NRC NEWS

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Computer Modeling and Simulation at the Nuclear Regulatory Commission

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Good afternoon. I'm pleased to have been invited to give you a brief overview of the work at the Nuclear Regulatory Commission that involves the use of computer-based modeling and simulation capabilities, and some areas where the NRC might have a future need for greater capability in this area.

To start, it is appropriate to note that the NRC is a regulatory authority and not a developer or advocate of technology. As such, our use of computational tools is primarily aimed at independently verifying the acceptability of design basis calculations that are submitted by a licensee or an applicant as justification that their design is in compliance with our requirements. Other closely related uses for these tools are rulemakings, generic safety issue resolution, and plant event assessments.

I very much appreciate the Department of Energy's (DOE's) interest in exploring ways in which the NRC regulatory mission can benefit from some of the research and computational approaches being developed by DOE. In particular, I want to thank DOE Undersecretary Ray Orbach for his support in this area. I personally believe that both DOE and NRC can collaborate on such initiatives while still carefully and appropriately maintaining our respective and independent roles and missions.

Neither our reactor licensees nor the NRC perform integral accident experiments in full-scale prototypes due to cost and safety concerns. Therefore, the performance of a reactor plant under the extreme upset conditions that are postulated for regulatory purposes is predicted using several system-specific analytical codes that have been benchmarked against experimental results of specific physical phenomena or reduced scale integral facilities. Our confidence in the accuracy of these codes is primarily limited by the extent to which they have been verified against applicable data.

Following the core melt accident at Three Mile Island Unit 2 in 1979, the NRC undertook a very substantial research program to develop insights into severe accident scenarios involving significant core melting. Such severe accidents were those that could progress well beyond the calculated design basis accident results that were verified by NRC licensing computer codes. The NRC sponsored development of computer-based models to predict the phenomenology of severe accident progression and benchmarked them, to the extent possible, with applicable severe accident experimental research results. These models are not used to demonstrate or confirm regulatory licensing or compliance, but continue to inform Commission policy as new research results are incorporated to provide improved safety insights into the consequences of severe accidents.

The use of fault tree logic and statistical approaches to generate probabilistic risk models of nuclear power plants has grown in complexity along with steadily increasing computational power and speed. Today we continue to add new and more computationally challenging elements to our risk models, such as the risk from internal fires. While this increase in complexity is aimed at providing more complete and detailed risk insights, it also creates significant challenges in making such insights understandable to the NRC, licensee decision-makers and others who use them.

The future of NRC computer simulation may include the integrated coupling of probabilistic plant risk models with severe accident (core-melt) progression models. Each of these types of models has ongoing programs to develop a greater degree of detail or accuracy. For example, the NRC recently started work with Sandia National Laboratories to better integrate probabilistic and severe accident models, using the most current accident research data and analysis. Its objective is to update a 25-year-old, unrealistically conservative analysis with the latest severe accident research and best available estimation techniques. Such large-scale model integration has not been previously accomplished, but today we have the computational capability to do it. Our degree of success with this first step will likely determine whether the Commission approves moving ahead with further work. One application being considered for such a large integrated model would be in faster-than-real-time simulation for use during training drills or actual events.

Since the Atomic Energy Commission, and later the Nuclear Regulatory Commission, began developing thermal-hydraulic accident analysis codes in the 1960's, they have evolved into complex, sophisticated codes that combine calculations that couple two-phase flow, multi-mode heat transfer to and from surrounding structures, clad oxidation chemistry, clad stress and strain, multi-dimensional reactor kinetics, and external control system effects. However, in general these codes are not based on "first principles." They use averaged equations that contain many idealizations and semi-empirical models bounded within specific flow regimes and geometries. For example, two-phase flow and heat transfer are much different with horizontal fuel bundles such as the natural uranium-fueled, heavy water moderated, CANDU reactor than in vertical fuel bundles common to U.S. plants; and NRC has had to develop film condensation models to evaluate passive heat removal systems for the licensing review of General Electric's Economic Simplified Boiling Water Reactor - the ESBWR.

DOE and NRC have also co-sponsored the development of reactor physics and neutronics codes, such as the SCALE code, for criticality safety, radiation shielding, waste characterization, and reactor core behavior. The NRC's future need for such capability will be driven by the safety analyses of high burn-up and mixed oxide fuels, spent fuel storage, and criticality controls in new fuel cycle facilities, as well as new reactor designs.

NRC code development and improvement utilize experimental data from a combination of benchmarking tests. These include separate effects tests to model specific physical phenomena, integral effects tests to assess predictive capability of the dynamic system, and scaling studies to ensure there are no significant distortions introduced into the code when using scale model experiments as benchmarks. I have always been a firm believer in making the necessary effort to validate predictive computer codes and models. I also believe that pooling our international research capabilities to accomplish such validation can be immensely beneficial from both an efficiency and effectiveness perspective.

In fact, from my very first speech as an NRC Commissioner, I have often reflected on one example from my work at Los Alamos about the lack of predictive success in the field of laser fusion. I participated in many of the early laser fusion experiments at a time when there was immense optimism that, based on the best calculations available at the time, modestly sized and fairly inexpensive lasers would provide enough energy to ignite fuel and enable efficient production of fusion energy.

Thirty years later, you don't hear much today about laser fusion supplying grid power in the near future. The early predictions for success with small lasers are now replaced by construction of the multi-billion dollar and two million joule National Ignition Facility at the Lawrence Livermore National Laboratory, where ignition and energy gain might be demonstrated, with attempts starting around 2010. This is a far cry from the early predictions. It seems that careful experiments, some done by my group at Los Alamos, simply did not support the optimism of the early calculations. Clearly, computational models are as good, or as bad, as the depth of the physics and engineering underpinning them.

The NRC has always employed prudent conservatism to account for uncertainty in our state of knowledge. The earliest thermal-hydraulic codes used to predict plant performance under the most limiting design basis accidents were a collection of discrete evaluation models that each addressed one aspect or physical phenomenon. This isn't too surprising for a number of reasons, not the least of which was the state of computer technology at the time. For example, how many in this audience can remember typing each line of code on a single punch card and then turning in your 'deck' of punch cards to be run on the IBM mainframe and waiting for several hours to get your results, only to find an error and that you have to do it all over again! Our modeling capability has always been limited by our computational capability, but uncertainty persists even as computational capability has increased by orders of magnitude.

In a 1975 review of AEC models for evaluating emergency core cooling performance, the American Physical Society reported that

> "Many elements of the evaluation models are uncertain and no large-scale system tests exist against which to evaluate overall system modeling; consequently the AEC has attempted to prescribe each of the discrete parts of the evaluation models conservatively. The implicit assumption behind this endeavor is that if all parts of the evaluation models are prescribed conservatively, then the resulting calculated system performance must also be conservatively prescribed. If this assumption is valid, it could clearly lead to over-designing of the system."

A combined U.S. and international research effort in excess of one billion dollars led to a revision of NRC requirements in 1988 that allowed the use of realistic calculations and codes to evaluate the performance of the emergency core cooling systems. The use of this rule has allowed better fuel utilization, increases in operational flexibility, and power uprates, all while maintaining adequate and well-understood safety margins.

Today we continue to advance and refine the codes we use in support of the NRC safety mission. We have consolidated most of our thermal-hydraulics codes into a single code that handles two-fluid compressible flow with up to three dimensional flow geometries and that can be coupled to a three dimensional reactor kinetics code. Plant-specific code runs can handle up to tens of thousands of discrete fluid volume nodes. Our steady progress in this area is driven by our safety mission and the care we are taking to ensure a very high confidence in the adequacy of these tools. Continuing development of our codes is focused on improving the physical models, such as situations where liquid films and droplets in the same computation volume can move at different speeds and in different directions, and better numerical methods. Since the NRC recovers 90% of its Congressional budget authority from fees we charge our licensees and applicants, we must always ensure there is a legitimate regulatory need for further code development.

In the neutronics and reactor physics arena, in the near term we are looking ahead to define our needs for the possible licensing of the Next Generation Nuclear Plant, and to improve the computational efficiency of our SCALE code. In the long term, there may be a need and interest in higher resolution and three-dimensional visualization tools. As applicants for new plants move toward the use of massively parallel high performance computers to justify adequate safety with less reliance on integral experimental data, the NRC will need to carefully evaluate if this approach is acceptable, and the extent to which experimental data must remain an essential element of code validation.

There may come a time when our computational capabilities and understanding of the relevant physical phenomena are good enough to rely on a "first principles" approach to simulation and modeling. Such calculations would need to demonstrate an improved fidelity to more accurately predict performance than do the current models. As the existing plants continue to age, one area of growing interest for more detailed simulation and modeling is that of material degradation, such as crack initiation and propagation. The NRC will utilize validated computational tools when they are adequate to the task, but we must always act conservatively in consideration of uncertainty, and we expect our licensees to do the same, when such validation does not exist.

In closing, I'd like to re-emphasize my strong belief that we must be guided by facts and data, not just theory and speculation, as we move forward into the future that safely achieves the technological benefits we seek. One of the best expressions of this idea comes from writer Robert Heinlein, who wrote:

> "What are the facts? Again and again and again – what are the facts? Shun wishful thinking, … avoid opinion, [and] care not what the neighbors think, … what are the facts, and to how many decimal places? You pilot always into an unknown future; facts are your single clue. Get the facts!" *

Thank you for your attention.

* *Time Enough for Love*, Robert Heinlein, Ace Publishing, 1973