

# Dr. Curtis Smith

## Research and Development Curriculum Vitae 2012

**SAPHIRE Basics**  
An Introduction to Risk Assessment Analysis Program Integrated Reliability (SAPHIRE) Software  
Curtis Smith  
James Knudsen  
Michael Calley  
Scott Beck  
Kellie Kvarfordt  
Ted Wood  
Idaho National Laboratory

**P-501 Advanced Risk Assessment Topics**  
Addressing Key Issues in the Development and Use of PRA for Decision Making Activities  
Curtis Smith  
Dana Kelly  
Idaho National Laboratory

**NUREG/CR-5632**  
**Incorporating Aging Effects into Probabilistic Risk Assessment — A Feasibility Study Utilizing Reliability Physics Models**  
Prepared by  
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A. Barak, NRC Technical Monitor  
Prepared for  
Office of Nuclear Regulatory Research  
U.S. Nuclear Regulatory Commission  
Washington, DC 20555-0001  
Massachusetts Institute of Technology

**Risk-Informed Incident Management for Nuclear Power Plants**  
by  
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B.S., General Engineering (1988), Idaho State University  
M.S., Nuclear Engineering (1990), Idaho State University  
Submitted to the Department of Nuclear Engineering  
in Partial Fulfillment of the Requirements for the Degree of  
DOCTOR OF PHILOSOPHY  
at the  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
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# Professional Knowledge

Probabilistic methods are becoming pervasive in many fields of science and engineering. The nuclear and aerospace domains have had a long history of developing and using these methods. As a safety, risk, and reliability engineer, Dr. Smith is a recognized leader and a key member of the Idaho National Laboratory's Risk, Reliability and NRC Programs department. His primary duties and responsibilities are to lead significant risk and reliability methods research and development efforts and applied engineering projects for the U. S. Nuclear Regulatory Commission (NRC), the National Aeronautics and Space Administration (NASA), and the Department of Energy (DOE).

Within the probabilistic risk assessment (PRA) community, Dr. Smith is recognized as an expert in the following areas:

- Complex system modeling methods and associated tools development
- Bayesian inference techniques
- Advanced quantification approaches
- Course development and instruction on PRA issues

In addition to having a nationally recognized role in PRA, Dr. Smith has been active internationally.

- In the 1990s, he served on technology-driven missions to the International Atomic Energy Agency (IAEA) and member countries in Eastern Europe and Russia.
- He has been active in international organizations such as the International Association for Probabilistic Safety Assessment and Management (IAPSAM) – as part of the technical program committee for the IAPSAM 8 conference, Dr. Smith was the organizer of 21 sessions containing over 80 papers on the topic of risk and reliability methods.
- He was the technical project manager and designer for the NRC's International Cooperative PRA collaboration activity and interacted with key PRA researchers from 17 countries.

**COOPRA**



Cooperative Probabilistic Risk  
Assessment Research

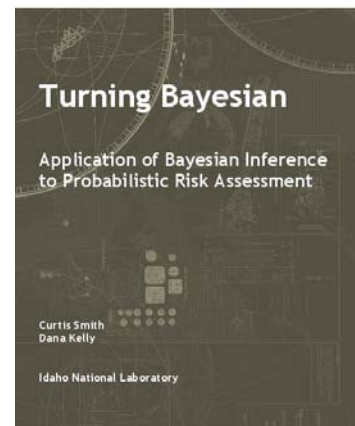
Dr. Smith obtained his undergraduate degree (B.S.) from Idaho State University (ISU). He continued his education at ISU and completed a nuclear engineering M.S.

- His doctoral thesis work at M.I.T. focused on formal decision making activities at nuclear power plants, work that is proving valuable for recent risk-informed decision making initiatives currently underway at NASA.
  - Dr. Smith's thesis was based upon a proposal to Électricité de France (EdF) researching the methodological framework and associated prototypical tool that could be used for an incident management advisory system.
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- While obtaining his Ph.D. at M.I.T., he worked half-time on PRA projects for the INL.

Dr. Smith has a strong desire to promote the science of probabilistic methods and has been an instructor and lecturer on PRA to the global community.

- Dr. Smith is the lead instructor and course material developer for a million dollar per year risk curriculum presented to the NRC staff. Courses he has taught and developed include PRA Fundamentals, SAPHIRE Basics, Advanced SAPHIRE, Probability and Statistics, Bayesian Probability, Advanced Topics in PRA, and Risk Evaluation for Event Assessment.
- Having taught five to ten courses a year over the last 15 years, Dr. Smith is training the current generation and next generation of regulators the fundamentals of risk and reliability assessment (he has taught more than 300 NRC students).
- Dr. Smith has presented a number of risk courses to NASA scientists and engineers over the last decade. He just recently received funding to establish a more formal, comprehensive NASA risk training curriculum, setting the stage to teach the next generation of “rocket scientists” the fundamentals of risk and reliability assessment.
- Dr. Smith was requested by the NRC to develop a special course for the NRC staff following the Davis-Besse vessel head corrosion incident. As part of the Lessons Learned Task Force, he developed the one-day course “Assessing the Adequacy of Models for Risk-Informed Decisions” in order to improve the NRC staff’s awareness of the factors that contribute to uncertainty in predictive models and the need to identify, characterize and communicate the uncertainties to a risk-informed decision-maker.
- His technical expertise is felt inside the INL also – he has mentored several university students as part of his INL activities, two of which are now employed as INL staff, and junior staff.
- Dr. Smith participates in and leads formal and informal technical seminars for the INL staff, recently completing a series of 17 lectures titled “Turning Bayesian – Application of Bayesian Inference to Probabilistic Risk Assessment” dedicated to educating attendees on a variety of probabilistic and Bayesian ideas.



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# Impact

Dr. Smith has positively impacted INL's mission over the last 19 years. As the DOE lead laboratory for nuclear energy research, the INL, as emphasized by John Grossenbacher, is striving to build strategic relationships with industry organizations and regulators (INL Strategic Plan FY 2007 -2016, Strategic Objective #5). Dr. Smith has been instrumental in supporting the INL's interactions with both the nuclear and aerospace industries.

- Dr. Smith was a key part of research that ultimately closed two generic safety concerns for the US nuclear industry. The first was Generic Safety Issue 15 (GSI-15) dealing with the Radiation Effects on Reactor Vessel Supports. The second issue was GSI-106, Piping and Use of Highly Combustible Gases in Vital Areas. This issue dealt with the potentially large volumes of combustible gases (primarily hydrogen) stored near safety-related systems. Dr. Smith's work was documented in NUREG/CR-5759. The issue was resolved with no new requirements, Generic Letter 93-06 was issued, and the NRC's Standard Review Plan was revised accordingly.
- Dr. Smith has also made significant contributions in the way that NASA views risk and performs risk assessment. His work through the multi-million dollar project for NASA Headquarters' Office of Safety and Mission Assurance has been a major factor in reshaping the use of PRA for NASA's high-profile manned and unmanned space projects.
- Dr. Smith is leading the work related to understanding and storing lessons-learned from the Fukushima accident into an INL-developed on-line information portal. This portal, located at [fukushima.inl.gov](http://fukushima.inl.gov), serves as a repository for a variety of accident information pertaining to the 2011 accident.
- Dr. Smith is currently the Pathway lead for the Risk-Informed Safety Margins Characterization (RISMC) for the DOE Light Water Reactor Sustainability (LWRS) project.

Dr. Smith's impact on NASA's technical activities include:

- Co-author on the NASA System Safety Handbook (NASA-SP-2010-580).
- Co-author on the Risk Informed Decision Making Guide (NASA-SP-2010-576)
- Rewriting Chapter 2 (System Safety) of NPR 8715.3, NASA General Safety Program Requirements.
- Developing the Constellation Probabilistic Risk Assessment SAPHIRE model
- Assisting in an update of the Systems Engineering Handbook (SP-2007-6105)

- Supporting the Interagency Nuclear Safety Review Panel (INSRP). INSRP activities are mandated by Presidential Directive (PD/NSC-25), dated December 14, 1977, to evaluate the risks associated with NASA missions using nuclear materials. Dr. Smith serves as an advisor to the Mars Science Laboratory (MSL) mission INSRP and is a member of the Uncertainty and Risk Integration working group. The product of this work will be a Safety Evaluation Report addressing the MSL Launch Approval Request to the President's Office of Science and Technology Policy.

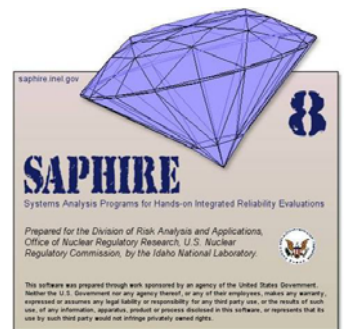


- Rewriting the NASA Agency Risk Management Procedural Requirements document (8000.4A).
- Completing a new NASA guidebook on the topic of Bayesian Inference for Risk and Reliability, which will serve as a standard-of-practice for quantitative inference for future NASA risk and reliability activities
- Developing a root-cause analysis tools to support NASA Headquarters as part of their incident investigation process.

Dr. Smith currently has a patent application being reviewed by the U.S. Patent and Trademark Office. This patent application, titled Hybrid Assessment Tool, And Systems and Methods of Quantifying Risk (USTPO number 11/428,888 filed 7/6/06), provides an advanced method of quantification for modern PRA methods. Once employed by industry codes, it will provide a method to quantify very complex models and will not suffer the limitations of classical methods (i.e., inaccuracies) or the limitations of some research methods (i.e., intractability).

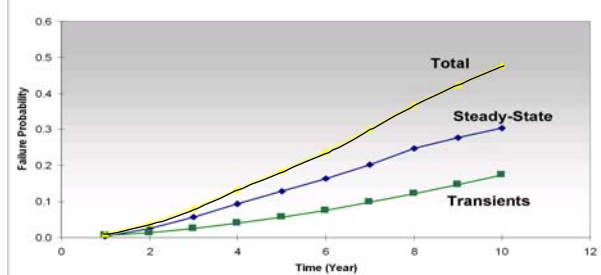
Dr. Smith has been successful in INL business development in the areas of safety assessment for NASA and NRC, the focus of his current department. Included in this business development are both short- and long-term projects such as:

- Dr. Smith is a lead instructor and course material developer for a million dollar per year risk curriculum presented to the NRC staff. This project has demonstrated sustained excellences for over 20 years at the INL and has seen growth over that time.
- For the past eight years, Dr. Smith has led the development of the Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE) suite of software codes, the premiere probabilistic risk assessment (PRA) tool for the creation and processing of Boolean risk models in the US nuclear industry. Under the technical lead of Dr. Smith, this project has doubled in size resulting in an increase of work-for-other funding.
- Dr. Smith has been instrumental in leading a multi-year safety support program for NASA Headquarters, including increased funding in the long-term areas of training and root-cause analysis software.

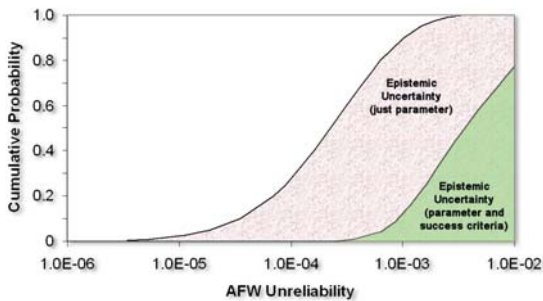


His technical impact on NRC programs has been extensive, with almost two decades of interactions with NRC staff, including Advisory Committee for Reactor Safeguards (ACRS) members. These interactions include:

- Advising ACRS members of state-of-the-practice PRA methods and tools, including current limitation and potential research avenues.
- Advising the NRC Office of Research on Advanced PRA Methods. Dr. Smith was requested by the NRC to provide recommendations on next generation PRA computational methods, including digraph approaches, dynamic methods, simulation, and parallel processing.
- Reviewing industry operational submittals such as an affirmation of engineered safety features testing protocol (“An Evaluation of the B&W Owners Group BAW-10182 Topical Report-Justification for the Increase in ESFAS Test Intervals”), a rejection of a General Electric proposed method for calibration (“INEL Evaluation of the Boiling Water Reactor Owner’s Group NEDC-32160P Topical Report “Calibration Interval Extension”), and quantitative evaluations of on-line operations as part of the NRC’s Maintenance Rule (“Configuration Risk Profile Analysis for the Crystal River 3 Nuclear Power Plant”).
- Contributing to the NRC standard in human reliability analysis (HRA) known as the SPAR-H methodology. Dr. Smith was an author on the SPAR-H technical report and was responsible for general application and overall uncertainty analysis within this method.
- Leading the development of one of the primary aging-related reports related to the quantitative evaluation of flow-accelerated corrosion. This work described the standard for incorporating reliability physics models into traditional PRA models.



- Key designer in providing a complete overhaul of the SAPHIRE software design for the latest version, SAPHIRE 8, in order to provide a PRA platform that will serve the NRC for its future risk-informed applications and modeling.



- Presenting technical arguments for a variety of technical issues, including model (aleatory and epistemic) uncertainty as it pertains to risk-informed decision making. Dr. Smith was the lead developer for a one-day NRC training course in response to the Davis-Besse reactor vessel head problem.

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## Publication Record

Dr. Smith has demonstrated a sustained and prolific publication history, with over 95 technical publications, including:

- 12 peer-reviewed archival contributions as journal papers or books
- 12 NUREG-series NRC peer-reviewed reports
- 40 external technical reports
- 30 conference and topical meeting papers
- 3 invention disclosures, with one submitted for a patent

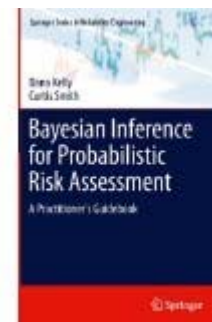
An additional measure of technical merit related to Dr. Smith's publication record would be to compare his publication frequency and volume to his peers. Within the Risk, Reliability, and NRC Programs department, there are 24 SE4 and SE5 staff members. Between August 2007 and late 2009, Dr. Smith co-authored four peer-reviewed journal articles – there were five total articles published in his department.

The makeup of the journal articles ranged from advanced methods for dynamic time-dependent modeling for reliability ("Construction of event-tree/fault-tree models from a Markov approach to dynamic system reliability," *Reliability Engineering and System Safety*, **93** (11) (2008) 1616–1627), aspects of the INL-developed SAPHIRE software for modern risk applications ("Key Attributes of the SAPHIRE Risk and Reliability Analysis Software for Risk-Informed Probabilistic Applications," *Reliability Engineering and System Safety*) to formal decision processes during nuclear incidents ("Decision making during nuclear power plant incidents - A new approach to the evaluation of precursor events," *Risk Analysis*).

A list of Dr. Smith's publications while at the INL include:

Peer-reviewed archival contributions as journal papers or books

- Kelly, D. L. and Smith, C. L., *Bayesian Inference for Probabilistic Risk Assessment*, Springer London, Springer Series in Reliability Engineering, Book ISBN: 978-1-84996-186-8.
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- Smith, C. L. et al., *Testing, Verifying, and Validating SAPHIRE Versions 6.0 and 7.0*, NUREG/CR-6688, October 2000.



- Russell, K. D., et al. *Systems Analysis Programs for Hands-on Reliability Evaluations (SAPHIRE) Version 6.0 - System Overview Manual*, NUREG/CR-6532, May 1999.
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- Jones, J. L. et al., *Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE) Version 5.0, Volume 9—Validation and Verification (V&V) Manual*, NUREG/CR-6116, Vol. 9, October 1994.
- Zeigler, S. L., et al., *Verification and Validation of the SAPHIRE Version 4.0 PRA Software Package*, NUREG/CR-6145, EGG-2713, February 1994.
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- Borgonovo, E. and C. L. Smith, *Composite Multilinearity, Epistemic Uncertainty and Risk Achievement Worth*, ESREL 2011, September 2011.
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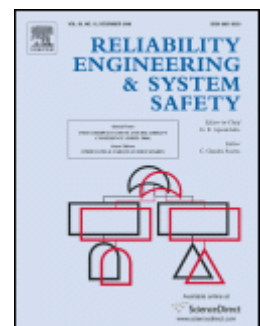
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## Professional Affiliations and Awards

Dr. Smith has a long-standing interaction with a variety of engineering and professional communities:

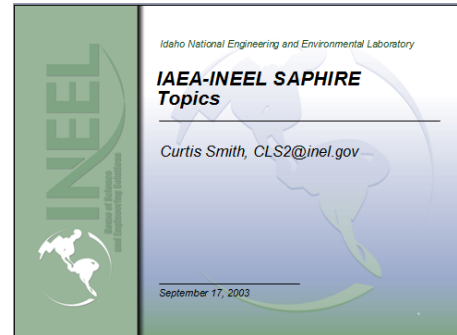
- Serving on the ASME SERAD Executive Committee. Safety Engineering and Risk Analysis (SERAD) is part of the ASME Engineering & Technology Management group. The goal of SERAD is to stimulate interest in and disseminate risk analysis and safety information as applied to the process of mechanical engineering. Dr. Smith is currently the Chair of the Executive Committee.
- Serving on the Idaho State University College of Engineering Advisory Council (EAC). The purpose of the EAC is to provide advice to the dean and faculty of the ISU College of Engineering.
- Steering Committee Member for the ELEUSI Research Center - University of Bocconi, Italy
- Past member of the ASME Engineering & Technology Management group operating board, Division Operations (Division Health & Training).
- Long-standing member of the national and local sections of the American Nuclear Society.
- Member of the American Society of Mechanical Engineers.
- Lifetime member and published author for the Idaho Academy of Sciences.
- Certificate of Appreciation in recognition of the efforts that resulted in a significant contribution to the work of the NRC on Maintenance Rule Baseline inspections, presented by the Office of Nuclear Reactor Regulation.
- Editorial Board for the *Reliability Engineering and System Safety* journal.
- Successful completion of the Idaho Engineer in Training qualification.
- Session chairperson for PSA '96 (1996), IAPSAM 6 (2002), PSA'02 (2002), IAPSAM 8 (2006), IMECE 2007, and IMECE 2008.
- Technical Program committee member and organizer PSA'02 (2002) and IAPSAM 8 (2006). As a member of the technical program committee for the IAPSAM 8 conference, Dr. Smith was the organizer of 21 sessions containing over 80 papers on the topic of risk and reliability methods.



- Technical Program Chair for the IAPSAM 12 (2014) meeting.
- Contributor to various educational lectures and workshops, including invited speaker for the ISU Physics and Engineering departments, support for the INL summer MeV School, and invited speaker for the 2011 National Physics Teachers Workshop. Topic: What about Japan and Nuclear Energy.

Dr. Smith has served as an internal and external review for a number of publications and projects, including:

- The U.S. Civilian Research and Development Foundation (CRDF).
- DOE.
- *Reliability Engineering and System Safety* journal.
- *Risk Analysis* journal.
- *Annals of Nuclear Energy* journal.
- *Nuclear Technology* journal.
- NASA. Dr. Smith was selected by NASA for the Independent Peer Review Panel for the Space Shuttle Probabilistic Risk Assessment (PRA).
- IAEA. Dr. Smith has provided lectures and reviews for safety applications at IAEA, including courses in the Ukraine and Vienna. He has provided technical expertise on PRA methods including risk monitor applications at member states.
- INL. Dr. Smith has been a technical reviewer for internal and external reports and projects for LDRD and programmatic applications.



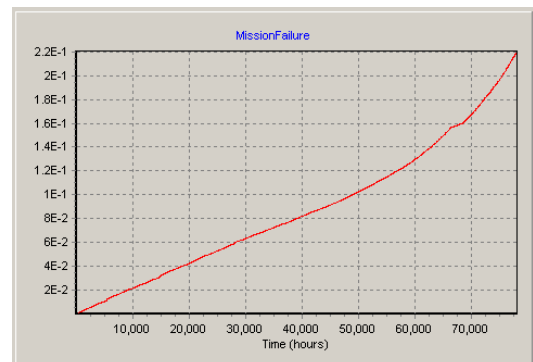


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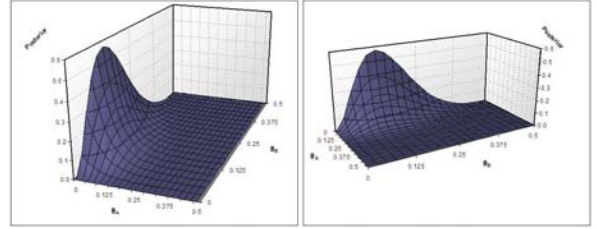
# Problem Complexity

Dr. Smith has had a demonstrated track of tackling difficult problems in a variety of domains:

- His recent Laboratory Directed Research and Development (LDRD) activities have focused on methods development. Included in these activities is a three-year project looking at quantitative approaches via Bayesian models related to nuclear proliferation detection and security/safeguards modeling.
- He has teamed with The Ohio State University on an LDRD exploring advanced methods in dynamic risk and reliability modeling and has assisted other LDRD projects such as the Simulations Enabled Safeguards Assessment Methodology (SESAME) activity.
- He has further worked on nonproliferation techniques, including aspects such as using social networking approaches to identify threat scenarios. This activity is designed to research using the power of the Internet to elicit scenario feedback from interested parties outside the research team and associated experts.
- He has researched integrating simulation methods with classical risk methods by integrating simulation into the existing analysis (e.g., SAPHIRE) framework. Currently, risk analysis approaches use either classical methods (e.g., fault trees, event trees) or simulation. He proposed to mix and use the best features of both, extending the existing SAPHIRE analysis platform.
- While working on Generic Safety Issue 15 (Radiation Effects on Reactor Vessel Supports) over 16 years ago, he proposed a solution to the problem of managing uncertainty calculations for the cost-benefit analysis by using a numerical Taylor series expansion approach.
- He has had a significant impact on the way the nuclear industry operates today include an investigation into methods to integrate surveillance testing and maintenance for nuclear power plants, being the technical lead for the Accident Sequence Precursor (ASP) parameter uncertainty improvements, and managing the Incorporation of Aging into PRA program.
- The aging project managed by Dr. Smith for the NRC resulted in the current state-of-the-art in quantitative modeling for aging mechanisms and yielding the oft-cited report Incorporating Aging Effects into Probabilistic Risk Assessment - A Feasibility Study Utilizing Reliability Physics Modeling, NUREG/CR 5632.



- Dr. Smith has been addressing application of Bayesian methods for a wide variety of PRA problems. Other recent activities include the formulation of Bayesian methods for determining human error probabilities for PRA based upon operational data.



- For the DOE, Dr. Smith was the technical lead investigating the separation requirements for a hydrogen production plant to be sited next to a high-temperature nuclear reactor for the DOE NE-20 program. In order to answer the risk-related questions for this next generation combined nuclear and chemical facility, he used PRA to answer three questions: what can happen, how likely is it, and what are the consequences?

- Dr. Smith is currently providing guidance on the NRC



Standardized Plant Analysis Risk model project related to reactor core melt mitigation strategies. He is responsible for providing novel but applicable mitigation strategies that may be modeled by the rest of the analysis team.

- Dr. Smith's patent application, Hybrid Assessment Tool, And Systems and Methods of Quantifying Risk, is an invention that uses a process wherein a binary decision diagram (BDD) quantifies a risk model while at the same time allows existing "minimal cut set" methods to be applicable. The process results in compact representations of complex models, thereby facilitating expanded realism in modeling capabilities. The method he developed provides exact probabilistic results for logic-based models, which is an improvement over traditional approximation techniques.
- His doctoral thesis work at M.I.T. focused on formal decision-making activities at nuclear power plants, work that is proving valuable for recent risk-informed decision making initiatives currently underway at NASA. Dr. Smith's thesis was based upon a proposal to Électricité de France (EdF) researching the methodological framework and associated prototypical tool that could be used for an incident management advisory system.

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# Responsibility

Dr. Smith is the project manager for six external projects, two for the NRC and two for NASA, one for the DOE, and one for the FAA.

*NRC SAPHIRE 7 Maintenance.* The NRC developed the SAPHIRE computer code for performing PRAs at the INL. SAPHIRE started out as a feasibility study for a PRA code to be run on a desktop personal PC and evolved through several phases into a state-of-the-art PRA code. Dr. Smith's responsibilities as project manager include ensuring technical and programmatic excellence for:

- Maintain the SAPHIRE computer code including corrections of identified problems.
- Provide technical support on PRA methods.
- Implement code updates.
- Perform testing, verification, and validation of the SAPHIRE software.

*NRC SAPHIRE 8 Development.* SAPHIRE version 8 is being designed to meet current NRC program risk-informed needs. As project manager, Dr. Smith is responsible for the development of the new SAPHIRE version, including new technical capabilities. Included in these responsibilities are ensuring technical and programmatic excellence for:

- Developing and releasing a beta and production SAPHIRE Version 8 to support NRC programs.
- Supporting the Significance Determination Process (SDP).
- Ensuring the quality of PRA calculations of SAPHIRE Version 8.
- Researching methods to improve that analysis capabilities of the SAPHIRE tool.

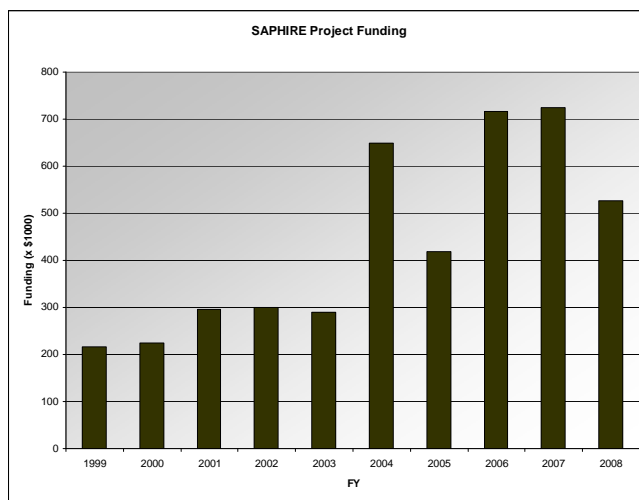
*NASA Safety Tools and Support.* NASA has funded the INL, through the federal earmark process, to support their safety activities. Dr. Smith's responsibilities as project manager include ensuring technical and programmatic excellence for:

- Integration of risk analysis in decision-making.
- Nuclear mission PRA methods.
- Human reliability analysis and database development.
- PRA software development including simulation capabilities.
- General PRA support for NASA.

*NASA Safety Training.* Training of NASA civil service staff and contractors on safety methods will be a key point in their transition to a more risk-informed mode of operation. Dr. Smith's responsibilities as project manager for this project will be to develop a series of courses based upon a safety curriculum wherein fundamental technologies and course level are explicitly considered. The project responsibilities include ensuring technical and programmatic excellence for:

- The design of the course topical areas.
- The development of course instructional materials.
- Creation of workshop activities to reinforce the instructional material
- Execution of the NASA safety courses.

Dr. Smith's other responsibilities include facilitating an increase in his department's internal and external business development. He has been instrumental in ensuring the continued development of the SAPHIRE project. As part of this development, modules such as the SAPHIRE SDP workspace has seen acceptance within the NRC and has helped to increase the NRC's reliance on the INL-developed SPAR models and SAPHIRE. As seen at right, following his assignment to the SAPHIRE project in 2003, Dr. Smith was able to rapidly increase external funding. Further, he has successfully grown the NASA project funding level and types of projects.



*DOE Fukushima Event Reconstruction.*

The purpose of this study is to reconstruct the events at Fukushima Daiichi in order to characterize and model the events.

The study will focus on collecting, verifying, and documenting data and will attempt to reconstruct the accident sequences for the reactors at Unit 1, 2 and 3 and the spent fuel pool at Unit 4 in order to assess severe accident modeling capability. The INL portion of this work will focus on establishing the accident timeline of events, including equipment actuation and system failures. When possible, the data collection will distinguish between causal events such as the effects from the earthquake versus the tsunami. Activities include:

- Develop an on-line information portal for the Fukushima project
- Verify data/timeline, focusing on the initial time periods described above.
- Populate this data/timeline into the information portal.

*FAA Uncertainty in Risk Assessment.* In the future, the FAA may be tasked with determining launch vehicle failure metrics as a part of launch decision making, in effect being a regulator of commercial space launch activities. This INL project was started to assist the FAA in developing methods for Bayesian inference applicable to manufacturer specific launch analysis. Uncertainty and the flexibility of analyses are considered along with results of the models for comparison.

*LDRD for the Development of a Bayesian Method for the Detection of Nuclear Proliferation.* As project manager for this LDRD, Dr. Smith is responsible for research aimed at designing and demonstrating a Bayesian-based decision support system for identifying proliferation by a nuclear fuel cycle facility operator. Key aspects of this research are to develop a system that will:

Duplication and Extension of Final		Risk Insights Snapshot	
<b>1</b>	<b>The Issue</b>	<b>4</b>	<b>Checking The Model</b>
	<p>We need a methodology to utilize all available information in a Bayesian fashion to model ELY PDF in phase allocation, yet follow the methodology set forth in " " on 8 PDF and Phase Allocation, Status and Recommendations"</p>		<p>Jeffreys non-informative prior affects the sparse data in the NN First 2 Launch dataset</p> <p>Validated versus reference results</p>
<b>2</b>	<b>Risk Statement</b>		
	<p>Given that</p> <p><b>CONDITION:</b> data utilization in [2] is limited to weighting data prior to Bayesian update, utilizes point estimates and updating in a conjugate fashion</p> <p><b>DEPARTURE:</b> The methodology presented in [2] is limited in its ability to handle non-conjugate distributed information, use of uncertainty, and multiple valid datasets</p> <p><b>ASSET:</b> posterior results, thereby leading to</p> <p><b>CONSEQUENCES:</b> loss of uncertainty information and its effects on the posterior, no ability to utilize multiple datasets through posterior averaging, and the inability to utilize non-conjugate information</p>		<p><b>Model</b></p> <ul style="list-style-type: none"> <li>Multiple models were checked versus reference results</li> <li>Results available for all phases</li> </ul> <p><b>Data</b></p> <ul style="list-style-type: none"> <li>Both NN datasets are used in the prediction</li> <li>Overall PDF is heavily tied to the NN First 2 Launch dataset</li> </ul> <p><b>Information</b></p> <ul style="list-style-type: none"> <li>Reference results from [2]</li> <li>Overall vehicle PDF mean (from [2]): 0.69</li> </ul> <p>80% Confidence Interval Vehicle PDF - Box Chart</p>
<b>3</b>	<b>Risk Results</b>		<b>Recommendations</b>
	<p><b>DEPARTURE:</b> expensive launch vehicle fails to perform its mission.</p> <p>The performance measure used to represent the departure risk level is: Unreliability (Probability of Failure)</p> <p>Overall vehicle PDF mean: 0.69.</p> <p>80% Credible Interval Vehicle PDF - Box Chart</p>		<ul style="list-style-type: none"> <li>Using OpenBUGS simplifies the analysis</li> <li>Weighting multiple datasets can provide a more objective prediction than anchoring the overall PDF to the results of one dataset</li> </ul>

- Identify leading indicators of proliferation.
- Measure the degree (via probability) to which the operator is planning or participating in proliferation.
- Provide a decision making tool including explicitly incorporating the influences of uncertainty.
- Allow new information can be added to model as it is obtained.
- Be a communications tool including multiple aspects of problem and uncertainty.

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## Liaison/Interface

Dr. Smith has served as an INL risk and reliability expert for over 15 years.

- He has worked with and advised NRC staff for briefings related to state-of-the-art cost-benefit analyses on several issues during the early 1990s.
- He has provided briefings to the US Senate science subcommittee members on Status of Fukushima and insights during the first week of the Fukushima accident.
- He serves on the ASME Safety Engineering and Risk Analysis (SERAD) Executive Committee, the ASME Engineering and Technology Management Division Operations Board, and the Idaho State University College of Engineering Advisory Council (EAC). He is a member of the Technical Program Committees for several leading international nuclear risk conferences.
- He has lectured to hundreds of scientist and engineers, world wide, serving as an INL representative. Reaching a million-miles on Delta was accomplished by interacting with individuals and organizations, including: MIT, the ACRS, the IAEA, the OECD Halden Research Project, the Ukrainian Institute for Radiation and the Protection of the Environment, the JRC Aging PSA Network, the Canadian Nuclear Safety Commission, and multiple private engineering consulting firms.
- He has interfaced with conference organizing committees as a member of the technical program committee on several risk and reliability conferences. For example, on the IAPSAM 8 conference, Dr. Smith was the organizer of 21 sessions containing over 80 papers and different national and international authors on the topic of risk and reliability methods.
- He interacts with staff from multiple NASA centers including NASA Headquarters, Jet Propulsion Laboratory, Johnson Space Center, Goddard Space Flight Center, Kennedy Space Center, and Ames Research Center.
- Dr. Smith has been a frequent lecturer and has developed and taught a varied spectrum of courses, including:

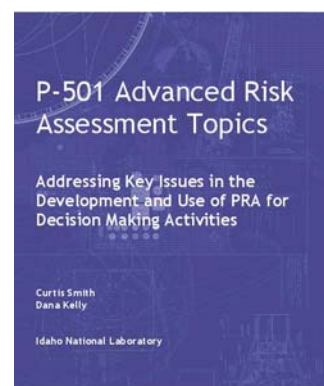
PRA Fundamentals

SAPHIRE Basics

Advanced SAPHIRE

Probability and Statistics

Bayesian Probability Inference



Advanced Risk Assessment Topics

Risk Evaluation for Event Assessment

Human Reliability Analysis

Assessing the Adequacy of Models for Risk-Informed Decisions

Turning Bayesian

Probabilistic Risk Assessment Methods (PRAM)

PRA of Space Systems

Application of Bayesian Inference to PRA of Space Systems

System Safety

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## Freedom to Act

In addition to the instruction and interaction with external organizations, Dr. Smith was the lead developer for the majority of INL's safety and risk analysis training material. In order to develop this material, he was generally given only a topical area (e.g., Bayesian inference) and asked to complete the course. He developed the majority of the material for the following courses: SAPHIRE Basics, Advanced SAPHIRE, Probability and Statistics, Bayesian Probability Inference, Advanced Risk Assessment Topics, Risk Evaluation for Event Assessment, Assessing the Adequacy of Models for Risk-Informed Decisions, and PRA of Space Systems.

Dr. Smith spent nine months in Norway, serving as the sole INL visiting scientist to the OECD-sponsored Halden Reactor Project performing human performance-related research. While in Norway, he:

- Performed PRA technical transfer activities.
- Participated in using the Halden reactor simulator for data collection efforts through simulator experiments and model development (e.g., Bayesian quantification of human reliability).
- Interacted with the research staff at the Halden Reactor Project, including providing a series of lectures on probabilistic methods.



Dr. Smith's specific focus of research while in Halden was to develop a Bayesian-based methodology to estimate human reliability analysis (HRA) probabilities for use in PRA, whereby the Bayesian analysis will utilize operational data, HRA modeling, expert judgment, and simulator data as applicable.

For the past eight years, Dr. Smith has led the development of the Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE) suite of software codes, the premiere PRA tool for the creation and processing of Boolean risk models in the US nuclear industry.

- SAPHIRE is the primary PRA software for the NRC and NASA, as well as many private organizations around the world, with over 30 foreign entities as part of the SAPHIRE Users' Group (also led by Dr. Smith).
- All 104 operating commercial nuclear power plants have been analyzed using SAPHIRE.
- The International Space Station, the Space Shuttle Program and NASA's Constellation Program have all used SAPHIRE to determine their risk profiles.

His current effort, SAPHIRE 8, is the "next generation" of risk tools, exploring the possibilities of new methods needed to evaluate the risk of future reactor designs. Dr. Smith was chartered with creating the framework and user interface for this next-generation tool.

In 2008, Dr. Smith was requested by NASA to develop a Safety Course curriculum defining how NASA staff and contractors are to be trained on safety topics. He was asked to support NASA's system safety programs and process by conducting technical training activities. The objectives of this training are to develop new curricula and courses supporting NASA's system safety and system engineering needs and conduct presentations of established courses in the safety assessment training curriculum.

Dr. Smith proposed a NASA safety curriculum that covered the different PRA technologies needed by NASA. Included in these technologies were concepts such as an overview of risk, Bayesian methods, and making decisions. Each course covered three different levels (from concepts to application). His proposal was funded by NASA.

Technology	Topic	Concepts	Theory	Application	
Background and Risk Theory	Risk theory	001 Risk Analysis Fundamentals	100 PRA Methods		
	NASA Safety Processes				
Probability theory					
Bayesian Methods	Bayesian inference		101 Probability and Statistics Basics	201 Application of Bayesian Inference to PRA of Space Systems	
	Parameter estimation				
	Uncertainty propagation				
Modeling Systems	Reliability determination	004 Reliability Fundamentals	204 Reliability Applications for Space Systems		
	Logic-based models		102 Modeling Space Systems	202 Application of SAPHIRE to PRA of Space Systems	
	Human interactions		103 Human Reliability		
	Dependent failures		102		
	Advanced failure modeling		203 Advanced Topics in Risk Assessment		
Usage of analysis tools					
Modeling Scenarios	Representing hazards	003 System Safety Fundamentals		202	
	Logic-based models	001 PRA Fundamentals	100		102
	Usage of analysis tools				
Modeling Consequences	Consequence modeling	003	206 Consequence Analyses for Space Systems		
	Usage of analysis tools				
Decision Support	Sensitivity and importance analysis	001 PRA Fundamentals	100	102	202
	Event and precursor analysis		205 Precursor Analyses for Space Systems		
	Decision analysis	002 Risk-Informed Decision Making	100		

Dr. Smith has actively participated in the INL's LDRD process for over 15 years, submitting proposals, reviewing other proposals, and leading funded projects. During the late 1990s, he was an advisor to the INL's Center for Risk and Reliability Analysis and worked on ideas such as the "Smart Reliability Optimizer," an innovative, Internet-based tool to



determine an system optimization strategy based upon minimal cut sets. Dr. Smith has submitted approximately two dozen LDRD proposals while at the INL and has received single- and multi-year funding for about a quarter of those proposals.