DEPARTMENT OF MECHANICAL ENGINEERING
THE UNIVERSITY OF TEXAS AT AUSTIN

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December 16, 1999

Nuclear Regulatory Commission
Attn: Document Control Desk
Washington D.C., 20555

Subject: Report on Technical Specification violation at The University of Texas

Reference: The University of Texas Reactor License, Docket 50-602

Dear Sir:

Attached is the required written report explaining the circumstances of a violation of Section 3.4.2.c, Limits on Explosive Materials, in the license Technical Specifications. The Nuclear Engineering Teaching Laboratory is continuing to investigate corrective methods and will inform the NRC and request review prior to taking final actions.

Please contact me if you require additional information at 512-232-5373.

Sincerely,

Sean O'Kelly
Associate Director

Attachments

cc: A. Adams, NPR Project Manager
S. Holmes, NPR Inspector

IE01

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The Nuclear Engineering Teaching Laboratory (NETL) at The University of Texas at Austin reported a violation of the facility license Technical Specifications on December 2, 1999.

The ultimate cause is believed to be an extremely small leak that developed or was present from the date of manufacture in a weld of the NETL TRIGA Reactor Reflector. The Reflector is an annular, machined block of graphite canned or encapsulated in 0.25 to 0.5 inch welded Alloy 6061 aluminum. The welds are tested using dye penetrant and helium leak tests during manufacturing. The weld and approximate leak location is shown in Figure 1.

The first indication of the problem was bulging or swelling of the Reflector as indicated by movement of the Rotary Specimen Rack (RSR) drive shaft upwards approximately 0.25 inch and noted in late October. Measurements were taken and confirmed the top of the Reflector had apparently moved upwards. Other measurements taken confirmed that the pool floor and neutron beamports had not moved. The Reactor Safety Committee was informed during a scheduled meeting of the unusual conditions.

A Pneumatic Transfer Tube was found stuck in the outer ring of the reactor grid plate, but was eventually removed. Visual inspections indicated a bulging of the inner wall of the Reactor Reflector had caused binding of the experimental device. Further inspection revealed obvious bulges or swelling of the large plates forming the inner wall of the Reflector. Four non-fuel graphite elements were also found to be binding. The locations of the graphite elements, pneumatic tube and approximate bulges locations are shown in Figure 2. The NRC and General Atomics (GA) were notified of the unusual circumstances and the continuing investigation.

Several possibilities for the cause were considered

1. **Galvanic Corrosion.** GA hypothesized that galvanic corrosion was causing the swelling. An individual at GA was involved in investigation of galvanic corrosion within a Thermal Column at a Japanese reactor several years ago. The Thermal Column is similar to the reactor reflector because it is typically a graphite block in an aluminum housing or can. In the electrochemical reaction the graphite is the cathode and the aluminum is the anode. The production of alumina (Al_2O_3) with a lower density and higher volume could theoretically produce bulging of the Reflector. The reaction requires an electrolyte to provide the conduction path. In general, solutions with high chloride (sea water in particular) or oxygen greatly enhance the corrosion rate. Graphite rubbed or smeared on aluminum has been found to cause pitting in the presence of water but not gross corrosion.

   The galvanic corrosion at the Japanese reactor was not caused by water leaking from the reactor pool, but an indirect leakage path through a crevice in the concrete pool structure. It would be expected that water seeping through cracks in concrete might have a high conductivity and large chloride concentrations. This is believed to have lead to the large amount of corrosion found in the Thermal Column at the reactor.

   The water used in a reactor pool is essentially deionized water with extremely low conductivity. The NETL staff believed that the low conductivity would prevent gross galvanic corrosion but also reasoned that the amount of bulging would require the 0.25 inch aluminum walls to be nearly corroded away. Ultrasonic testing of the Reflector later confirmed that the aluminum plates were the correct thickness with no indications of large-scale galvanic corrosion.

2. **Growth of the graphite Reflector due to irradiation or heat**. All graphite vendors contacted and ORNL verified that growth of the graphite from temperature would be insignificant as compared to the aluminum and it would require very high radiation exposures (much greater than obtained from a 1 MW TRIGA) to produce significant swelling.

3. **Structure sagging or failure under load.** Rejected based on indications of uniform bulges and upward expansion of the upper Reflector surface.

4. **Off-gassing from unknown material.** It was suggested that an artifact or object remaining within the Reflector or graphite during manufacture could produce gases that would cause swelling. GA assured NETL that there was nothing in the Reflector but graphite during manufacture.

5. **High heat buildup in an experiment.** GA suggested that an experiment device could absorb radiation energy and radiate the energy off as heat causing local high temperatures and heat damage to the surrounding Reflector. This was rejected because the swelling and bulges were not a localized phenomenon and in some cases were not near an experiment location. The temperatures required would have been difficult to obtain because of the high thermal conductivity of the aluminum, graphite and cooling water.

6. **Flooded Reflector**. Expansion of noncompressable materials at reactor temperatures could possibly cause the pressures necessary but it was expected that the pathway that allowed flooding would also allow pressure relief. Ultrasonic testing did not indicate a discernable water level in the Reflector. Flux measurements in Beam Ports did not indicate severe losses of neutrons due to absorption.

Repeatable (in size and location but spread in time) bubbles were eventually noticed while unloading the fuel from the reactor at a rate of one per 1.5 hours. At this point it became clear there had been a failure of the Reflector outer boundary producing a leakage into the system and gas venting. Plans were made for draining the reactor pool and installing a continuous vent or purge system to compensate for the leak. It was hoped that the Reflector could remain dry and not compromise the Reflector characteristics or several experiment locations.

Several bubbles were captured in a funnel and flask system to determine the gases in the Reflector. The first test was a crude flame test to see if the gases would ignite. The gas sample blew out a flame with no indications of combustion. Several more gas samples were captured to determine the leak rate (~30 ml/hour) and for analysis. One sample was checked with a toxic gas meter (used for entering confined spaces) and indicated high concentrations of Hydrogen, Oxygen and Hydrocarbons when the meter pegged off scale, but the concentrations and components eventually determined with the meter were inconclusive. Two samples were sent to a local company (TRI in Austin) on 11/30/99 for Gas Chromatography and to the UT Chemistry department for Mass Spectroscopy.

The Gas Chromatography results were

Hydrogen	Nitrogen	Oxygen	Carbon Dioxide	Methane	Carbon Monoxide
64%	5%	30%	920 ppm	16 ppm	245 ppm

NETL staff concluded that the mixture was explosive and the total volumes exceeded the limits allowed by Technical Specification 3.4.2.c, Limits on Experiment Materials. The Specification states

> Explosive materials in quantities greater than 25 milligrams shall not be irradiated in the reactor or experimental facilities. Explosive materials in quantities less than 25 milligrams may be irradiated provided the pressure produced upon detonation of the explosive has been calculated and/or experimentally demonstrated to be less than the design pressure of the container.

Gas Volume was calculated to be approximately 41 liters by simple subtraction of the apparent graphite volume from the volume of the aluminum housing. The pressure in the Reflector was assumed to be in equilibrium with the pressure of the tank (20 feet depth) at 1.6 atmospheres. This yielded, by the Ideal Gas law and the above analysis, approximately 4 grams of hydrogen. The change in enthalpy for the reaction of hydrogen and oxygen to produce liquid water is –286 kJ/mole which was divided by two to consider hydrogen as the only reactant. Finally, the conversion of 104 joules per 25 mg of TNT was taken from the NETL SAR and Technical Specifications.

$$\frac{\text{(4 grams Hydrogen)(143 kJ/mole)(1mole Hydrogen/1 gm)}}{\text{104 joules/25 mg TNT}}$$

The result was an initial calculation that indicated the NETL had exceeded the 25 mg explosive limit by at least 5500 times. The amount of gas and the violation were reported to the NRC.

Later calculations resulted in higher pressures to account for the deformation of the aluminum Reflector. Dr. Karl Frank of the UT Department of Civil Engineering calculated it would take approximately 200 psi to cause the displacements in the 0.25 inch aluminum plate. Calculations using this pressure and an equivalence provided by a 1987 EPRI report on Hydrogen Water Chemistry (1000 scf H_2 = 27.1 lbs TNT) would make the total Hydrogen explosive material to be 6203 times the 25 mg limit or 155 gms of TNT.

Heat of Combustion of H_2 and TNT

Substance	Formula	Molecular Weight	MJ/mole	MJ/kg
Hydrogen	H_2 (gas)	2	0.244	122.051
TNT	$C_7H_5N_3O_6$ (solid)	227	3.4363	15.138

From "Handbook of Chemical Engineering" by Publishing House of Chemical Industry, China 1989

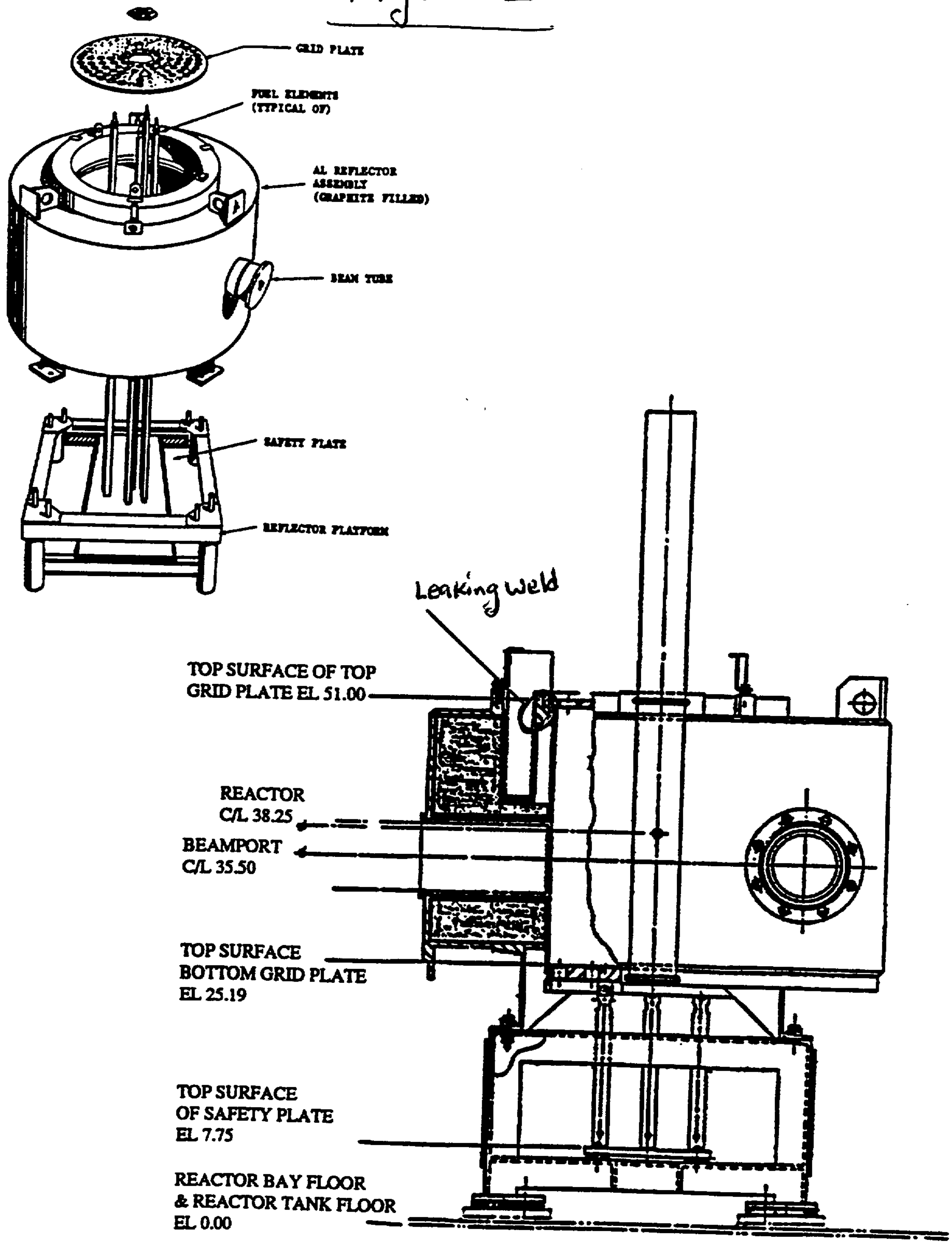
Note: Heat of explosion for TNT is 4.187 MJ/kg

The NETL staff believes the risk of a detonation of the H2/O2 mixture in the Reflector's present condition is slight. There are no ignition sources present in and around the Reflector and the reactor area has been placed off-limits to personnel not involved in evaluation or repair operations. The reactor core had been unloaded for visual inspections and will remain unloaded until the condition is corrected and permission given to return to normal operations. The fuel and the Cobalt-60 irradiator will be removed from the reactor pool and temporarily stored to avoid lengthy safety reviews and evaluations while attempting to correct the Reflector condition.

The NETL has been consulting with various experts in hydrogen, gaseous fuels and explosives to determine the best method of venting the flammable gases. At this time, it is believed that a controlled venting of the internal gases by slowly drilling or piercing the aluminum container is the most likely means of correcting the present conditions.

The NETL intends to complete the removal and storage of reactor fuel and the Co-60\ irradiator before December 23. A review package will be prepared and submitted to the NRC and the UT Reactor Safety Committee on the method of venting the reactor Reflector and the intentions to continue reactor operations with a flooded Reflector. Replacement or repair of the Reflector will be deferred to a later date to expedite the return to reactor operations to complete student and faculty projects.

Figure 1

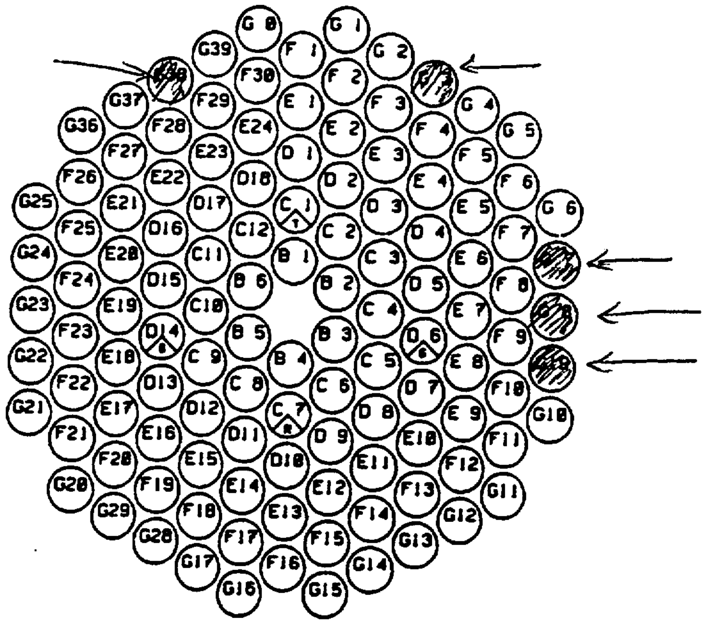


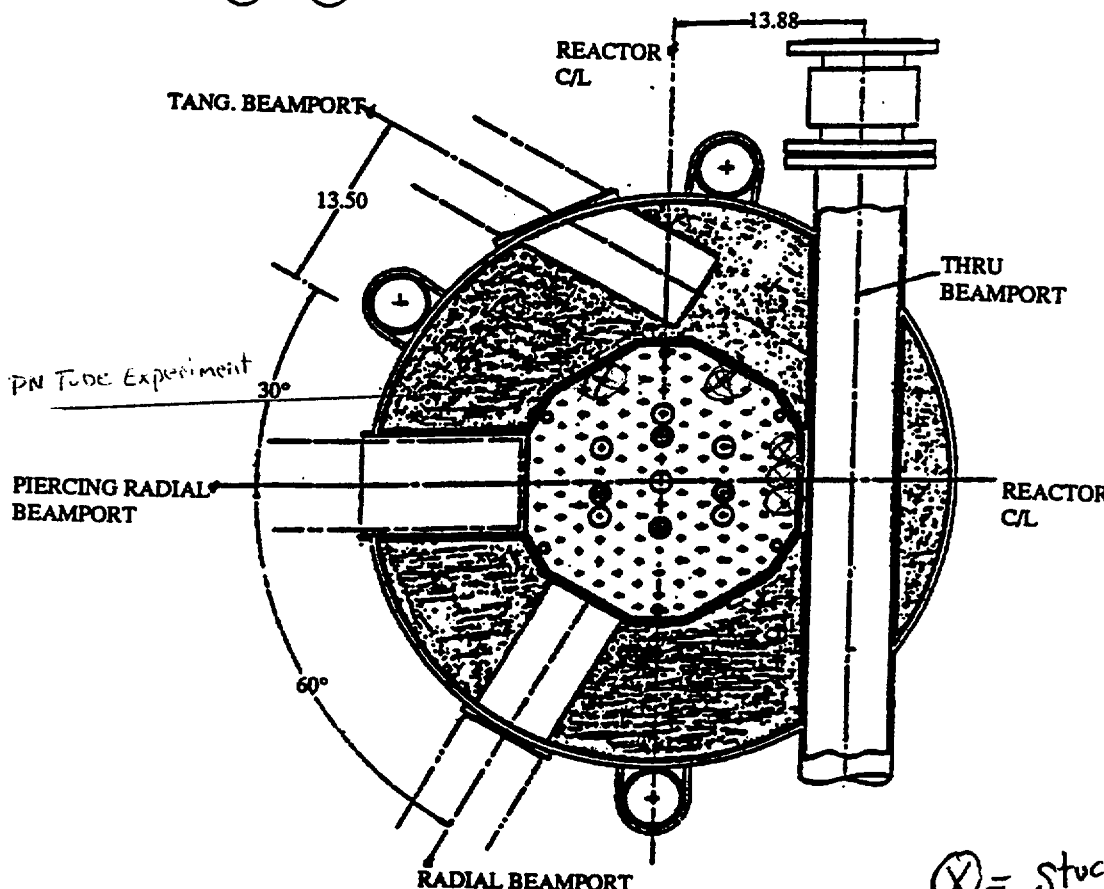
TRIGA reactor - elevation view

REACTOR, REFLECTOR, AND SHIELDING

Figure 4-25

Figure 2





Ⓧ = stuck element or device

TRIGA reactor - cross section through beamports

CORE ARRANGEMENT

Figure 4-27