BNL-76750-2006-CP

Experience Using Phenomena Identification and Ranking Technique (PIRT) for Nuclear Analysis

David J. Diamond

Presented at PHYSOR-2006 Topical Meeting
Vancouver, British Columbia, Canada
September 10-14, 2006

ES&T Department / NEIS Division

Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

Notice: This manuscript has been authored by employees of Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy. The publisher by accepting the manuscript for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

This preprint is intended for publication in a journal or proceedings. Since changes may be made before publication, it may not be cited or reproduced without the author's permission.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Experience Using Phenomena Identification and Ranking Technique (PIRT) for Nuclear Analysis

David J. Diamond
Brookhaven National Laboratory, Bldg. 130
Upton, NY 11973-5000 USA

Abstract

The Phenomena Identification and Ranking Technique (PIRT) is a systematic way of gathering information from experts on a specific subject, and ranking the importance of the information, in order to meet some decision-making objective. It has been applied to many nuclear technology issues including nuclear analysis in order to help guide research or develop regulatory requirements. This paper is meant to introduce the process to those who may be unfamiliar with it and, by going through some examples, demonstrate its usefulness in helping to improve our understanding of nuclear analysis and/or show where our priorities should be in making changes to the way we do nuclear analysis.

Keywords: PIRT; Phenomena Identification and Ranking Technique; expert elicitation

1. Introduction

The Phenomena Identification and Ranking Technique (PIRT) is a systematic way of gathering information from experts on a specific subject, and ranking the importance of the information, in order to meet some decision-making objective, e.g., determining what has highest priority for research on that subject. It has been successfully applied to many nuclear technology issues since it was first developed and applied in the late 1980s [1] and then developed into a generalized process. [2] The objective of this paper is to explain how it has been applied to issues related to nuclear analysis in the U.S. In particular, the paper discusses why and how these studies (so-called PIRTs) were carried out, whether they were successful and what was learned—technically and about the PIRT process itself.

The PIRT process results in lists of phenomena which are germane to a particular subject (a very specific figure-of-merit). The "phenomena" can actually be the condition of a particular reactor/system/component, a physical or engineering approximation, a reactor parameter, or anything else that might influence the figure-of-merit. The process proceeds by ranking these phenomena using some scoring criteria in order to help determine what is most important. That ranking, as well as the rationale for the ranking along with the information obtained to explain the ranking, can assist in decision making. The PIRT methodology brings into focus the phenomena that dominate an issue, while identifying all plausible effects to demonstrate completeness.

An important part of the process is to also identify the uncertainty in the ranking, usually by scoring the knowledge base for the phenomenon. Again the rationale for the scoring is an important product of the elicitation. When a phenomenon is identified as being important but the corresponding knowledge level is low it is an indication that more effort must be applied, e.g., more research support.

Examples of successful PIRT applications exist in thermal-hydraulics, severe accidents, fuels, materials degradation, and nuclear analysis. Each study has a different objective and modified the basic PIRT approach in some way to fit its own needs. In order to understand the PIRT process one must look at a particular PIRT and see how it was carried out. Items that are common to all PIRTs are the use of a facilitator and subject matter experts. The latter are brought in to provide information to supplement the knowledge of the panel members.

In nuclear analysis most efforts that have received wide circulation in the U.S. have been sponsored by the Nuclear Regulatory Commission (NRC). The studies were organized by the research arm of the NRC and, therefore, were aimed at identifying what is important to pursue in terms of regulatory research. The subjects covered in these studies were:

- Rod Ejection Accidents for Pressurized Water Reactors [3]
- Power Oscillations Without Scram for Boiling Water Reactors [4]
- Burnup Credit in Spent Fuel Casks [5]
- Coolant Void Reactivity for the ACR-700 Design [6]
- Steady State Power Distribution for the ACR-700 [6]

In the following sections the process and results from some of these PIRTs are explained.

2. Nuclear Analysis for the ACR-700

There were two nuclear analysis PIRTs carried out to understand where the technology gaps were for the preliminary ACR-700 design. The objectives were to identify potentially important safety issues as they apply to the ACR-700 design, to discuss the technical basis for resolution of these issues, and to provide guidance for where there is a need for additional experimental databases as well as additional development of analytical tools. One PIRT considered the steady state power distribution as it impacts a loss-of-coolant accident (LOCA) and the other the coolant void reactivity as it impacts a LOCA due to a large header break. The panel that carried out the PIRT consisted of five members; small enough so that agreement could be reached on judgments. In the following we consider the PIRT on power distribution.

The figure-of-merit (FoM) was the calculation of 1) the bundle power distribution throughout the core at full power and 2) the corresponding peak fuel element power density. Item 1 helps determine the hydraulic conditions during the event and the latter is used specifically to calculate the peak-clad temperature which must meet a specified acceptance criterion. The core is assumed to be at equilibrium fueling conditions. Note that analysis of bundle power distributions must consider time-average power as well as the "ripple" which takes into account the movement of fuel and the corresponding xenon redistribution.

The PIRT tables were organized according to three main elements of the calculation of power distribution: specifying reactor operating conditions, core simulation calculations (which means using a computer code to model the steady-state neutronics and thermal-hydraulics of the core), and lattice physics analysis (which means the application of a computer code to provide the nuclear data that are input to the core simulation). This approach provides information on both the fundamental physics involved and the safety analysis methods.

The panel compiled a list of 67 "phenomena," i.e., either the specific reactor conditions that define the state of the reactor, or the models found within the computer codes, or the key parameters being calculated by the codes. This list is placed in two tables for each of the three calculational elements. One of the two tables provides the definition of each phenomenon related to that element. The other table has the "importance" and "knowledge level" for each phenomenon along with the rationale for that decision (see definition of terms below). In those situations where additional research is "needed" (as defined below) a comment is made in the column containing the knowledge level.

As used in the tables, **Importance** is given according to a three-level scale: High/Medium/Low. High (**H**) implies that the phenomenon/model/parameter has a controlling impact on the FoM. Simulation of experiments and/or analytic modeling with a high degree of accuracy is critical. Medium (**M**) implies that the phenomenon has a moderate impact on the FoM and only a moderate degree of accuracy is required for analytic modeling or measurements. Low (**L**) implies that the phenomenon has a minimal or zero impact on the FoM.

Knowledge Level is also given according to a three-level scale: Known/Partially Known/Unknown. This is related to whether we understand how well the phenomenon/model/parameter is calculated or used in determining the FoM. Known (**K**) implies fully or almost fully known (more than 75% of what we could expect to know). Partially known (**P**) implies the knowledge base is moderate (25-75% of the knowledge base is established). Unknown (**U**) implies that the knowledge base is low (less than 25% of the knowledge base is established). No assessment of knowledge is given if the importance is low (NA, not applicable, is given). A knowledge level of (**K**), known, implies that additional research on this phenomenon is not necessary even if the importance level is high. Conversely, a knowledge level of (**U**), unknown, implies that this phenomenon is a priority for additional research, particularly if the importance level is high, but also if the importance is only medium. A knowledge level of (**P**), partially known, implies that research is suggested if the phenomenon is of high importance. The diagram below summarizes the implications.

Importance

		H	**M**	**L**
Knowledge	**K**			
Level	**P**	*		
	U	*	*	

*** Research in this area is suggested**

The important results from the PIRT tables for the core simulation element are summarized in Table 1. For each of the phenomena there is a definition, the importance and knowledge level ranking with rationale, and lastly, comments on how to close the technology gap.

The table shows that there are gaps that need to be filled by a combination of experimental data and analytical support. The experimental work is from the ZED-2 critical facility and post irradiation examinations (PIEs). The most important use of the ZED-2 experiments from this table is to provide measurements at a simulated core-reflector interface in order to help validate the core simulator modeling of these boundaries and to help validate the calculation of form factors.

The calculational support suggested by the PIRT includes sensitivity studies using appropriate methods. Benchmark calculations using methods more rigorous than those expected to be the norm are also suggested. Examples that were identified as being most urgent to resolve include calculating the bundle power near the core-reflector interface and the fuel element power everywhere, the latter requiring de-homogenization (flux reconstruction). Interstitial effects, end effects, and core-reflector interface effects make the reconstruction difficult.

3. Rod Ejection Accident in a Pressurized Water Reactor

In this PIRT the ultimate objective was to understand high burnup fuel behavior under reactivity initiated accidents in order to be able to define research needs and help develop new regulatory criteria. One aspect of the rod ejection accident is the transient analysis itself and it is only this portion, which relates to nuclear analysis that is discussed herein. A specific plant, fuel, and a (high) burnup were chosen in order to limit the focus; something that is always important in a PIRT. Subsequent to the PIRT a report was written summarizing the implications. [7]

Table 1. Power distribution phenomena with technology gaps – core simulation.

Phenomenon – Definition	**Importance (H/M/L) Knowledge Level (K/P/U)**	**Suggested Work**
Number of energy groups How many neutron energy groups are considered in the calculations; in particular, the adequacy of two neutron energy groups.	**H -** Epithermal resonance capture is important to determine the pin power; therefore spatial/spectral effects are important at the lattice physics level as well as at the core level. **P** - At the core-reflector interface there are spectral effects that may be important.	Sensitivity calculations could be carried out such as by creating a special color set at the core-reflector interface.
Spatial discretization The choice of the spatial mesh grid and mathematical method to discretized continuous space.	**M -** Analysis by AECL shows the importance of finer mesh at reflector-core interface. Otherwise mesh size should not be so important if homogenization and spatial discretization method are appropriately done. **P** - Experience from LWRs and CANDUs is relevant. However, the particulars of leakage from the compact ACR core have not been experimentally confirmed.	ZED-2 experiments and/or computer simulations would be helpful. If diffusion theory is used, the methods used to calculate the homogenized diffusion coefficient (e.g., the B1 method) could be validated using integral transport or subregion Monte Carlo methods.
De-homogenization The flux/pin-power reconstruction and calculation of the detector response.	**H** - Must be used to determine the pin power. **U** - Interstitial effects, end effects, and core-reflector interface effects would make the reconstruction difficult. There is little experience with pin power reconstruction methods for (non-orthogonal) CANFLEX type lattices.	Fuel cell-reflector lattice physics calculations can be used to address some of the uncertainties. Three-dimensional subregion calculations can resolve end effect and interstitial questions. Experiments at ZED-2 could also be used to assess calculation of form factors. New pin power reconstruction methods may need to be developed for CANFLEX fuel.

Table 1 (Cont'd)

Phenomenon – Definition	Importance (H/M/L) Knowledge Level (K/P/U)	Suggested Work
Incremental control devices (full and partial rod insertion) The instantaneous effect of control device feedback on the neutron cross-sections or on other nuclear data. The concern is whether the functional/tabular dependences of the data are adequate.	**H -** Affects local and global power distribution due to introduction of absorption in the control devices. **P -** Based on CANDU analysis. However, there is no experience with pin-power reconstruction with transverse devices present.	Three-dimensional spatially detailed calculations can resolve control absorber concerns. ZED-2 experiments could also be used to assess accuracy of control device representation.
Core-Reflector interface (radial, axial) The boundary conditions at the external reactor boundary.	**H -** The power distribution is very dependent on modeling core-reflector interface effects. **U** - Core-reflector effects would make the reconstruction difficult and there is little experience available.	Fuel cell-reflector lattice physics calculations can be used to address some of the uncertainties. Experiments at ZED-2 could provide measurements at simulated core-reflector interface locations that can be used to validate core simulators.
Reactor boundary (axial) The boundary conditions at the external reactor boundary.	**M** - The axial boundary of the reactor is very complex. **P -** There is limited calculational basis available.	Monte Carlo calculations can be performed to investigate alternate axial boundary conditions.
Time-averaging of power Since the ACR is continuously refueled, consideration has to be given to a time-average or bounding power.	**M -** Differences between time average and bounding distributions may not be large. **U** - Only simplified methods are now used. Ripple effect of two-bundle push with enriched U bundles needs to be assessed in regard to magnitude of ripple.	There is a need to investigate rigorous methods to quantify the effect of simplified methods.

The results for the phenomena that influence the power history and the calculation of fuel pin enthalpy and clad temperature (the figures-of-merit) are given in Table 2. Instead of determining a single score for importance and uncertainty the table indicates the number of panel members voting for a particular score. This is the result of the fact that there were 22 panel members and even with some declining to vote, there is no unanimity. To overcome this problem an importance ratio (IR) and knowledge ratio (KR) are defined to make it easier to interpret the results. The ratios are defined as $100*(S_1+S_2/2)/ (S_1+S_2+S_3)$ where the scores S_n go from highest importance/most well-known down as n goes from 1 to 3.

The result of this PIRT was that there were no phenomena that were both of high importance and high uncertainty suggesting that additional research would be needed.

Table 2: Plant transient analysis PIRT.

		Importance				Uncertainty			
Subcategory	**Phenomenon**	**H**	**M**	**L**	**IR**	**K**	**P**	**U**	**KR**
Calculation of power history during pulse (includes pulse width)	Ejected control rod worth	12	0	0	100	13	0	0	100
	Rate of reactivity insertion	3	5	1	61	10	3	0	88
	Moderator feedback	0	6	2	38	12	2	0	93
	Fuel temperature feedback	12	0	0	100	12	1	0	96
	Delayed-neutron fraction	10	1	0	95	13	1	0	96
	Reactor trip reactivity	0	0	10	0	13	1	0	96
	Fuel cycle design	11	2	0	92	12	0	0	100
Calculation of pin fuel enthalpy increase during pulse (includes cladding temperature)	Heat resistances in high burnup fuel, gap, and cladding (including oxide layer)	3	15	0	58	5	10	0	67
	Transient cladding-to-coolant heat transfer coefficient	2	15	0	56	4	10	0	64
	Heat capacities of fuel and cladding	15	2	0	94	12	3	0	90
	Fractional energy deposition in pellet	0	1	13	4	12	2	0	93
	Pellet radial power distribution	4	12	0	63	10	3	0	88
	Pin-peaking factors	15	1	0	97	12	0	0	100

4. Summary and Conclusions

The PIRTs that have been carried out for the NRC have resulted in increased understanding of a number of subjects and new directions for research. It is concluded that the PIRT approach, a systematic way of getting an expert elicitation, has been successful in each of the nuclear analysis applications discussed in this paper.

References

1) "Quantifying Reactor Safety Margins: Application of CSAU to a LBLOCA," B.E. Boyack, et al, Part 1: An overview of the CSAU Evaluation Methodology; G.E. Wilson et al., Part 2: Characterization of Important Contributors to Uncertainty, W. Wulff et al., Part 3: Assessment and Ranging Parameters; C.S. Lellouche et al., Part 4: Uncertainty Evaluation of analysis Based on TRAC-PF1/MOD1; N. Zuber et al., Part 5: Evaluation of Scale-up Capabilities of Best Estimate Codes; I. Catton et al., Part 6: A Physically Based Method of Estimating PWR LBLOCA PCT, *Nuclear Engineering and Design 119 (1) pp 1-117*, May 1990.
2) Wilson, G.E. and B.E. Boyack, "The Role of the PIRT Process in Experiments, Code Development and Code Applications Associated with Reactor Safety Analysis," *Nuclear Engineering and Design, 186 (1-2): pp 23-37,* November 1998.
3) B.E. Boyak, et al., "Phenomenon Identification and Ranking Tables (PIRTs) for Rod Ejection Accidents in Pressurized Water Reactors Containing High Burnup Fuel," NUREG/CR-6742, U.S. Nuclear Regulatory Commission, September 2001.
4) B.E. Boyak, et al., "Phenomenon Identification and Ranking Tables (PIRTs) for Power Oscillations without Scram in Boiling Water Reactors Containing High Burnup Fuel," NUREG/CR-6743, U.S. Nuclear Regulatory Commission, September 2001.
5) G.H. Bidinger, et al., "Burnup Credit PIRT Report," NUREG/CR-6764, U.S. Nuclear Regulatory Commission, May 2002.
6) D.J. Diamond, et al., "Phenomena Identification and Ranking Technique (PIRT) Applied to the ACR-700 Design," U.S. Nuclear Regulatory Commission ADAMS accession number ML043230335, Brookhaven National Laboratory, August 2004.
7) R.O. Meyer, "Implications from the Phenomenon Identification and Ranking Tables (PIRTs) and Suggested Research Activities for High Burnup Fuel," NUREG-1749, U.S. Nuclear Regulatory Commission, September 2001.

Printed on recycled paper