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MICRO-SIMULATION TECHNOLOGY

September 20, 2002

Subject: **Necessity of Plant Specific Accident Projector**

To Chairman: George E. Apostolakis
Vice Chairman: Mario V. Bonaca

Advisory Committee on Reactor Safeguards

Last Friday (9/13) at ACRS meeting, I was among the public attending the staff presentation that you presided on transient analysis methods. I couldn't agree more that the difference between transient and accident is diminishing and eventually one code should cover all. Although given the opportunity to raise questions, I did not raise in time a crucial suggestion that has recently troubled me exceptionally. Namely, transient analysis codes could progress into a new direction. The technology, as well as the nation's security needs, demand us to move ahead by equipping every plant in this country with a reliable plant specific transient predictor.

In response to a significant incident occurring at a nuclear power plant, the onsite and supporting personnel mostly rely on their individual training and experience to take mitigation actions. Some important judgments are quantitative, e.g. timing to exhaustion of water in the steam generators, core uncovery, or start of dose release. They require quick and reliable computation prior to the eventual consequences. Currently available codes and plant analyzers are not geared for this task. But advancement in both reactor study and computer technology makes it possible to have a plant specific accident projector on-hand to meet the challenge.

Using well-established technical know-how in transient thermal-hydraulics, over the past 17 years we have developed a PC-based plant simulator. As a matter of fact, 15 years ago I was asked to make a presentation to the ACRS including Drs. David Hetrick, David Okrent and Bill Kerr. As a result, the Committee acquired the code for its staff analysts. Recently we expanded the scope to include intentional damage to plants and spent fuel pools. Enclosed is a brief technical description.

We do **NOT** predict the maximum extent of damage - that is the responsibility of NRC, as it has already initiated a study. Instead between the maximum and minimum (zero for no damage), the user will input a failure fraction. For example, users will be prompted to enter an initial containment breach by an aircraft crash, followed by the size of the reactor cooling system piping hole, as well as the number of trains of AC power that remain operational. From that point on, the simulator rigorously calculates all parameters of plant operation and radioactive material release. The user can conduct further mitigation actions, such as getting available firewater system on-line, and their impact will be

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instantly reflected. Modern computer power ensures that this process can be completed many times faster than the real-time. Therefore the analysts can study alternate routes for mitigation and choose the one with least damage.

In addition to accident at the operating plant, the spent fuel pool simulator projects timing to boiling, fuel uncovery, clad fire and dose release. It is now generally recognized that consequence from a pool incident could be worse, since it is less hardened and stored more than the core.

Important findings from the new NRC study can be incorporated into the software so that it reflects the state-of-the-art technology. In addition to use for the response team, normal use in training, emergency exercise or even demonstration to non-technical people are also possible.

We are not promoting just our own product – software technology to convert any detailed transient analysis code to a simulator is well available. But this is the most advanced way to counter a real-life nuclear accident or security breach. Other than security enhancement, the innovative approach is a proactive measure to secure public safety.

In sending this letter with its attachment, it is my hope that you will distribute it to your Committee and related staff. My company has contacted a few utilities about this concept and has gotten positive responses. Some simulator/security system vendors and spent fuel re-racking firms are also interested and would like to participate in its development. I personally would like to have the ACRS informed and receive their comments and guidance. If you are interested, we will be happy to make a presentation.

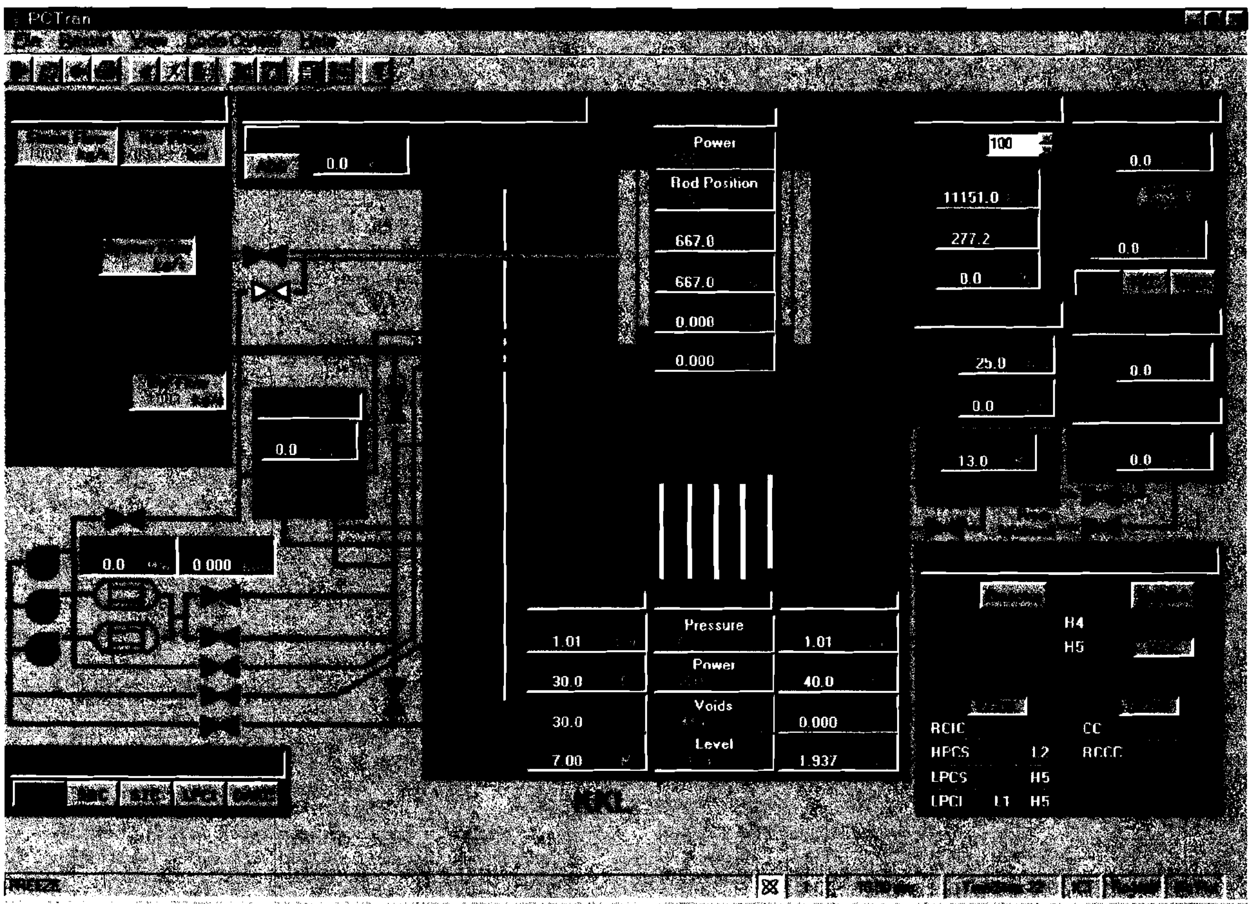
Sincerely,

L. Cliff Po

L. Cliff Po, PhD

PCTRAN© for Accident Simulation

PCTRAN is reactor simulation software specifically designed not only for design-basis accidents, but also security events such as terrorist attack resulting in containment or fuel pool failure. Given the increased concern for such events, PCTRAN can prepare a nuclear power plant's personnel with realistic training and exercise. The Windows-based simulator extends simulation to severe accidents and generates radiological release source terms. Running on a Pentium-based desktop computer, the simulation speed can be either real-time or many times faster. This fourth generation PCTRAN product from Micro-Simulation Technology designed strictly in the Windows operating system environment. Operation is most user-friendly by way of a graphical-user-interface (GUI). All input/output are fully compatible with MS Office and other Windows products.



In the plant mimic, there are icons showing simultaneous containment failure, reactor coolant boundary leak and fuel pool damage. The combined radiological releases contribute to the site boundary dose. It can aid determination of protective actions such as shielding or evacuation.

TRANSIENT SIMULATIONS

Selection of a transient is menu-driven that includes all possible disturbances to a plant such as:

- Normal operation control - startup, shutdown, power ramp
- Loss-of-coolant-accident (LOCA) or steamline break
- Loss of flow, single or two-phase natural circulation
- Turbine trip with or with bypass, station blackout
- Steam generator tube rupture (PWR)
- Feedwater transients
- Anticipated transient without scram (ATWS)
- Damage to containment or spent fuel storage facility (for example, caused by airplane crash)
- Intentional sabotage by terrorist group to cause a reactivity event, fire or loss of diesel
- Any combination of above

PCTRAN is most powerful in its versatile and interactive control. The user can at any time manually trip the reactor or the pumps, open or close a relief valve, override the ECCS or change the set points for a number of the control systems. All transient parameters are available for trending during execution or printed after the run. The data can be saved in Access or Excel files for later usage. The restart capability can virtually extend a transient simulation to indefinite time period.

RMS and Source Term

Available as an option, the extended simulation model keeps track of fission product transport along the major release pathways. Normal and accident condition readings of major area, effluent, and process radiation monitors throughout the plant are displayed in a separate mimic. Iodine and noble gas isotope release source term is calculated periodically. Also available as an option is the severe accident extension to core melt, corium formation and containment failure model. Existing full-scope simulators currently used for training and emergency exercise do not match these capabilities.

AVAILABLE PLANT MODELS

MST has completed the following models in Windows:

- GE BWR 2, 3, 4, 5, 6 and ABWR with Mark I, II, III or advanced containment
- Westinghouse 2, 3 and 4-loop PWR with large dry or ice condenser containment
- C-E PWR's of 2x4 hot/cold loops
- B&W PWR's of once through steam generators
- Framatome PWR's
- ABB BWR's

The above models are "plant specific" with best effort to duplicate the plant's design and performance. Detailed documentation was prepared in modeling methodology and verification against the plant's FSAR and known data. The software has been installed at the government regulatory agencies of US, Japan, Switzerland and Taiwan and over one hundred facilities in the world.

Free CDROM

A full capability demonstration package is available upon request. Please contact

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FREQUENTLY ASKED QUESTIONS

Q1 Can I change the plant design and operational data to make them represent my plant?

A1 Yes. PCTRAN is structured to use Microsoft Access database files for its input. The design parameters such as plant geometry, thermal-hydraulics and reactor physics data, RPS and ECCS set points, and pump and valves characteristics are grouped into data tables. A consistent set has been prepared for a typical plant of the same type as yours. You can easily edit that to fit your plant by either going to the "Edit" button in the menu bar or use Access to edit the input database.

Q2 Can I change the design of the NSSS and radiation monitor system mimics to better fit my plant configuration and layout?

A2 For changes of this scale, you need to acquire the PCTRAN source code license. The source code is written in Microsoft Visual Basic 6. Some knowledge in VB6 is required. In addition, we will set up a one-week training class to help you be fully prepared for complete model modification.

Q3 What kind of documentation and instructions will be provided?

A3 We provide a detailed theory manual and user's instructions. The theory manual covers reactor physics, thermal hydraulics, heat transfer, plant system description and modeling technique. Therefore all transient calculations have a rigorous theoretical basis. The user's manual contains every step in setting up the plant model and performing a specific run. Standard Windows graphical user interface is used for interactive control.

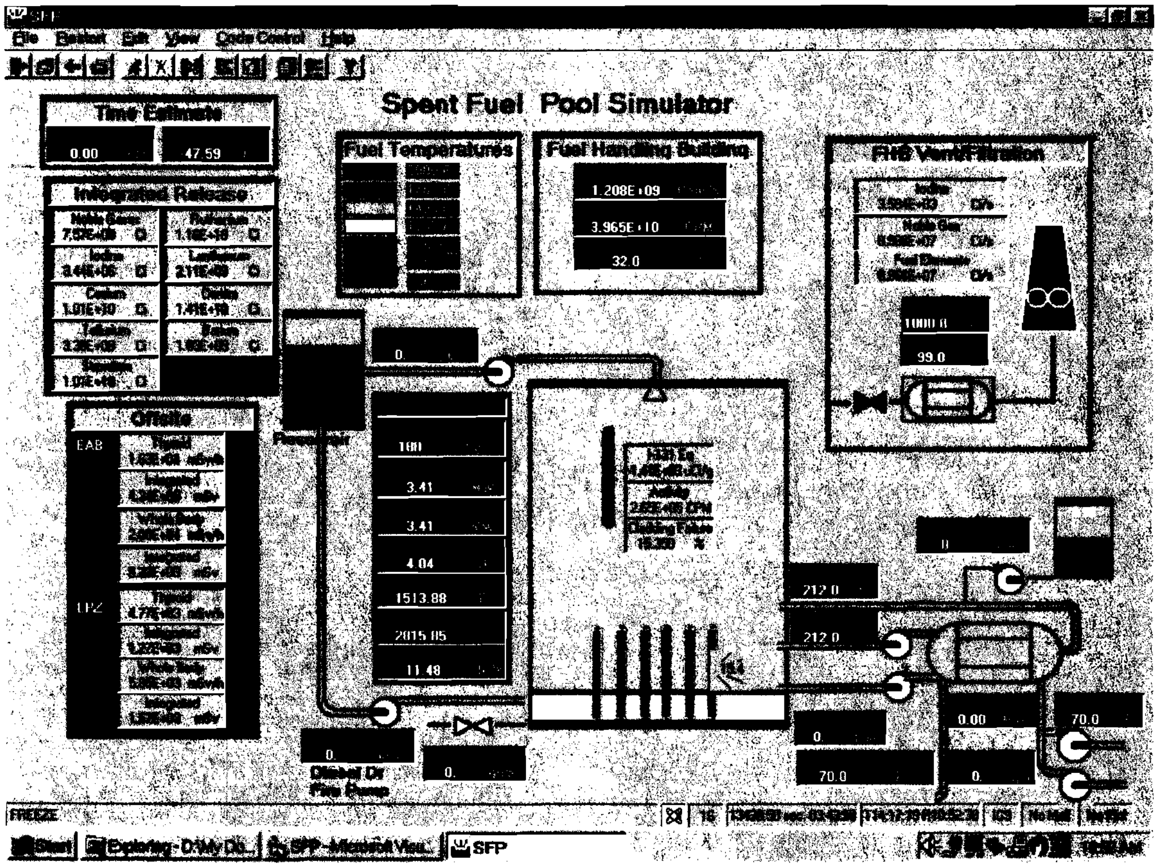
Q4 To what extent have validation and verification (V&V) been performed for PCTRAN and each plant model?

A4 PCTRAN is a product of 16 years experience. For each plant type there is a detailed verification chapter in the documentation. ALL categories of FSAR's chapter 6 (ECCS), chapter 14 (Transient Analysis) and /or chapter 15 (Accident Analysis) for the chosen plant have been benchmarked. Reasonable agreement has been reached in every case.

A PC-based Simulator for Spent Fuel Pool Accidents

- PC Windows-based SFP simulator and analytical tool
- A tool for emergency exercise, training and demonstration to non-technical personnel such as management, politician and public
- Plant Specific in SFP geometry, cooling system, fuel burn-up history and isotope inventory
- For any given drain-down, drop-cask or loss-of-cooling event, instant estimate of pool boiling and dose release time
- Determine the possibility of return-to-criticality
- Selection of high-fidelity real-time or fast-time simulation
- Calculate zirconium fire and steam interaction rate
- Prediction of clad burst, fission product release timing and pattern
- Comply with NUREG 1738 (SFP accident), 1465 (Revised Source Term), etc.
- Project release isotope strength and site boundary doses

- Provide radiation monitor readings according to shielding and volatile material discharge
- Choice of makeup by diesel pump, firewater hose, spray, etc.
- Decision in either promote air cooling to prevent a zirconium fire or block it to extinguish the fire
- Decision of protection action or evacuation



In a conversation with emergency preparedness personnel in the U.S. northeast, a concern about terrorist attack to the spent fuel pool (SPF) was raised. This is a more realistic threat and would cause greater harm than the event, e.g. aircraft crash into the containment. Since the SFP building is not as strong as the containment, and it stores perhaps 4 times more radioactive materials.

The event of a spent fuel pool draining or evaporation followed by zirconium fire has been analyzed. USNRC report NUREG –1738 titled "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants" was published prior to 9/11 (in February of 2001). This type of events could also happen at plants in operation. A few years ago, a loss-of-cooling event at one US nuclear plant heated up the area floor to the level of "melt the rubber boots". It has resulted in a harsh penalty from the NRC.

Current concern of a so-called "dirty bomb" indicates that a weapon that would disperse radioactive elements may become a weapon of choice for terrorists. As EP professionals, we may want to think hard about how to prevent and mitigate this from happening

PCTRAN/SPF will conduct thermal-hydraulic and radiological calculations for a loss of cooling event. All modeling is plant specific – considering the pool inventory of cycle burn-up, geometry, and cooling system design. The time to bulk boiling could be as short as a few hours. Then it takes days to boil off and uncover the fuels. A heavy load drop such as the casks may crush the fuels and add sufficient positive reactivity to reach criticality. The simulator can make either accelerated run for practical exercise purpose or even instant projection and "jump" to the degraded state You can simulate an intentional drain-down or earthquake caused structure damage event by opening a drain valve at the bottom of the pool (of course, there is no such valve in the actual pool). According to the NUREG, it takes 2 to 40 hours to heat the fuel to 900°C. This again, will be simulated in a fast pace for training or exercise. During this course the fuel clad will swell and burst. The breach in the clad releases radioactive gases present in the gap. Later when it reaches the point of rapid oxidation in air or steam, this reaction is exothermic (i.e. produces heat). The energy released from the reaction, combined with the fuel's decay heat, can cause the reaction to become self-sustaining and ignite the zirconium. The fire would result in a significant release of the spent fuel fission products, dispersing them from the reactor site. The dosage could cause up to hundreds of early fatality in the worst-case scenario. PCTRAN/SPF will reproduce all these quantitatively.

In the PCTRAN/SPF mimic for a typical SPF shown above, there is a circulation cooling system with heat exchangers relieving the decay heat to the environment. There are regular makeup pump and emergency diesel-driven firewater pumps. Simple point-and-click will disable or enable any of the functioning components or systems. When the fuels are exposed and heated up, their temperatures will be indicated in color. In addition to fission gases in the gap, damaged fuel aerosols such as alkali metals, tellurium, barium, cerium, lanthanides, etc. will be traced. We will use NUREG –1465 "Accident Source Terms for Light Water Power Plants" for the release mechanism. Their contribution to the Fuel Handling Building radiation monitors and release path through the vent and wall leakage will form the site boundary doses.

As compared to typical nuclear power plant accidents, a SFP accident is slow in its evolution. A loss of cooling takes days to evaporate the pool water and hours to heat-up to the point of burning. However, it could become fast-paced following a catastrophic earthquake or intentional sabotage. During the course, should water supply be resumed anytime, it will mitigate the consequence. One possibility is that either by administrative error or intentional sabotage, if fresh water rather than the required borated water is used, reduction of pool boron concentration may cause a return to criticality. Another consideration is that when water level reaches 3 feet above the top of the fuel, the radiation level may become high enough to prohibit human access. The simulator also provides radiation monitor readings in the neighborhood. Using the tool for training or exercise will give the staff a quantitative feel and realistic appreciation of the event. Should an event occur in real life, the tool can make instant and precise projection of the timing to pool boiling, fuel uncovery and dose release. It is practical for determination of protective actions such as notification, shielding and evacuation.

Quiz on Spent Fuel Pool Safety/Security

1. If you lose the spent fuel pool (SFP) cooling system, how long does it take approximately to heatup and boil off the pool inventory to critical level? Assuming your last fuel discharge is pretty recent (a few months ago)
    a. A few hours
    b. A few days
    c. A few weeks
    d. A few months
2. What does the "critical" level mean? And how is it defined?
    a. When the pool water starts boiling
    b. Water level drops to 3 feet above the fuel and the radiation level in the area becomes inaccessible to people
    c. Water level is at the top of the fuel
    d. The pool is boiled dry
3. Is a catastrophic earthquake or heavy load drop possible to drain the pool rapidly (than boil-off by loss of cooling)?

Yes/no

4. Is return-to-criticality by a cask drop at a SFP possible?

For PWR yes/no

For BWR yes/no

5. What is the likely consequence for a return-to-criticality event for a light water reactor's SFP?
    a. Catastrophic explosion, Chernobyl type consequence
    b. Sudden neutron flux increase, fatal dose to people in the neighborhood
    c. Localized and limited damage to affected assemblies
    d. Self-regulating, criticality will not last long
6. After water level drops to the critical level and without cooling, how long does it take for the fuel clad to heat up to release radioactivity? In the order of
    a. Minutes
    b. Hours
    c. Days
    d. Weeks
7. When the fuel cladding zirconium is heating up, what chemical reaction is likely to happen?
    a. Zr – water (steam) reaction to generate hydrogen and turn into zirconium oxide
    b. Oxidation with air and become zirconium oxide (zirconium fire)
    c. Both a and b if water (steam) is present
    d. No reaction
8. The oxidation process is
    a. heat absorbing and will not ignite
    b. Exothermic (heat releasing) and may become self-sustaining
9. Maintain ventilation in the building will help zirconium surface cooling and prevent zirconium fire. True/false

10. After zirconium fire is taking place (at temperature > 1600F), maintaining ventilation in the building will fuel the fire. True/false
11. Consequence for a worst case SFP accident is likely to be
    a. More severe
    b. Less severe
    c. Comparable

to that of a operating power plant

12 The instant death estimate for the worst case SFP release is in the order of
   a. 10's
   b. 100's
   c. 1000's
   d. 10,000's

13. The late (cancer) death estimate for the worst case SFP release is in the order of
    a. 10's
    b. 100's
    c. 1000's
    d. 10,000's
14. The late cancer death is mostly due to the radioactive release of
    e. Noble gases
    f. Iodine
    g. Cesium 137
    h. Ruthenium 106
15. Taking potassium iodide (KI) will block further absorption of the following radioactive isotopes in the thyroid
    i. Noble gases
    j. Iodine
    k. Cesium 137
    l. Ruthenium 106

PCTRAB/SFP *will provide not only the answers for the above qualitatively (yes/no or a, b, c etc),* ***but quantitatively*** *the important timing and values for practical use. To ask for a live demo, please contact MST.*