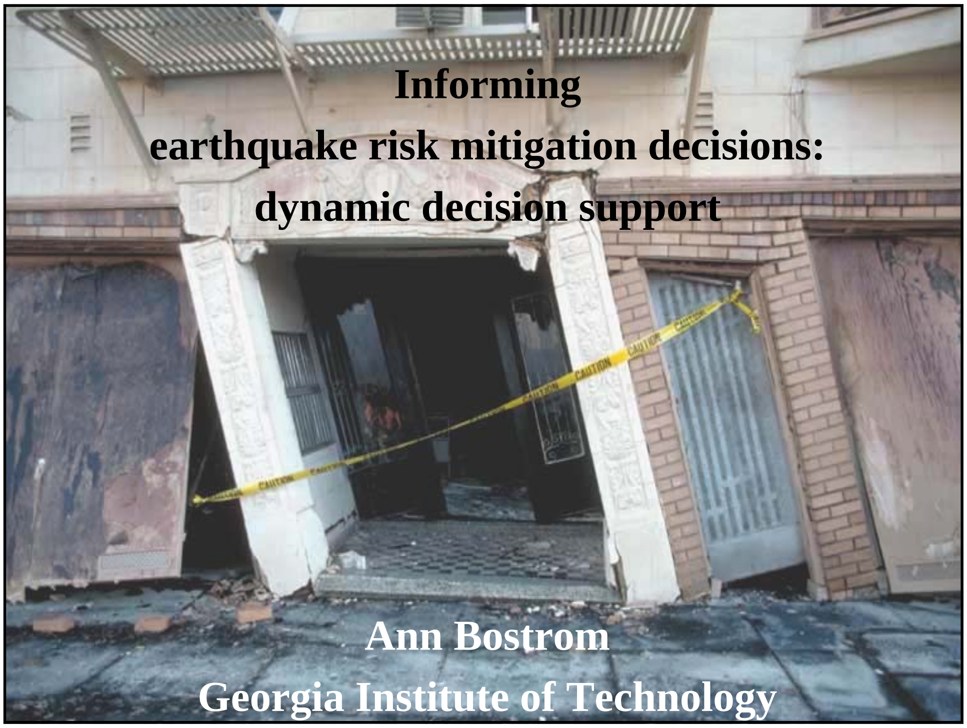
Dr. Huang Shimin, China Academy of Building Sciences, China

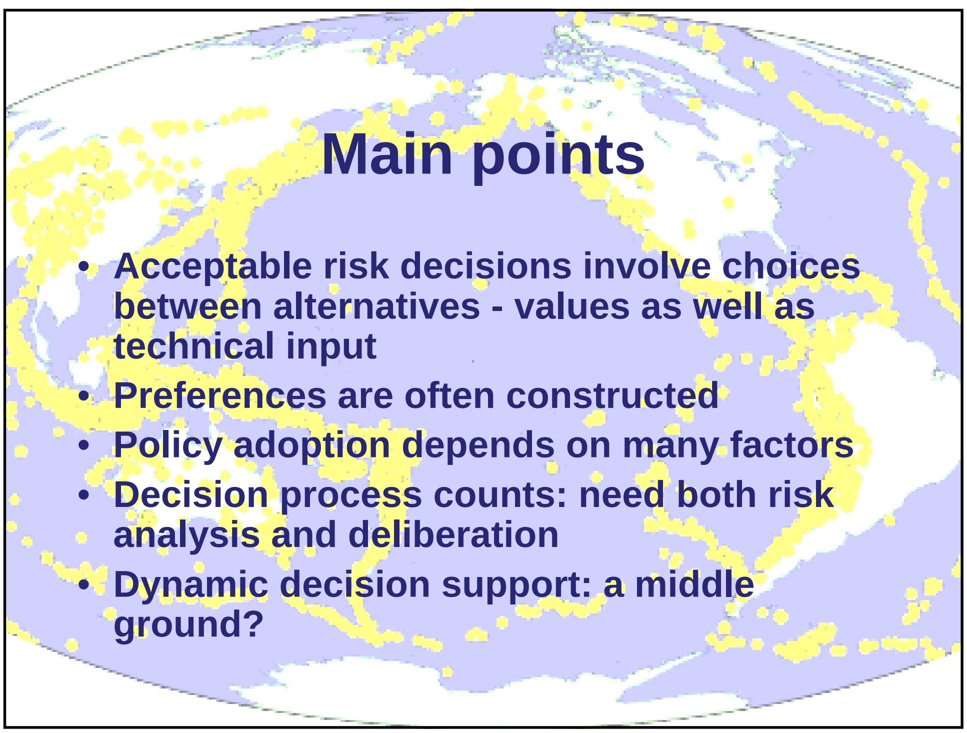
Ms Cathy Taraschuk, Institute for Research in Construction, National Research Council, Canada

Ms Suzanne Townsend, Office of the Hon Clayton Cosgrove, New Zealand

Mr. Armin Wolski, Arup, USA

## Appendices


Informing
earthquake risk mitigation decisions:
dynamic decision support
Ann Bostrom
Georgia Institute of Technology


Main points
• Acceptable risk decisions involve choices between alternatives - values as well as technical input
• Preferences are often constructed
• Policy adoption depends on many factors
• Decision process counts: need both risk analysis and deliberation
• Dynamic decision support: a middle ground?

## Choice

- Acceptable risk problems are decision problems, and so
- "require a choice among alternative courses of action."

(Fischhoff, 1981)

## A prior definition?

- A priori definition of acceptable risk for societal risk management:
  - Implicit: best available technology
  - Explicit: $10^{-6}$ cancer risk, "life safety"
- Potentially problematic.

## Constructing preferences

- How risk problems are framed influences subsequent judgments of acceptability.
- Sometimes consequences are judged acceptable only by virtue of the processes that produced them.

## Constructing preferences (cont)

Potential deaths from earthquake-related building collapse may be valued differently depending on numerous factors, including:

1. Whether the building is presented as one of many
2. What other attributes are evaluated at the same time

(Norinder 2001, Sælensminde 2003)

## Constructing preferences (cont)

3. Assignment of causality
4. The relative emphasis given various causal factors in the description of the collapse, for example, whether the building was up to code

(McDaniels et al. 1998, van der Pligt et al. 1998)

## Constructing preferences (cont)

5. Who might be injured or die

   For example - value of statistical life is contingent on age

   (Rosen 1988, Bleichrodt and Quiggin 1999)
6. Recent experience (Kates 1962, 2002), which helps to anchor the frame of reference for evaluating consequences

   (Tversky and Kahneman 2000)

## Constructing preferences (cont)

7. Discount rates: economic analyses find that they vary for future risks

(Cropper et al. 1991, 1992)

8. Return periods: considering different return periods might produce different assessments for the same system consequences.

## Many influences on policy adoption

- Low public perceptions of earthquake risk
- High upfront cost
- Uncertain benefits of mitigation actions
- Lack of technical and financial resources
- Competing interests among stakeholders
- Differences in the values held by stakeholders.

Influence the type of risk mitigation policy adopted—building codes, retrofit ordinances, or disclosure requirements.

## Risk management decisions

In sociotechnical systems (like those earthquake risk mitigation entail), risk management decisions are

- contextually complex
- with hierarchical structures
  - from individual decisions about equipment and surroundings (e.g., decisions and actions by construction workers),
  - up to policy and budgetary decisions made by regulatory bodies and other government actors

(Rasmussen 1997)

## Decision processes and consequences

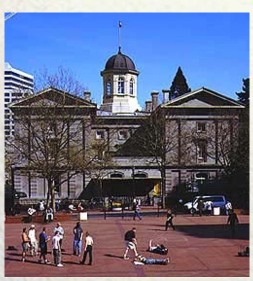
- Earthquake risk mitigation adoption is a function of more than seismic risk reduction:
  - U.S. General Services Administration
  - Pioneer Courthouse, Portland, Oregon, USA
  - Palo Alto, California, USA
- Different risk mitigation decisions imply different levels of acceptable consequences.
- Acceptable consequences in earthquake mitigation cannot typically be derived analytically by a single decision maker.

## U.S. General Services Administration

Seismic retrofit decision processes for federally owned buildings

– Multi-stage, hierarchical decision making with multiple attributes, many decision makers
– Propriety software for seismic analysis (ST-Risk)
– Vague definition of tolerable risk (“life safety”)
– Ultimately congress decides - little opportunity otherwise for public input or insight

## Pioneer Courthouse



Sample seismic retrofit decision for a federally owned building, the Pioneer Courthouse in Portland, Oregon

– Public not consulted
– Historical properties of building not taken into account by GSA
– Produced controversy and conflict

## Palo Alto, California

- Local government ordinance for seismic retrofit of privately owned buildings
- Met widespread opposition from building owners
- Eventually decision was overturned, voluntary approach adopted

(Berke and Beatley, 1992)


## Better risk decisions

Participative, democratic processes —not necessarily consensual in character— are likely to improve the quality of societal risk decisions

(Beierle 2002)

## Dynamic decision structuring

- Support iterative definition of
  - Decision attributes (death, downtime and dollars)
  - Decision alternatives
- Provide a platform for interaction between technical experts and other stakeholders
  - To translate, apply and assess relevant science and technical information, including risk assessment
  - Value-focused deliberations
  - Increase transparency and access to risk assessment and mitigation option information

## Dynamic decision support

Develop integrative and adaptable decision support tools, to:

- speed the diffusion of new seismic retrofit technologies
- highlight which risk reduction strategies and technologies are most likely to meet the objectives of decision makers.

## Main points

- Acceptable risk decisions involve choices between alternatives - values as well as technical input
- Preferences are often constructed
- Risk policy adoption depends on many factors, not just risk assessment
- Decision process counts: need both risk analysis and deliberation
- Dynamic decision support: a middle ground?

## Additional references of potential interest:

- HM Treasury report

  Managing risks to the public: appraisal guidance, June 2005
- U.S. Office of Management and Budget Proposed risk assessment bulletin, 2006

## Acknowledgements

- National Science Foundation for research support, through the Mid America Earthquake Center
- Rama Mohana R. Turaga and Branco Ponomariov (co-authors)
- Peter May, Barry Goodno and others for helpful comments on earlier drafts

## *Observations on the Use of Risk Concepts*

Paul A. Croce
Vice President & Manager of Research (Retired)
FM Global

IRCC Workshop on the Use of Risk in Regulation
Sheraton Fisherman's Wharf Hotel
San Francisco, CA
October 17, 2006

## *My perspective*

- FM Global
  - Largest insurer against property damage and business interruption worldwide (all risk)
  - All occupancies except nuclear power plants
  - Operating philosophy
    - risk improvement and loss prevention
    - better to avoid a loss than to recover from one
    - almost all loss is avoidable
  - Underwriting provided using engineering information of insured properties coupled with scientifically based technical solutions

**PAC** 2

## *My perspective*

- FM Global
  - 4000 employees; no actuaries; 1700 engineers in the field
  - Perform scientific research to support underwriting, engineering, and to provide loss prevention solutions to clients
  - Write our own installation and occupancy standards
  - Conduct our own performance and reliability tests of materials, products and systems (FM Approvals)

**PAC** 3

## *My perspective*

- FM Global experience
  - Largest property insurer in the world…and growing
  - After 9/11, only property insurer writing new business
  - After four Florida hurricanes (2004), lowest losses among leading insurers
  - With Katrina (2005), largest exposure with fewest losses among top ten property insurers
  - Our approach works!

**PAC** 4

## My perspective

- Research scientist, first line manager in fire related research
- Worldwide safety and risk consultant
  - Chemical, other process industries
  - Transportation
  - Financial and computer based industries
- VP & Manager of Research
  - Loss prevention research for all perils
  - Loss-causing phenomena & prevention solutions
    - Fire Hazards & Protection
    - Structural Hazards & Response
    - Risk, Reliability & Failure Prevention

**PAC** 5

## My perspective

- Success in process industries (non-nuclear)
- Comparison between PI and building regulation
- Issues in building regulation
- Suggestions for building regulation

**PAC** 6

## *Process Industries (PI) in the 20th Century*

- Phenomenal growth
- Petroleum & refining, petrochemical, chemical, specialty chemicals, pharmaceuticals, utilities, pulp & paper, machinery & metals processing
- Success from opportunities, leadership, skills, technology, safety

**PAC** 7

## *Safety Management in the Process Industries in the 20th Century*

- Early operations were quite dangerous
- Pre-1930's - who caused the loss, punish the guilty
- Pre-1970's - find breakdown, fix man-machine interface
- The 1970's - development and application of quantitative risk assessment techniques
- In the 1980's - systemic approach gains credibility, accepted by leading industries, government agencies (post Bhopal); focus on management systems
- The 1990's - characterized by broadened acceptance, regulations, international standardization

**PAC** 8

## *Integrated Risk Approach in PI*

- Combine requirements of
  - good industry practices
  - regulations and directives
  - international standards
- Benefits
  - Meet all relevant requirements
  - Internal consistency
  - Eliminate duplication, overlap
  - Cost-effective
- Strong rationale for success

**PAC** 9

## *Where used in PI*

- Several countries use risk-based regulations
- Many companies use risk concepts proprietarily
- Potential fatalities are typically used as (best) risk measure
- Public sector use (with fatality as risk measure)
  - Health & Safety Executive (UK)
  - Western Australia
  - European Union
  - Santa Barbara Planning Commission (California)
  - EPA, several states require risk management plans

**PAC** 10

## *...but does it work?*

PAC

11

## *Safety Management in the Process Industry in the 20th Century*

- Early operations were quite dangerous
- Pre-1930's - who caused the loss, punish the guilty
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PAC

12

## Safety Management in the Process Industry in the 20th Century

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PAC 13

## Safety Management in the Process Industry in the 20th Century

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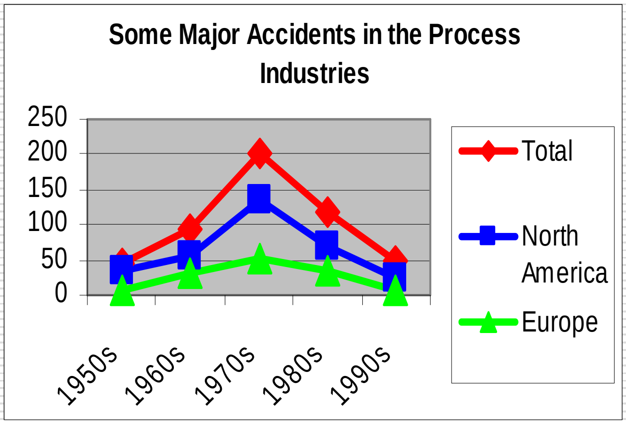
- Pre-1970's - find breakdown, fix man-machine interface
- The 1970's - development and application of quantitative risk assessment techniques
- In the 1980's - systemic approach gains credibility, accepted by leading industries, government agencies (post Bhopal); management systems developed
- The 1990's - characterized by broadened acceptance, regulations, international standardization…in USA, EU

PAC 14

## *Major process industry accidents*

*(assembled by Lees in Loss Prevention in the Process Industries)*




**PAC** 15

## *Major process industry accidents*

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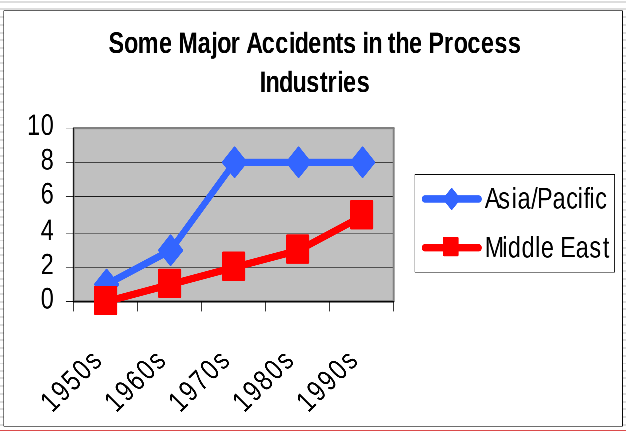


**PAC** 16

## *...but does it work?*

Apparently so....

PAC 17

## *Observations on risk management in PI*

- Resulting process improvements are real
- Reasonable approach to scenario development
  - Most probable, worst case, likely worst case
  - Full risk profile
- Corporate safety culture - starts at the top!
- Safety management systems - CCPS/AIChE
- Integrated approach for acceptability guidelines; most often accepted by decision-makers

PAC 18

## *Observations on risk management in PI*

- Some inconsistency among practitioners
- Cost - more expensive up front but…

The PRICE of Safety

- Productivity, Profitability
- Reliable operations, supplier
- Image (responsible, reliable)
- Community support
- Employee well-being

PAC 19

## *Observations on risk management in PI*

- Some inconsistency among practitioners
- Cost - more expensive up front but…

The PRICE of Safety

- Productivity, Profitability
- Reliable operations, supplier
- Image (responsible leader)
- Community support
- Employee well-being

- Overall, use of risk in PI works well

PAC 20

## *Integrated Risk Approach Now Applied to*

- Petroleum and refining, petrochemical, chemical, specialty chemicals, pharmaceuticals, utilities, pulp & paper, machinery & metals processing
- Mechanical assembly processes
- Transport and transportation systems
  - Land, water, air, space
- Computer-based technologies and processes
  - Banks, exchanges (financial transactions)
  - Airlines
- Communications technologies
  - Central offices

**PAC** 21

## *Building Regulation*

- Performance-based regulation adopted by several countries; use is expanding; use of risk as performance criterion is being sought
- Each country implements PB design, regulation differently
- Earthquake resistance for special, key facilities
- Fire a key concern; some problems, many inconsistencies
- In many cases, practice outdistancing science (?)

**PAC** 22

## *Comparison of Use of Risk Concepts*

| Process Industries | Building Regulation |
|---|---|

***PAC*** 23

## *Comparison of Use of Risk Concepts*

| Process Industries | Building Regulation |
|---|---|
| Standardized process elements | Large variety of building designs, construction |

***PAC*** 24

## Comparison of Use of Risk Concepts

| Process Industries | Building Regulation |
|---|---|
| Standardized process elements | Large variety of building designs, construction |
| Risk quantification methods well defined | Risk more difficult to quantify |

PAC 25

## Comparison of Use of Risk Concepts

| Process Industries | Building Regulation |
|---|---|
| Standardized process elements | Large variety of building designs, construction |
| Risk quantification methods well defined | Risk more difficult to quantify |
| Risk assessment approach accepted | No set general method to quantify, assess risk |

PAC 26

## Comparison of Use of Risk Concepts

| Process Industries | Building Regulation |
|---|---|
| Standardized process elements | Large variety of building designs, construction |
| Risk quantification methods well defined | Risk more difficult to quantify |
| Risk assessment approach accepted | No set general method to quantify, assess risk |
| Full risk profile | Design scenario(s) |

**PAC** 27

## Comparison of Use of Risk Concepts

| Process Industries | Building Regulation |
|---|---|
| Standardized process elements | Large variety of building designs, construction |
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| Risk assessment approach accepted | No set general method to quantify, assess risk |
| Full risk profile | Design scenario(s) |
| Fewer, more experienced practitioners | Many consultant, facility, corporate practitioners |

**PAC** 28

## Comparison of Use of Risk Concepts

| Process Industries | Building Regulation |
|---|---|
| Standardized process elements | Large variety of building designs, construction |
| Risk quantification methods well defined | Risk more difficult to quantify |
| Risk assessment approach accepted | No set general method to quantify, assess risk |
| Full risk profile | Design scenario(s) |
| Fewer, more experienced practitioners | Many consultant, facility, corporate practitioners |
| Cost effective | Cost effective ??? |

**PAC** 29

## Comparison of Use of Risk Concepts

| Process Industries | Building Regulation |
|---|---|
| Standardized process elements | Large variety of building designs, construction |
| Risk quantification methods well defined | Risk more difficult to quantify |
| Risk assessment approach accepted | No set general method to quantify, assess risk |
| Full risk profile | Design scenario(s) |
| Fewer, more experienced practitioners | Many consultant, facility, corporate practitioners |
| Cost effective | Cost effective ??? |
| Hazard expertise with process industries | Hazard expertise with practitioners |

**PAC** 30

## *Issues for Building Regulation*

Prevailing view…

- Regulator qualifications
- Risk quantification
- Consistency
- Adequacy of tools
- Practitioner skills and expertise
- Appropriate PB goals

PAC 31

## *Issues for Building Regulation*

Prevailing view…

- Regulator qualifications
- Risk quantification
- Consistency
- Adequacy of tools
- Practitioner skills and expertise
- Appropriate PB goals

My view…

- Appropriate PB goals
- Adequacy of tools
- Consistency
- Risk quantification
- Practitioner skills and expertise
- Regulator qualifications

PAC 32

## Issues for Building Regulation

Prevailing view…

- Regulator qualifications
- Risk quantification
- Consistency
- Adequacy of tools
- Practitioner skills and expertise
- Appropriate PB goals

My view…

- Appropriate PB goals
- Adequacy of tools
- Consistency
- Risk quantification
- Practitioner skills and expertise
- Regulator qualifications

PAC 33

## Possible Fire Safety Outcomes

- Life safety
- Safety for room-of-origin occupants
- Safety for building occupants
- Safety for general public
- Public security
- Protection for building of origin
- Protection for neighboring structures
- Protection for historical buildings
- Protection for firefighters
- Protection for first responders
- Protection for infrastructure
- Facility operability

PAC 34

## *Possible Fire Safety Outcomes*

- Life safety
- Safety for room-of-origin occupants
- Safety for building occupants
- Safety for general public
- Public security
- Protection for building of origin
- Protection for neighboring structures
- Protection for historical buildings
- Protection for firefighters
- Protection for first responders
- Protection for infrastructure
- Facility operability

**PAC** 35

## *Achieved Fire Safety Design Outcomes*

- Life safety (evacuation of occupants)
  - Safety for building occupants
  - Safety for room-of-origin occupants

**PAC** 36

## *Fire Safety Design Outcomes Not Achieved*

- Safety for general public
- Public security
- Protection for building of origin
- Protection for neighboring structures
- Protection for historical buildings
- Protection for firefighters
- Protection for first responders
- Protection for infrastructure
- Facility operability

**PAC** 37

## *By focusing on life safety (evacuation of occupants)…*

- Missing other desired outcomes
- Not taking advantage of knowledge base
- Perhaps not using resources optimally to get to desired end result

**PAC** 38

## *Alternatively, with a criterion of…*

**PUBLIC WELL-BEING**

…a different approach might be…

PAC 39

## *Possible Fire Safety Outcomes*

- Life safety
- Safety for room-of-origin occupants
- Safety for building occupants
- Safety for general public
- Public security
- Protection for building of origin
- Protection for neighboring structures
- Protection for historical buildings
- Protection for firefighters
- Protection for first responders
- Protection for infrastructure
- Facility operability

PAC 40

## *Possible Fire Safety Outcomes*

- Life safety
- Safety for room-of-origin occupants
- Safety for building occupants
- Safety for general public
- Public security
- Protection for building of origin
- Protection for neighboring structures
- Protection for historical buildings
- Protection for firefighters
- Protection for first responders
- Protection for infrastructure
- Facility operability

**PAC** 41

## *Achieved Fire Safety Outcomes*

- Protection for building of origin
  - Life safety
  - Safety for building occupants
  - Safety for room-of-origin occupants
  - Safety for general public
  - Protection for neighboring structures
  - Protection for historical buildings
  - Protection for firefighters
  - Protection for first responders

**PAC** 42

## Achieved Fire Safety Outcomes

- Protection for infrastructure
  - Protected
    - Building stock
    - Livelihood supplies
    - Communications
    - Utilities
    - Transportation systems
    - Electronics and computer systems
  - Facility operability

PAC 43

## By using broader criteria…

- Life safety achieved…
- Fire service and other responders protected
- Less overall damage and disruption
- High degree of public security realized
- Maintenance of economy
- Faster and less costly recovery
- Consistent with approach for earthquake
- May be more expensive up front, but less so over time… and public well-being is better served

PAC 44

## *Suggestions for building regulation*

- Life (public) safety is not enough!
- Goal should be PUBLIC WELL-BEING
- Protect building of origin and critical infrastructure
  - Much is already known
  - Measurement of risk not so important
  - Easier to test and assure adequacy
  - Easier to achieve consistency
  - Can be integrated with earthquake approach
  - Some work needed, but more quickly achieved
- IRCC role to assure consistency worldwide

***PAC*** 45

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Questions?

***PAC*** 46

# Quantifying risk by performance-based earthquake engineering

Greg Deierlein
*Stanford University*

*…with contributions by many*

**2006 IRCC Workshop on Use of Risk in Regulation**

## Performance-Based Earthquake Engineering

To transform earthquake engineering assessment and design …

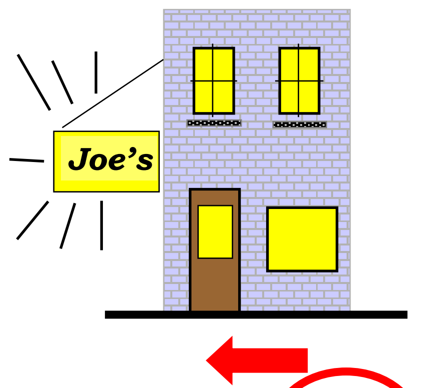
**Traditional Approach**

- Non-scientifically defined seismic hazard
- Indirect design approaches
- Undefined and uncertain outcomes

**Perform.-Based Approach**

- Scientifically-defined seismic hazard
- Direct design approaches
- Defined outcomes with probabilities of achieving them

# Equivalent Lateral Force Design



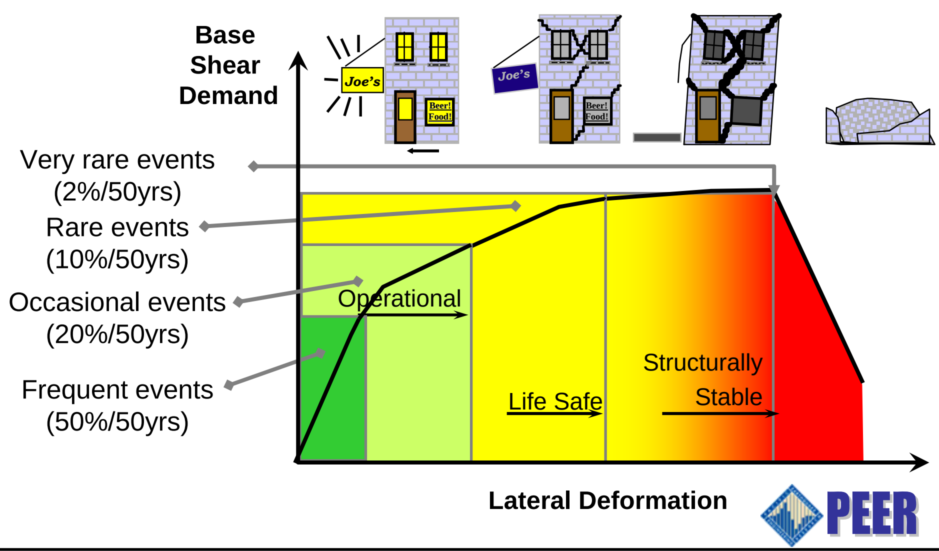

- Linear analysis model
- Simplified design base shear
- Prescriptive details
- Uncertain outcomes
- Owners informed of code conformance, but not building performance

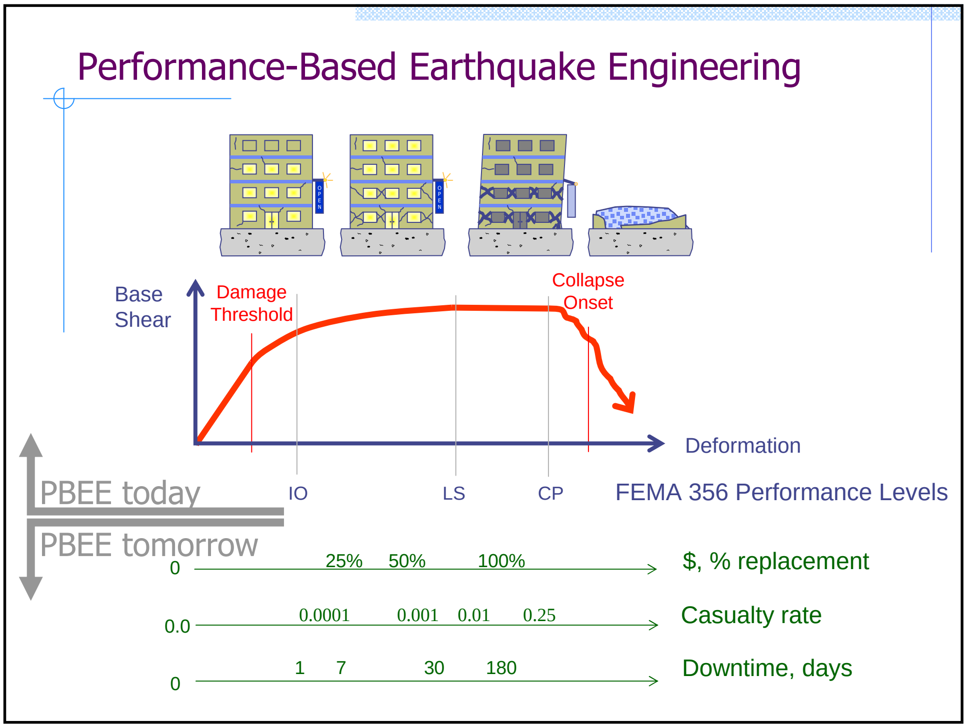
$$V = \frac{ZICS}{R}W = \frac{V_{elastic}}{R}$$

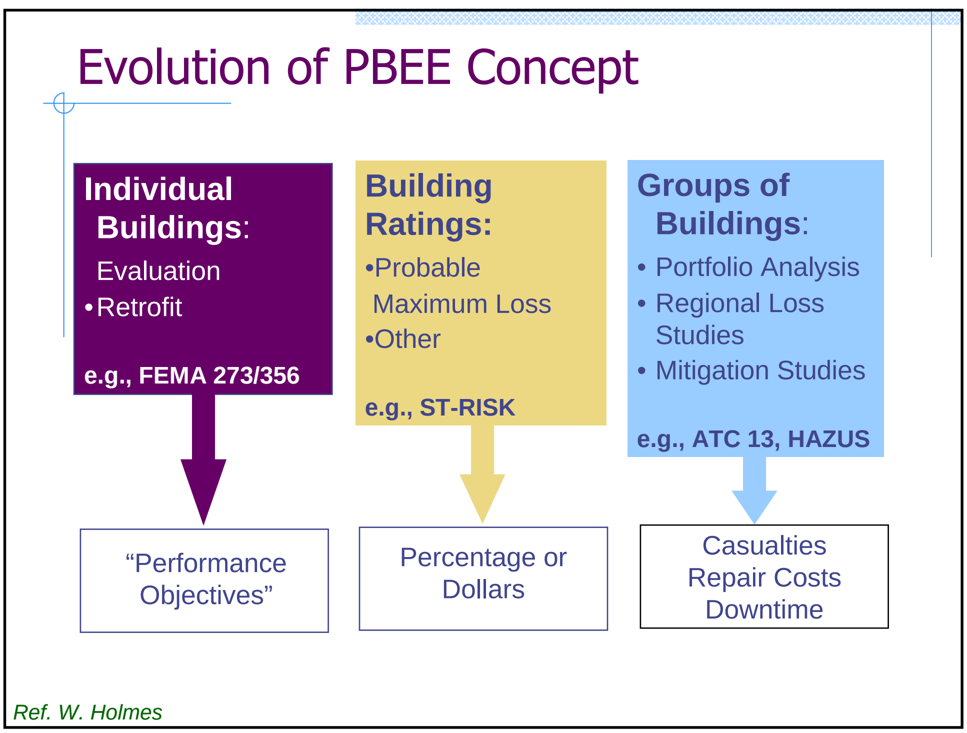
**R = 2 to 8**

Ref: R.O. Hamburger

# Assessment by Static Pushover Analysis




Performance-Based Earthquake Engineering
Base Shear
Damage Threshold
Collapse Onset
Deformation
PBEE today
PBEE tomorrow
IO
LS
CP
FEMA 356 Performance Levels
0
25%
50%
100%
$, % replacement
0.0
0.0001
0.001
0.01
0.25
Casualty rate
0
1
7
30
180
Downtime, days

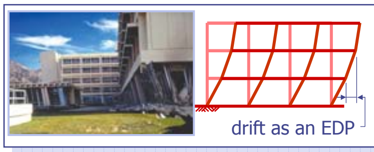

Evolution of PBEE Concept
Individual Buildings:
Evaluation
•Retrofit
e.g., FEMA 273/356
Building Ratings:
•Probable Maximum Loss
•Other
e.g., ST-RISK
Groups of Buildings:
• Portfolio Analysis
• Regional Loss Studies
• Mitigation Studies
e.g., ATC 13, HAZUS
"Performance Objectives"
Percentage or Dollars
Casualties
Repair Costs
Downtime
Ref. W. Holmes

# Performance-Based Methodology

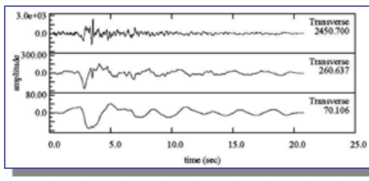
- Collapse & Casualties
- Direct Financial Loss
- Downtime

**Decision Variable**

**Damage Measure**



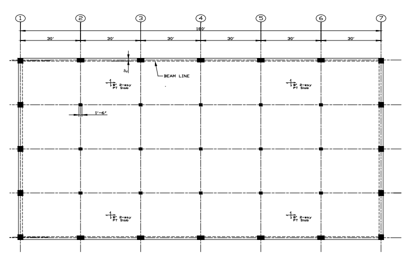

**Engineering Demand Parameter**

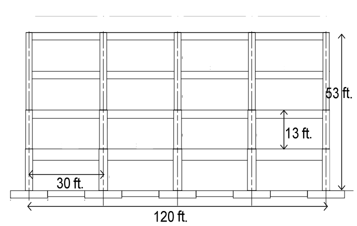


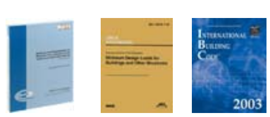

**Intensity Measure**

# Benchmarking Building Performance

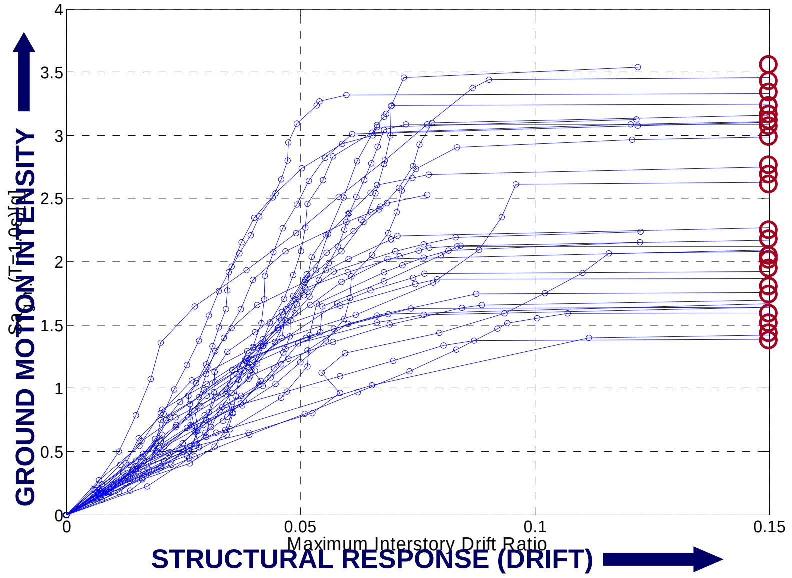
- Office occupancy
- Los Angeles Basin
- Design Code: 2003 IBC / 2002 ACI / ASCE7-02
- Design Base Shear
  - R = 8.0
  - V/W = 0.094
- Maximum considered EQ demands:
  - $S_s = 1.5g$; $S_1 = 0.9g$
- Maximum inelastic design drift of 1.9% (2% limit)





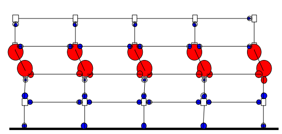



## Incremental Dynamic Analysis – Collapse

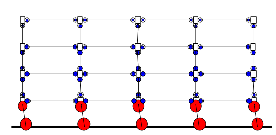



9

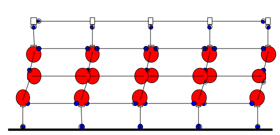
## Sidesway Collapse Modes



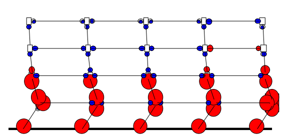
40% of collapses



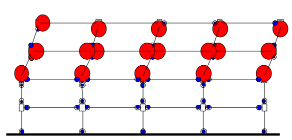
27% of collapses



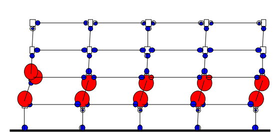
17% of collapses



12% of collapses



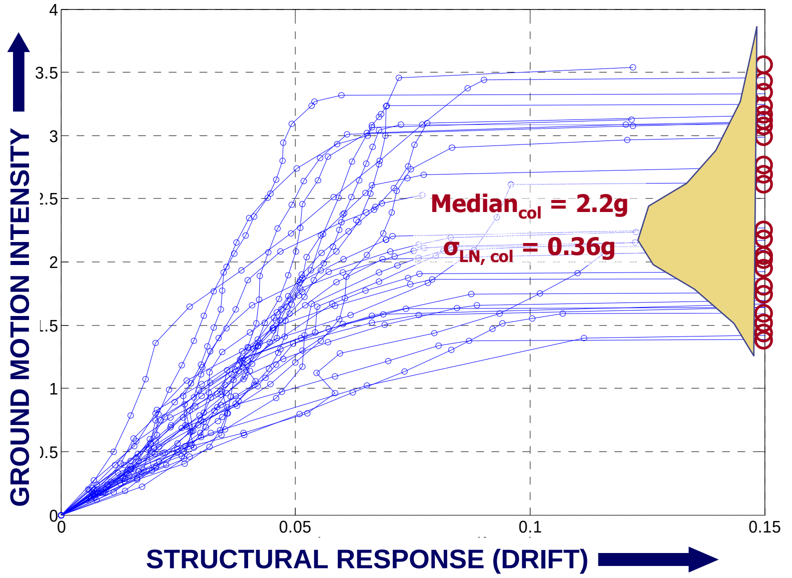
5% of collapses



2% of collapses

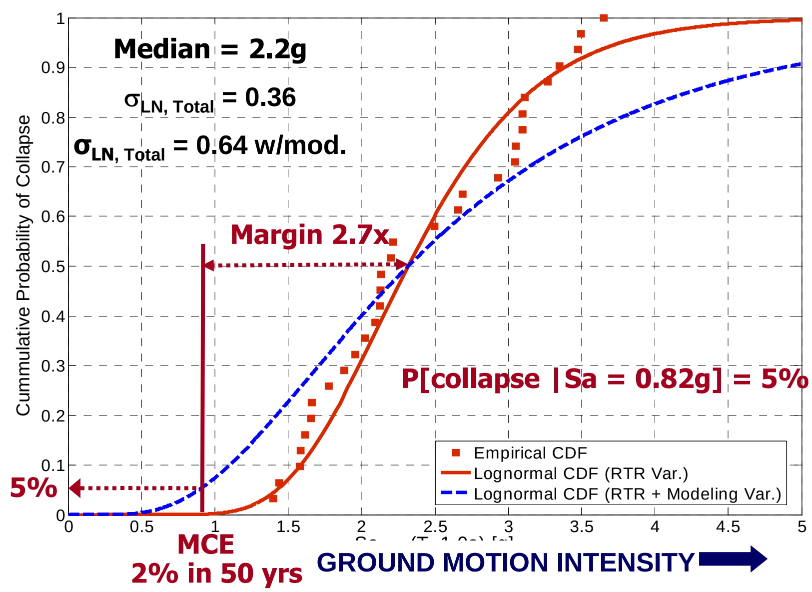
10

## Incremental Dynamic Analysis – Collapse



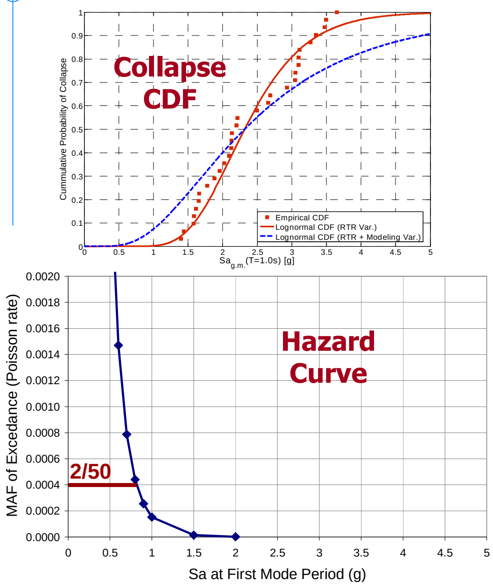

11

## Collapse Capacity – with Modeling Uncert.




12

# Mean Annual Frequency of Collapse




### Collapse Performance

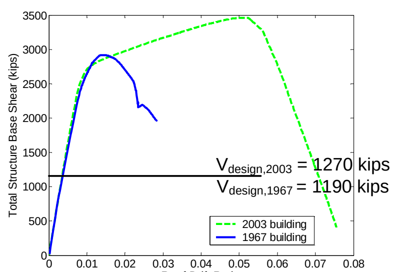
- Margin: $S_{a,collapse}$ = 2.7 MCE
- Probability of collapse under design MCE = 5%
- $MAF_{col} = 1.0 \times 10^{-4}$ (about ¼ of the MCE 2% in 50 year ground motion)

13

# Comparison: 1967 vs. 2003 Buildings



**2003 Design Codes**



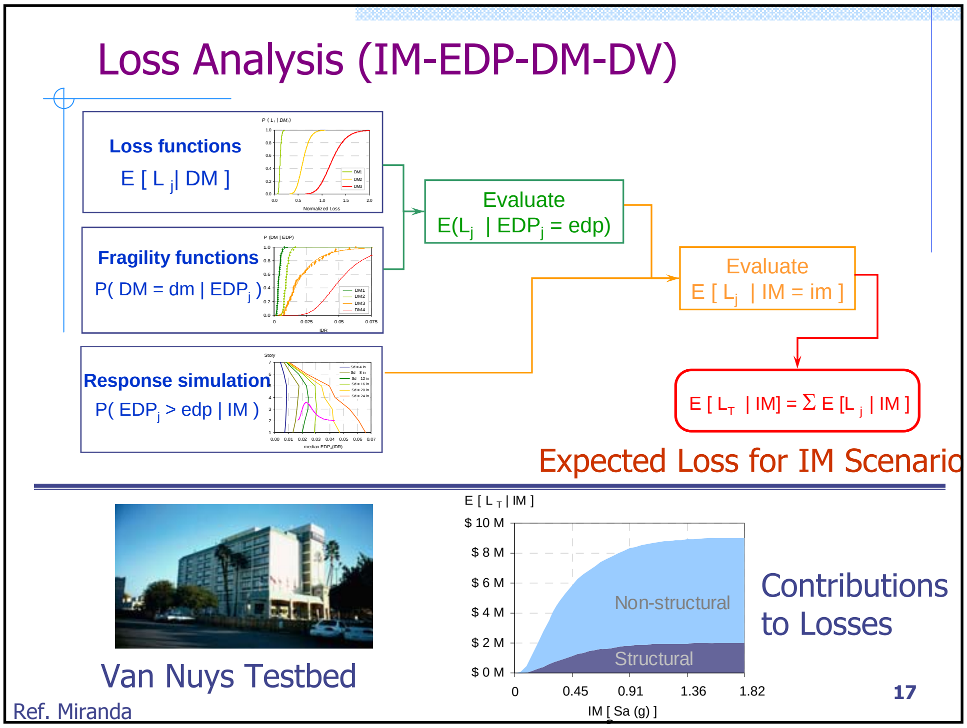

| Building | Collapse Risk | |
|---|---|---|
| | $P_{col.}$/MCE | $MAF_{collapse}$ |
| 2003 | 5% | $1 \times 10^{-4}$ |
| 1967 | 40 to 80% | 20 to 50 $\times 10^{-4}$ |

## Building code, regulation and policy issues

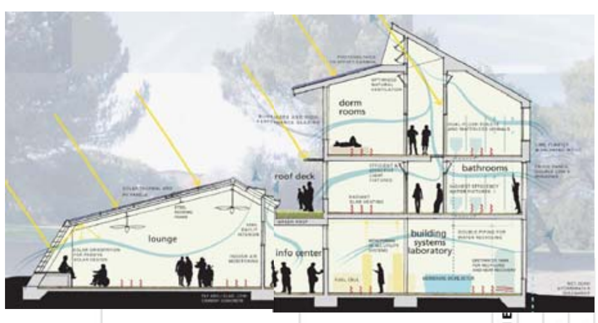
- Benchmarking performance of building codes
  - Absolute safety and performance
  - Relative safety and performance across:
    - systems/materials
    - building heights/configurations,
    - seismic hazard categories
    - use/occupancy
- Non-ductile RC Building Risks
  - how bad is the problem?
  - technologies to address it cost-effectively
  - policy, incentives and regulation
- Residential High Rise
  - structural systems not envisioned by code
  - tenant & societal performance expectations
- New Innovative structural systems
- Regulatory and implementation aspects
  - role of codes and standards
  - peer review process

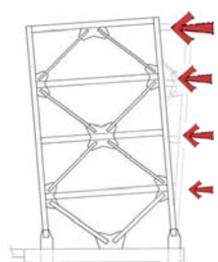
*The engineering community's best-kept secret …*

> **"The purpose of the earthquake provisions herein is primarily to *safeguard against major structural failures and loss of life*, not to limit damage or maintain function."**
>
> **1997 Uniform Building Code**




## Seismic & Green Design



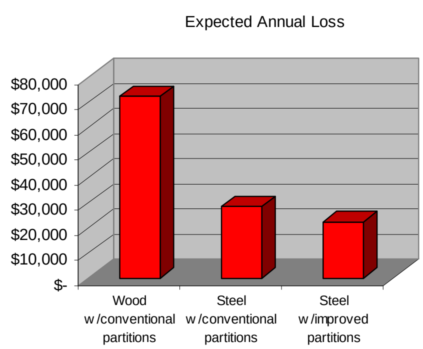
**Rocking Frame**

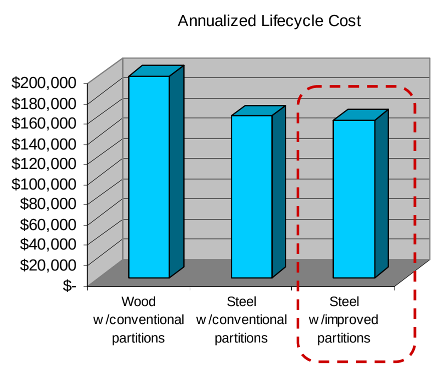
## Design Decision Matrix

| | Dorms | Common/Lab Space | Embodied E | Mass | Insulation | First Costs | Construction Speed | EQ Losses | Research Value | Thermal Comfort | Deconstructability | Flexibility | Total (Weighted) | Life Cycle Costs | Carbon Impact |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Weight (1-5) | 3 | 1 | 1 | 5 | 1 | 3 | 2 | 2 | 1 | 1 | | | |
| 1a | Wood Bearing Wall[1,2,3,4] | Wood / Steel Hybrid[8] | 1 | 4 | 3 | 1 | 3 | 5 | 5 | 3 | 3 | 4 | **56** | **23** | **10** |
| 1b | Wood Bearing Wall[1,2,3,4] | Concrete Podium[6] | 2 | 3 | 3 | 2 | 3 | 5 | 5 | 3 | 4 | 5 | 65 | 28 | 12 |
| 2a | Steel Frame/Mtl Deck/Conc Topping[2,5,6] | Steel Frame/Mtl Deck/Conc Topping[7,8] | 4 | 2 | 3 | 3 | 1 | 2 | 2 | 2 | 2 | 1 | **50** | **22** | **17** |
| 2b | Steel Frame/Mtl Deck/Conc Topping[2,5,6] | Concrete Podium[6] | 4 | 1 | 3 | 4 | 1 | 2 | 2 | 2 | 2 | 1 | 54 | 27 | 16 |
| 3a | Wood Post and Beam[1,3,4,6] | Wood / Steel Hybrid[8] | 1 | 4 | 3 | 3 | 3 | 4 | 5 | 3 | 2 | 2 | 60 | 30 | 10 |
| 3b | Wood Post and Beam[1,3,4,6] | Concrete Podium[6] | 2 | 4 | 3 | 3 | 3 | 4 | 5 | 3 | 3 | 2 | 64 | 30 | 13 |
| 4a | Metal Stud Bearing Wall[2,4,10] | Steel Stud & Joist / Steel Beam Hybrid[8] | 4 | 4 | 3 | 2 | 3 | 4 | 5 | 3 | 5 | 4 | 69 | 25 | 19 |
| 4b | Metal Stud Bearing Wall[2,4,10] | Concrete Podium[6] | 4 | 4 | 3 | 2 | 3 | 4 | 5 | 3 | 5 | 5 | 70 | 25 | 19 |
| 5 | Concrete Slab and Walls[6,12] | Concrete Slab and Walls[6] | 5 | 1 | 3 | 5 | 4 | 2 | 2 | 1 | 5 | 2 | 67 | 35 | 19 |
| 6 | CMU Bearing Wall/Wood Floor[1,2,3,10,11] | CMU Bearing Wall/Wood & Steel Floor[8] | 3 | 2 | 3 | 3 | 5 | 4 | 4 | 4 | 4 | 4 | 70 | 32 | 14 |
| 7 | Straw-Bale/Wood Frame[1,2,3,4,13] | Wood / Steel Hybrid[8] | 2 | 2 | 1 | 3 | 3 | 5 | 3 | 1 | 3 | 5 | 58 | 33 | 9 |

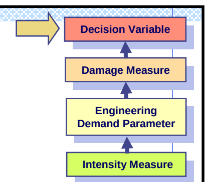
# Life-cycle Financial Assessment

| SCHEME | Initial construction cost | Cost Premium | Expected Annual Loss from Earthquake Damage | Annualized Lifecycle Cost |
|---|---|---|---|---|
| Wood with conventional partitions | $6,375,000 | $0 | $72,141 | $199,641 |
| Steel with conventional partitions | $6,605,000 | $230,000 | $28,244 | $160,344 |
| Steel with improved partitions | $6,700,000 | $325,000 | $22,258 | $156,258 |




# Performance to Decision Making



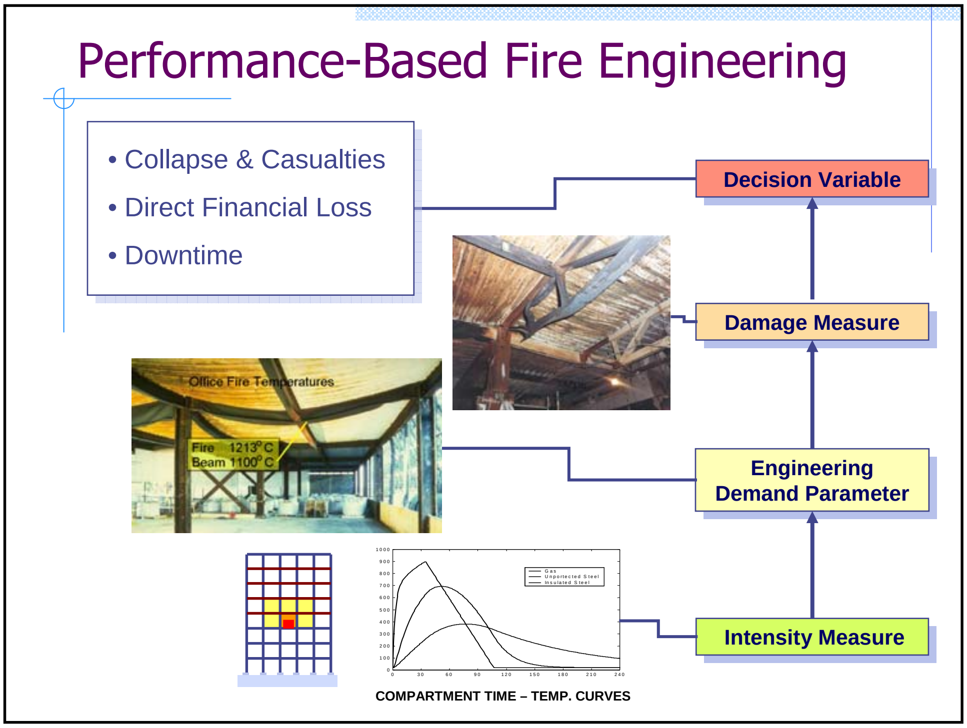

***Damage to Decision Variables (DV's):***

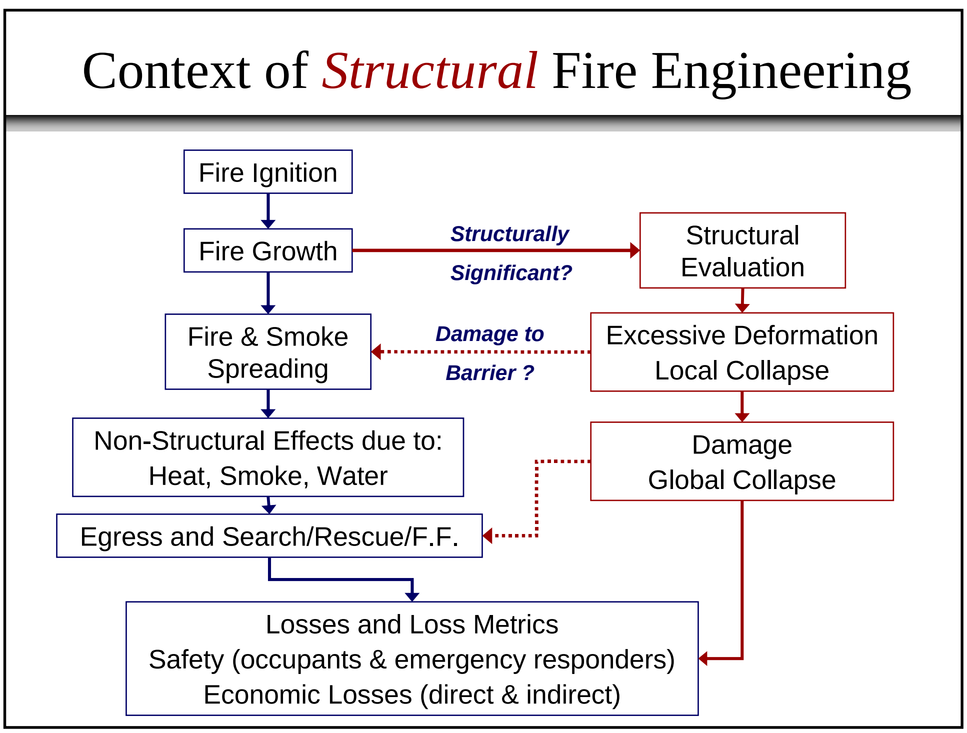
- Casualty Modeling (collapse + other hazards)
- Direct $ Loss (content losses & repairs)
- Continued Use and Functionality
- Downtime (mobilization and repair duration)

**Decision Process:**

- Economic Modeling (e.g., Benefit-Cost Analysis)
- Risk Management (socio-political constraints, insurance, mitigation, ...)
- Decision Arena (single facility, campus of facilities, large inventory)

20


Performance-Based Fire Engineering
• Collapse & Casualties
• Direct Financial Loss
• Downtime
Decision Variable
Damage Measure
Office Fire Temperatures
Fire 1213°C
Beam 1100°C
Engineering Demand Parameter
Intensity Measure
COMPARTMENT TIME – TEMP. CURVES

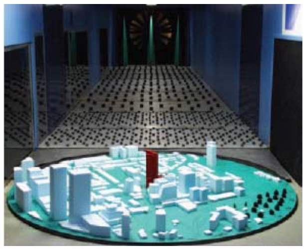

Context of Structural Fire Engineering
Fire Ignition
Fire Growth
Structurally Significant?
Structural Evaluation
Fire & Smoke Spreading
Damage to Barrier ?
Excessive Deformation Local Collapse
Non-Structural Effects due to: Heat, Smoke, Water
Damage Global Collapse
Egress and Search/Rescue/F.F.
Losses and Loss Metrics
Safety (occupants & emergency responders)
Economic Losses (direct & indirect)

## Relative Risk Levels

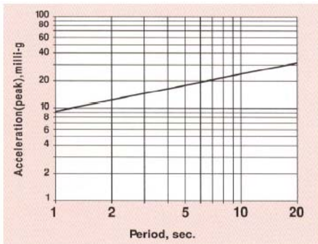
| ***Loading & Event*** | ***Mean Annual Frequency*** |
|---|---|
| Gravity & Wind (LRFD limit state) | *0.0007 ($7 \times 10^{-4}$)* |
| Earthquake (collapse prevention) | *0.0004 ($4 \times 10^{-4}$)* |
| Nuclear Reactor (earthquake hazard) | *$1 \times 10^{-5}$* |
| Fire (flashover, $100 m^2$ office) | *$1 \times 10^{-6}$* |
| Fire + (1.0D + 0.5L) (flashover, $100 m^2$ office) | *$1 \times 10^{-7}$* |

## Performance-Based Wind Engineering

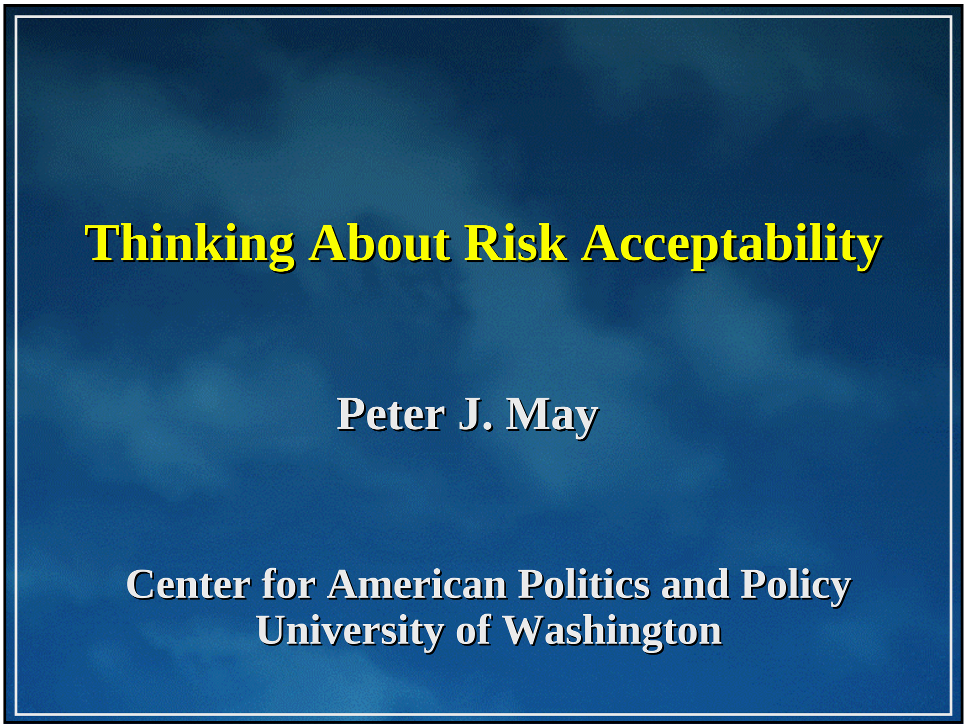
WTC 1972

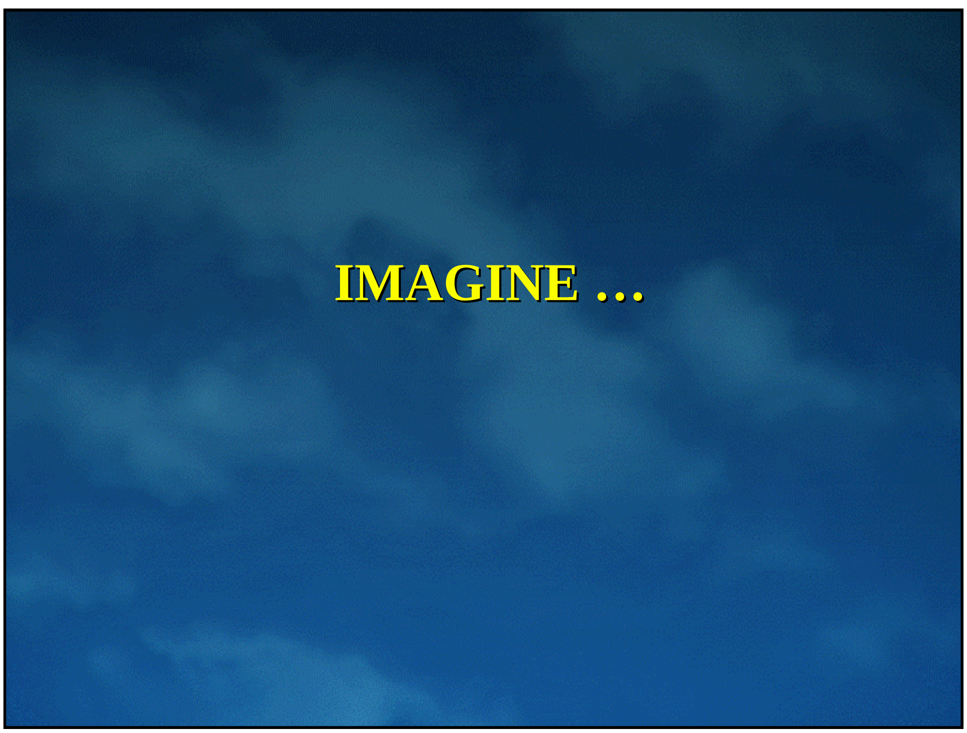


Wind Tunnel Testing




Guidelines for 5-Yr Acceleration


Thinking About Risk Acceptability
Peter J. May
Center for American Politics and Policy
University of Washington


IMAGINE …

## You are invited to a get together at our home** …

*** Please note that we think the house is seismically safe. The building inspector said “it will stand up in the Big One,” but the builder seemed concerned. In the event of an earthquake, you may be injured but we don’t think you will die in our house. We think, as we hope you do, that this is ACCEPTABLE…*

## Driving directions are enclosed **


***NOTE that there were a number of accidents last year on the bridge you will need to cross to get to our house. However, we travel that bridge every day and feel the benefits of living where we do outweigh the risk of an accident on the bridge. We hope you find your one-time commute to our house ACCEPTABLE.*

# NOW IMAGINE…

# DOT COM CORPORATION ANNUAL REPORT FIRST OF MANY, WE HOPE

**Accounting Notes:**

*Note 142. DOT COM's corporate facilities are located in a zone that is subject to earthquake hazards. Engineering consultants note that considerable damage could be done to computing facilities in the event of an earthquake. Company officers find this ACCEPTABLE given the fact that there is limited corporate cash on hand or ability to raise funding to make facilities seismically resistant.*

# FINALLY, IMAGINE…

# PS 105 ELEMENTARY SCHOOL

PARENT-TEACHER
OPEN FORUM

REPORT TO PARENTS

## School Safety

*The school district has engaged in an evaluation of the seismic safety of schools. Since PS 105 was built in 1974 and is ranked low in seismic risk, no seismic improvements are anticipated. Children may be injured in the event of an earthquake, but we do not expect many to be killed. District officials and voters, with their rejection of the last bond request, find this ACCEPTABLE.*

## REALITIES

**For individual, organizational, and societal perspectives about risk**

- We accept many risks without explicit evaluation -- too "costly" to do so
- We "take" risks because benefits are attractive and more easily observed than the risks
- Our attention is often focused on benefits, not the risks
- To the extent there are decisions about lowering risk, COST dominates
- Rarely do we talk about "acceptable risks"

## SOCIETAL PERSPECTIVES ABOUT PUBLIC RISKS

### Hurricanes, Earthquakes, and other events with regional impacts

- Scale: "Public bads" that affect more than individuals – requires governmental intervention
- Externalities: Unintended consequences often not considered (e.g. fire following earthquake)
- Interdependencies: The "Social Fabric" – social and economic disruption as increasing concern

## THREE KEY QUESTIONS

### Societal Perspectives and Acceptable Risk

- Q1: Is the concept meaningful?
- Q2: Can a standard be established?
- Q3: Are public officials willing to talk about it?

## QUESTION 1: A PROBLEMATIC CONCEPT

- Framing of the decision makes a difference
  - “safety” versus “risk” – latter forces attention to zero risk
- Acceptance is not automatic
  - It depends! – on the benefits
  - It depends! – on the costs of reducing risks
- Risks cannot easily be compared
  - How value (or fear) depends on benefits and host of other considerations

## QUESTION 2: ESTABLISHING A STANDARD

- “Acceptable risk” is the residual of other choices
- “Acceptable risk” is a moving target – “Searching for safety”
- A credible process for establishing relevant goals is critical – NRC experience instructive here

## QUESTION 3: LET'S NOT TALK ABOUT IT

- Elected officials do not like probabilities and associated uncertainty
- The operative words are "unacceptable costs" with respect to costs of addressing risks

## What to do?

- Don't Ask, Don't Tell -- let people ignore risks
- Obfuscate – stick to vague terms and standards = "life safety"
- Formulate – keep it technical with unclear implications
- CHANGE THE FRAMEWORK to emphasize consequences and safety goals

## Challenges for Changing the Framework
### To Emphasize Consequences

- Multiple decision considerations involved
  - Relevant consequences will differ among decision makers and decision situations
- Level of desired information also varies
  - By stage of education in decision process
  - By desire for refined estimates of impacts

    moving from vague notions about loss of life to more refined probabilistic statements

    Moving from scenario-based results to probabilistic results

## Toward a New Framework

- Shift language from "risk avoidance" to "safety goals"
- Allow for consideration of different dimensions of safety (e.g. seismic safety)
  - Public safety – potential casualties
  - Repairability of structure -- cost
  - Usability of structure -- downtime
- Express safety improvements in relative terms – relative risk notion of health risks

# Beyond All of This …

## Eventual Success Depends Upon

- Deliberative, transparent processes that allow for wide participation in setting goals/standards
- Ability to inspire confidence in the goal/standard-setting process and results
- A regulatory system that is robust enough to adapt to changing societal goals and gaps in regulatory provisions

# RISK-INFORMING REGULATORY DECISIONS

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IRCC Workshop on the Use of Risk Concepts in Regulation

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## OUTLINE

- Regulatory structure
- Use of risk results in regulatory applications
  - Establishing acceptance criteria
- Dealing with uncertainty
- Quality of risk model input to decision-making

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## NRC REGULATORY STRUCTURE

- Essentially a deterministic regulatory structure (10 CFR part 50)
- Increased consideration of risk to increase efficiency and effectiveness, and to provide focus on those aspects of plant design and operation most significant to safety
  - New regulations
  - Alternative approaches to addressing current licensing requirements
- Recognizing the limitations of risk models, NRC has adopted a risk-informed approach to use of risk results in regulatory decision-making

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## USE OF RISK RESULTS IN REGULATORY APPLICATIONS

- The philosophy is discussed, in the context of changes to the licensing basis, in RG 1.174
- Risk results are derived from models known as Probabilistic Risk Assessments (PRAs)
  - Scenarios (what can go wrong)
  - How likely are they
  - What are their consequences
- PRA analyses are one, but not the only, input to the decision

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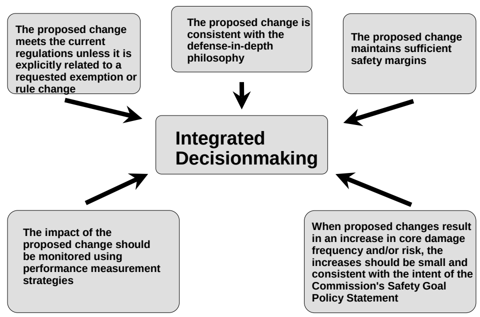
## Principles of Risk-Informed Decisionmaking

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## FORMULATION OF PRA INPUT TO APPLICATION

- Identify those systems, structures and components (SSCs), operator actions, and plant operational characteristics affected by application
- Describe impact of proposed application on SSCs, etc. (cause-effect relationship)
- Map impact onto elements of the PRA model
- Evaluate impact on risk

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## FORMULATION OF PRA INPUT TO APPLICATION (Cont'd)

- Define acceptance guidelines or criteria (e.g., acceptance guidelines of RG 1.174)
  - Results required (risk metrics)
  - Method of comparison
- These activities result in an identification of
  - Scope of risk contributors
  - Level of detail required

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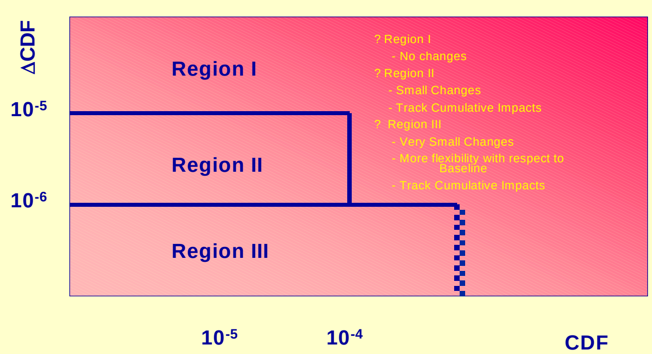
## CORE DAMAGE FREQUENCY ACCEPTANCE GUIDELINES




Acceptance Guidelines for Core Damage Frequency

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## ESTABLISHMENT OF ACCEPTANCE GUIDELINES

- Based on and consistent with existing guidelines
  - Safety Goals and subsidiary objectives (established in a Commission Policy Statement)
  - Regulatory Analysis Guidelines

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## ISSUES THAT IMPACT THE VALUE OF PRA INPUT

- "Quality" of PRA model
- Treatment of uncertainty
  - Parameter (e.g., component failure probability, initiating event frequency) uncertainty
  - Model uncertainty (e.g., success criteria)
  - Completeness (e.g., missing initiating events or modes of operation, errors of commission)
- Incompleteness from unknown sources is one of the main reasons why the NRC has adopted a risk-informed rather than a risk-based process

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## CHARACTERIZATION OF INPUT UNCERTAINTY

- Parameter uncertainty characterized by probability distributions representing state of knowledge about “true” value
- Model uncertainty may be represented as a discrete probability distribution over several models, with the probabilities representing the analysts’ relative degrees of belief in the validity of the models. More commonly, a single representative model is assumed
- By definition, incompleteness is not addressed in the model structure, but scope of model needs to be understood

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## APPROACH TO DEALING WITH UNCERTAINTY IN PRA RESULTS

- Objective is to provide assurance that the conclusion drawn from the PRA analysis is robust in light of the uncertainties
- Strategy
  - Identify and prioritize sources of uncertainty (with respect to their importance to the results being used)
  - Assess whether the uncertainties affect the acceptability of the change in risk

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## PARAMETER AND MODEL UNCERTAINTY

- Address parameter uncertainties by propagating uncertainties and using resulting mean value for comparison with acceptance guidelines
- Address model uncertainties by developing an understanding of whether there are plausible, alternative assumptions that would impact the result of the comparison with the acceptance guidelines

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## APPROACHES TO ADDRESSING INCOMPLETENESS

- Provide qualitative arguments or bounding analyses
- Design the application so that it does not impact the unmodeled contribution to risk
- Make conservative decisions to compensate for missing contributions
- Perform a full scope PRA

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## "QUALITY" OF PRA

- NRC is less concerned with the quality of the PRA in its own right than with the quality of the decisions made
- The PRA must be capable of supporting the results used in the application in terms of scope, level of detail
- Different applications require use of different PRA elements: some, e.g., categorization of SSCs by risk significance, use the complete PRA; others, e.g., a simple tech spec change, require only a portion of the PRA
- Those elements of the PRA required for an application must be performed in a technically competent manner consistent with industry good practices

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## APPROACH TO ENSURING PRA QUALITY

- Use of consensus standards (developed by ASME and ANS) endorsed in a regulatory guide
  – "what to do" rather than "how to do"
- A key requirement is that for a peer review
- Audit as considered necessary

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# The Use of Risk Concepts in Regulation

Report of the IRCC Workshop
San Francisco, CA, USA
17-18 October 2006

ARUP