State of New York)
County of New York):

STATEMENT OF DR. MICHIO KAKU
CONCERNING SPENT FUEL POOL BOILING

My name is Dr. Michio Kaku. I am an associate professor of theoretical physics at the City College of the City University of New York, where I have been teaching for the past 8 years. Prior to this position, I was a Lecturer on the faculty at Princeton University.

INTRODUCTION

I have read the contention concerning spent fuel pool boiling at Big Rock and the statements submitted by Mr. David P. Blanchard, Raymond F. Sacramo, and Daniel A. Prelewicz.

I find the results of the latter three parties interesting, but unfortunately rather irrelevant to the discussion on spent fuel pool boiling. None of them address the crucial question: what would happen to the spent fuel pool if the water boiled off and an explosion were to take place (given sufficient generation of hydrogen gas by the oxidation of zirconium).

These parties state that it would take about a month to boil off the water in the spent fuel pool but that make-up water could be added in time. At TMI, however, the containment (2½ years after the accident) is still largely inaccessible to maintenance and repair crews. Only now are we even beginning to process the 700,000 gallons of water on the basement floor with zeolite Epicor II demineralizers.

It is not out of the question to postulate that a malfunction will take place in the make-up water piping, in the same way that many of the systems malfunctioned at TMI.

Then we must ask the crucial question: will the exposure of the rods result in high enough temperatures (about 1100^0 C) to result in metal-water and metal-air reactions in the racks of fuel rods? As we know, about 50% of the zirconium oxidized at TMI, resulting in a pressure peak of 28 psi within the containment, so these are not academic considerations. Given the fact that zirconium is quite flammable (in fact, an incindiary under certain conditions) and given the fact that zirconium fires have taken place in the past, it is prudent to ask these questions.

The question that must be asked, from a scientific point of view, is whether a simple computer calculation should be done to duplicate the conditions in a boil-off. The calculations involve only second order partial differential equations, and can be done within a few months at the maximum by any physicist.

The calculation is in several steps, and I think is scientifically worthwhile:

1) After boil-off, we must calculate the maximum heat and temperatures within the racks. We must know several parameters: the exact three-dimensional geometry of the racks, the rate (kilowatts/foot) generated by the racks which drives up the temperatures, the heat losses in the air and concrete and other convection and conduction effects.

To begin, we must divide up the entire pool into a fine mesh of lattice points so we can iteratively solve the standard Fourier equation:

$$k \nabla^2 T + S(x,y,z,t) = \rho c(x,y,z,t) \frac{\partial T}{\partial t}$$

where k = thermal conductivity (Btu/ft)/(hr ft^2 ^{o}F), T = temperature, ^{o}F S = source strength, Btu/hr ft^3, rho = density, ft^3/lb, t = time, hrs, c = specific heat, Btu/lb^{o}F.

Of course, the specific heat will vary with a function of space, depending on the thermal properties of the concrete, fuel rods, racks, air, etc., and we must correctly put in the source terms (which may be time dependent and actually vary along the length of the rods).

Notice that the equations are not steady-state, but are designed to calculate the rate at which the temperatures will rise in the racks.

2) We must be careful of dissipative effects, which will modify the above equation. Most important are the convection terms, which depend on the circulation of air within the racks. Also, if there are remaining pools of water in the pool, they will also contribute to convection effects.

3) We must add in radiative effects, proportional to T^4, which are also dissipative.

4) We must include conductivity effects of the concrete, which are also dissipative.

If heat flux and temperatures are high enough, we must include the effects of transitions from nucleateboiling to film boiling and even steam binding. DNB effects may be important, depending on the thermal boundary conditions, because they may prevent the dissipation of heat in boiling.

This calculation should be done in three-dimensions. Many of the calculations in thermal-hydraulics are done in two-dimensions, and they are also highly speculative. A full three-dimensional calculation will accurately simulate a real boil-off.

Once this computer calculation is done, then the real test is to see if the temperatures can rise above 1100° C. At this point, the metal-water reaction begins, and at a few hundred degrees higher the effect becomes auto-catalytic, i.e. the reaction is exothermic and actually feeds off itself. At some point, a conflagration may actually start because of auto-catalytic effects on the metal-water reaction.

At this point, we must now calculate the maximum explosive energy that can be released by detonating the hydrogen gas. We will assume that there are sources of sparks in the containment (such as spark-operated switches) which will ignite the hydrogen gas.

Unfortunately, reliable mathematical models for hydrogen gas explosions do not exist, but we can reasonably approximate a hydrogen gas burn by using either the idealized constant volume adiabatic combustion model, or the one-dimensional Chapman-Jouquet detonation model. The latter calculation will probably yield more megajoules of energy than the former calculation.

Then we must compare the maximum energy yields from this calculation against the maximum breaking strengths of the containment structure. As is well known, a modern 1,000 megawatt PWR can withstand static internal pressures of 60 psi, and can probably even handle as much at 100 psi. BWR, of course, can only withstand a fraction of that pressure. Such is the nature of small-volume containments.

Unfortunately, I do not know the strength of the containment at Big Rock, but because it is an earlier design, it is safe to say that the breaking strength of the containment is only a fraction of that found for a modern 1,000 megawatt PWR. Thus, it is not an academic question of how much energy can be released by a hydrogen gas burn or detonation within the containment. (For example, it is acknowledged by the NRC's Rogovin Report on TMI that a 28 psi pressure peak that occurred within the dome probably would have ruptured the dome if the reactor had been a Mark III GE reactor or a Westinghouse ice-condenser model, where we find ratings of as low as <u>10-15 psi</u>.)

In addition, even if a hydrogen gas burn or explosion does not take place, we must still calculate the static pressures being generated within the

Short Biography

Graduated from Harvard Univerity, 1968.

Summa Cum Laude, Phi Beta Kappa, 1st in his graduating physics class.

Received Ph.D. from the Univ. of Calif. at Berkeley in 1972

Lecturer at Princeton University in physics, 1972-3.

Presently Assoc. Prof. at the City College of the City University of N.Y.

Published about 35 papers in various areas of theoretical physics: nuclear physics, unified field theories, hadron interactions, general relativity, etc.

Contributed to five books on physics.

Recently (1981) elected a Fellow of the American Physical Society.

Specialties include: neutron transport theory, reactor physics, modeling of ECCS systems, unfified field theories, supergravities, strong interactions.

Spoken at many international physics conferences: e.g. 1978, Moscow, as a guest of the Soviet Academy of Sciences; 1977, Caracas, Venezuela; 1981, Cambridge University, England, as an invited speaker on null field dynamics.

A complete list of professional physics publications can be made at request.

containment. At TMI, we came 30-60 minutes of melting at least half of the core. A breach of the reactor vessel would have resulted in large pressures within the containment. Added to these pressures, we must now include the pressures caused by the spent fuel pool:

1) steam pressure caused by the vaporization of the pool.

2) additional pressure caused by hydrogen gas

3) additional carbon dioxide gas generated by the slow disintegration of concrete as temperatures rise within the pool.

All three of these contributions must be calculated in the event that static pressures rise to above the rating of the containment structure.

Conclusion

In this document, I only want to show that the crucial calculations involved in the contention have not yet been done. These calculations are not hard, but they do take a certain amount of serious thought in order to mathematically duplicate the most realistic conditions of a hydrogen gas burn or explosion. Any competent physicist, given a few months of work and a computer, can do the calculation.

The calculation has not yet been done. The calculation lies at the very heartof the contention, so therefore I strongly urge that it be done. All the doubts can never be laid to rest until this calculation is performed (and performed accurately in three dimensions).

A spent fuel pool contains enormous quantities of radiation. Like a nuclear core (which contains 10 billion curies of radiation), there is a very small probability that a very large disaster can take place. It is worth calculating the effects of such a large disaster, no matter how small the probability, as long as the initiating scenario has merit.

Dr. Michio Kaku

Michio Kaku

Sworn to before me this 17th day of February, 1982

Notary Public, State of New York

CERTIFICATE OF SERVICE

I certify that copies of the foregoing Statement of Michio Kaku Concerning Spent Fuel boiling were served on the attached list on the 9 day of March, 1982 by delivering copies to the office listed thereon or by U.S. mail, first class postage prepaid.

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