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Summary of Two Criticality Accidents at the Russian Research Center "Kurchatov Institute"

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INTRODUCTION

Since the early 1950's, the Russian Research Center "Kurchatov Institute" constructed numerous facilities to study critical parameters of reactors. Over the lifetime of these facilities, two criticality accidents occurred; the first on February 15, 1971 and the second just a few months later on May 26, 1971. While these two accidents are typically classified as "reactor" or "critical experiment" accidents rather than "process" accidents, they provide valuable information to the spent fuel operations at the Idaho National Engineering and Environmental Laboratory (INEEL).

The primary criticality accident scenarios for the storage basins at the INEEL are those that occur as a result of over batching. While any such accident would be well shielded and would not result in a significant radiation exposure to nearby workers, it is important to know the bounding energy release that would result. The information from the following two accidents will help accident analysts make reasonable estimates of bounding values.

CRITICAL ASSEMBLY ACCIDENT February 15, 1971

Experiments to evaluate the relative effectiveness of iron and metallic beryllium as a reflector on a power reactor core were in progress at the critical experiment facility, SF-7. The core measured 1200 mm high and 1000 mm in diameter and held 349 fuel rods. Criticality was obtained by adding water to the core and immersing the fuel rods. The safety rods consisted of a lattice of boron carbide rods that could be inserted throughout the core to compensate for the operative reactivity margin. The boron carbide lattice did not cover the three outer rows of fuel rods. The fuel rods were enriched to about 20% ^{235}U (typical of icebreakers).

The first stage of the experiment consisted of a core configuration in which the neutron flux was non-uniformly distributed along the core radius. Measurements showed that the completely water flooded core with the boron carbide safety rod lattice inserted was deeply subcritical (~10%) and the reactivity increased slightly (+0.8%) after substituting the iron side-reflector with a beryllium side-reflector.

The second stage of the experiment consisted of a core configuration in which the neutron flux was uniformly distributed along the core radius. One hundred forty-seven fuel rods with the maximum loading of burnable neutron absorber were inserted into the central part of the core that was covered by the poison safety-rod lattice. Two rows of rods (118 rods) containing less absorber were then inserted. The periphery row (84 rods) did not contain burnable neutron absorber material.

The second stage of the experiment, according to the plan, began with the beryllium reflector in place because it was in place at the end of the first stage. However, criticality calculations for this core configuration were performed only for an iron reflector. Based on results of the comparison between beryllium and iron reflectors for the first configuration, the head of the experimental team, D. A. Mastin, determined that substituting iron with beryllium would not result in any considerable increase in reactivity. Therefore, the additional calculations were not performed.

The core configuration with the beryllium reflector was assembled in the dry critical facility tank and left for the night. The next morning D. A. Mastin entered the facility control room (see Figure 1) and without waiting for the arrival of the control desk operator and the controlling physicist, switched on the pump and began adding water to the critical assembly tank. D. A. Mastin considered the system to be far from critical. The control equipment was switched on but the neutron source had not been placed in the critical assembly and the control rods were not actuated.

R. A. Lednev, a scientist from Gorky who was training at the SF-7 experimental facility, arrived and was standing near the critical assembly tank discussing the experiment with D. A. Mastin. Suddenly they saw a blue luminescence reflecting from the ceiling and heard a rapidly increasing signal from an audible neutron flux indicator. They thought that something had happened in another facility and ran from the critical assembly room. Other workers who were in the room also left. The manager of the facility, N. A. Lazukov, was informed of the event. N. A. Lazukov and a dosimetry technician tried to enter the room to drain the water out of the critical assembly tank but the radiation levels and the steam that filled the room made it impossible to approach the control desk. The pump had continued adding water to the tank. After five to seven minutes, the electricity supply was shut off at the substation and the pump ceased.

Later assessments showed that about fifty pulses occurred. Since the neutron source was not in the critical assembly the core reached critical on prompt neutrons, a fast pulse occurred, water boiled and splashed out of the tank, and the chain reaction terminated. When the water was pumped to the critical level the process was repeated. Total energy release was ~2×10^{19} fissions (~640MJ) with each event averaging about 5×10^{17} fissions. The rate of reactivity insertion was comparatively small (~0.15 β_{eff}/second) so the fuel rod cladding did not rupture and the room was not contaminated.

Three days later the water level was measured and found to be 560 mm from the core bottom and the lattice was flooded. The difference between excess reactivity margins for a core with iron and beryllium reflectors was ~10%.

D. A. Mastin and R. A. Lednev were injured during the accident. They each received ~1500 rem to their feet. Other personnel in the room were behind shielding and received much smaller doses.

The two major causes of this accident are as follows:

1. An inaccurate determination was made that the reactivity worth of the beryllium reflector (calculations had not been performed) was essentially the same as the iron reflector (calculations had been performed).

2. Serious violations of SF-7 operating requirements occurred.

   - Action that could change the core reactivity should have been considered an experiment. The addition of water was an obvious change to the core reactivity and should not have been initiated without a full operating crew (scientific leader, controlling physicist and the control desk operator).

   - Before initiating the experiment (adding water) all control equipment should have been tested, the neutron source should have been introduced into the core and the safety rods should have been inserted.

   - Any reactivity addition should have been done in a "step-by-step" fashion. The function, 1/M, should have been plotted and extrapolated to the critical value after each step.

CRITICAL ASSEMBLY ACCIDENT May 26, 1971

An experimental program to measure the effective critical masses formed by a certain type of highly enriched (~90% ^{235}U – the rods were very similar to those described in Reference 1) fuel rods was in progress at the experimental critical facility, SF-3. The critical number of fuel rods at various hydrogen-to-^{235}U atomic density ratios (ρ_H/ρ_5) was being determined. This ratio was changed by varying the pitch of the fuel rods within the lattices while preserving the hexahedral form of the cell. The table below gives the lattice pitch value and the corresponding number of rods, N. The table shows that the critical number of rods decreased abruptly in the 7-9 mm pitch range.

Pitch, mm	7.2	9.5	11.5	14.4
N	1790	590	370	260

Efforts were made to make the experiments as clean as possible, with minimum perturbations in the system. The assembly consisted of a 20-mm-thick Plexiglas® base plate, which supported the weight of a lattice of fuel rods, and 2-mm-thick aluminum plates used to hold the end of the rods in position. Plexiglas® was chosen since its' hydrogen content is similar to water. The guiding devices for emergency protection and control rods were placed into the lateral reflector. The rod endings projected above the upper lattice ~2-3 mm. The construction was quite delicate and fragile.

For each lattice pitch, a system containing considerably fewer rods than the estimated critical number, was assembled in the dry critical assembly tank. This system was then flooded with water and reactivity measured until the water reflector above the rods was no less than 20 cm. Fuel rods were added, a few at a time, until the system became critical. Procedures were followed in a "step-by-step" fashion and the function, 1/M, was plotted and extrapolated to the critical value after each step.

In the last experiment, the critical number of fuel rods with the smallest pitch (7.2 mm) was measured. This number was 1790 and exceeded the minimum critical number of rods for an optimum pitch by approximately seven times.

After the experiment was over, the head of the experimental team, B. Erofeev, ordered the insertion of all control and emergency protection rods and the neutron source was removed from the core. Four staff members entered the critical assembly compartment for examination. Erofeev then ordered the water be removed through the fast dumping (emergency) valve.

The water from the critical assembly tank could have been drained through the slow dumping valve in 15 to 20 minutes or through the fast dumping valve in 20 to 30 seconds. During the previous experiments, the water was drained through the slow dumping valve.

The Plexiglas® support plate almost completely covered the tank section and the size of the gap between the plate edge and tank wall was less than the size of the fast dumping valve outlet. For this reason, upon initiating the fast dumping operation, the Plexiglas® base plate sagged and the fuel rods fell out of the upper lattice plate (see Figure 2). The fuel rods fell into a fan-shaped array in which the pitch between rods came close to optimum and the lattice went critical. The rate of reactivity insertion was calculated to reach ~ 2 βeff/second.

During the criticality accident, two periphery rows of fuel rods were destroyed by the energy release. Fragments of these fuel rods resembled welding rod fragments. Water splashed out of the tank.

The integral energy release in the flash, estimated from the core radioactivity, was $\sim 5 \times 10^{18}$ fissions (~160 MJ). This value is, in all probability, universal for uranium-water systems in an open tank under conditions of rapid reactivity insertion. The chain reaction stops either because of fuel destruction or because of loss of water.

Radioactive contamination of the critical assembly room was minimal and there was no contamination of the outer premises, however the accident consequences were tragic for the personnel involved. A technician, I. I. Vasil'ev, who was close to the tank when the pulse occurred, received a dose of ~ 6000 rem and died five days after the accident.

V. Erofeev received a dose of 2000 rem and died in 15 days. Two other staff members inside the critical assembly room received doses of 700-800 rem. Physicians managed to save their lives but not their health.

The construction of the critical assembly was the main cause of the accident. No calculations were performed for the components of the system and the construction as a whole. Improper and hasty actions by personnel during the final stage of the experiment also contributed to the cause of the accident.

LESSONS LEARNED

The causes and consequences of these two accidents have been thoroughly analyzed. As a result, technical and organizational improvements of critical facilities were initiated.

A system of procedural steps was introduced determining the obligatory sequence of operations in a critical facility thereby forbidding the next step if the previous one was not completed. Procedures for restructuring the core in the dry tank and subsequent achievement of a critical state by remote control were established. Procedures were also established for returning the system to subcritical by remotely pumping water out or manipulating the control rods.

Additional shielding to decrease radiation exposure was immediately installed outside the critical assembly tanks.

In-depth planning for experiments was also introduced. This planning included the following three-step procedure: (1) determining the experiments' purpose, (2) identifying the experimental stages and safety measures, and (3) establishing procedures for every working shift.

As a result of the accidents, experiment plans and procedures required the signature of the experiment leader with concurrence from the controlling physicist. Any deviations from the plans or procedures require written confirmation.

REFERENCES

1. "Water-Moderated Hexagonally Pitched Lattices of $U(90\%)O_2$ + Cu Fuel Rods with GD or SM Rods," HEU-COMP-THERM-004, International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03/II, 1996 Version or Later.

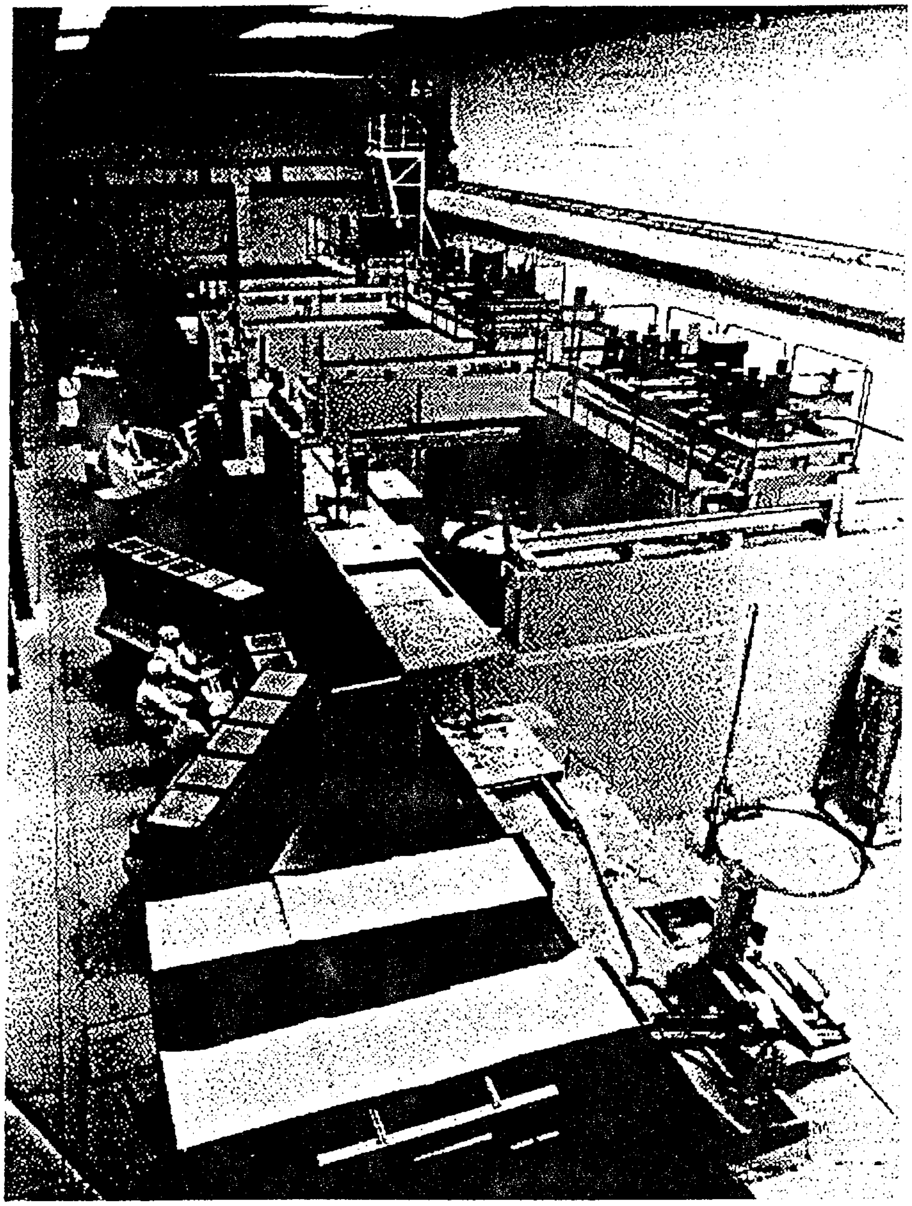

Figure 1. Photograph of the SF-7 control and experimental rooms in which the first accident occurred.

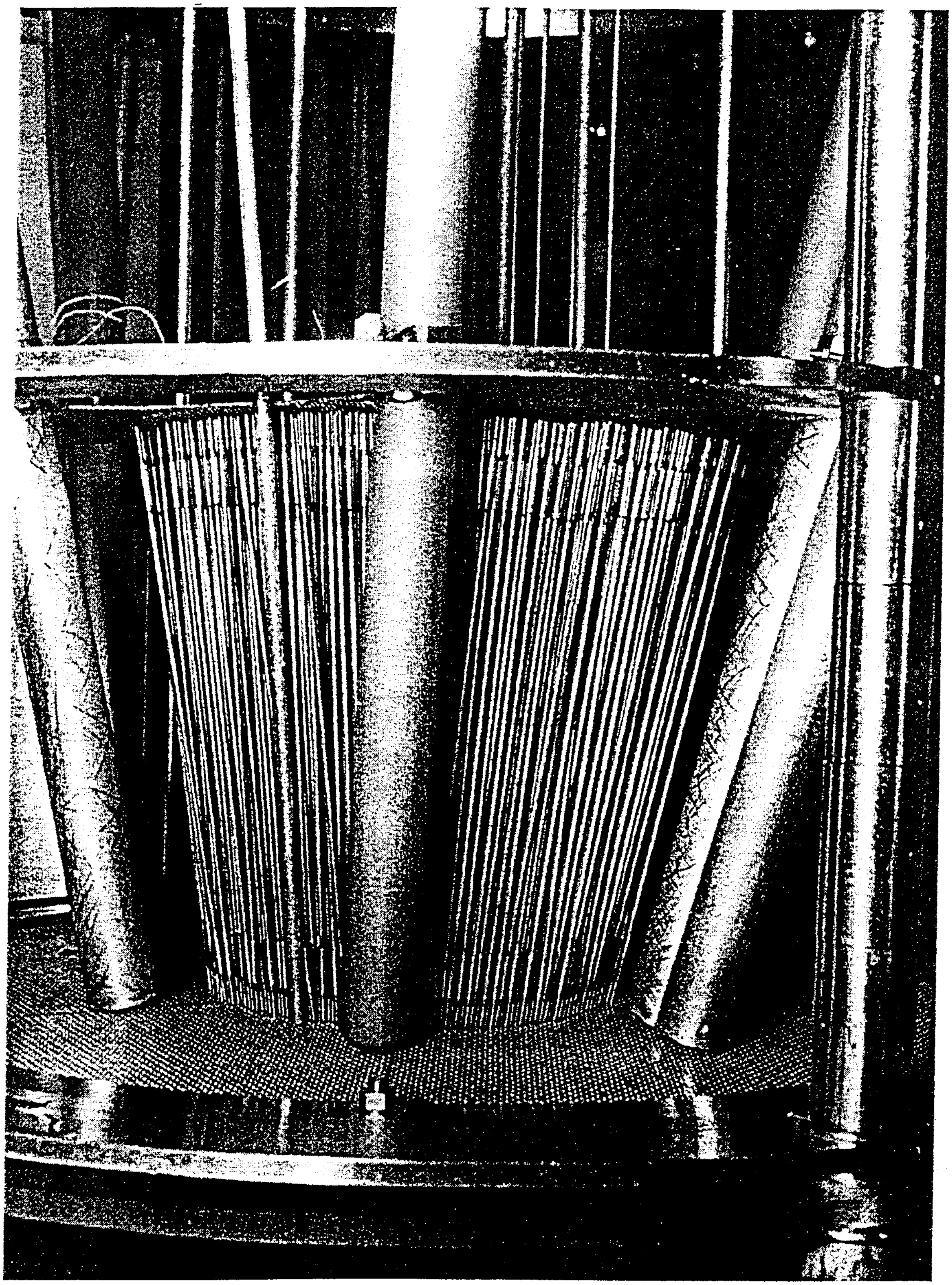

Figure 2. Mockup of the accident configuration for the May 26, 1971 accident.