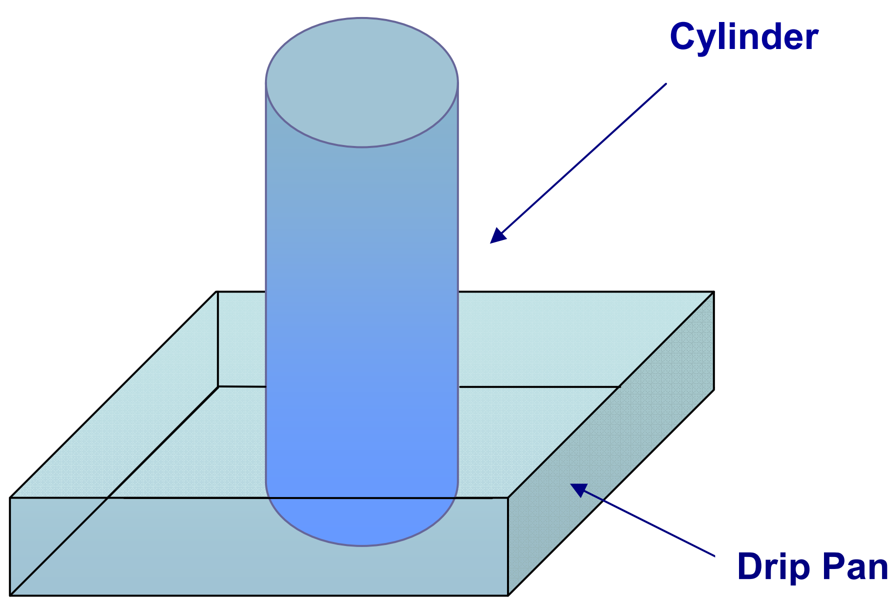
22.05 Reactor Physics - Part Eight

Criticality Accidents

1. **Background:** The neutron life cycle analysis is useful for analyzing criticality accidents. These have occurred while conducting experiments to measure cross-sections and life cycle parameters, while processing fissile materials, and while operating reactors. We note a few of these here. Criticality accidents, while not common, are not a thing of the past. Their prevention requires constant vigilance and close supervision by management.

2. **Experiments:**

   a) **Accident with Cylinder of Fissile Liquid** – One of the more well-known fatal accidents involved the setup shown below. A graduated cylinder was filled with a solution of fissile material. The cylinder was placed upright in a drip pan so that any minor spillage would be collected.



The cylinder broke and the fissile liquid collected in the drip pan. A blue flash was observed. The experimenter was splashed with liquid and, although he showered immediately, he later died.

What went wrong? The surface to volume ratio of the liquid changed dramatically when the liquid went from being contained in a tall thin cylinder to a short-wide pan. If we take both the cylinder and the pan to be cylinders then:

$$\text{Surface/Volume} = \frac{2\pi RL}{\pi R^2 L}$$

$$\propto \frac{1}{R}$$

So, as R increases, which it did once the liquid spilled into the pan, the surface to volume ratio decreased. Neutron leakage is proportional to the surface area. There was less leakage and criticality resulted.

b) Pu-239 Sphere Accident – There were two accidents involving a sphere of plutonium. In the first, a researcher was stacking tungsten bricks that were to serve as a reflector around the sphere. A brick slipped and criticality resulted. In the second, the sphere was surrounded by two hemispherical reflectors. These were held apart by a screw driver. The screwdriver slipped, the Be completely encased the Pu sphere, and criticality resulted. In both cases, the person doing the work later died from radiation exposure. (Note: The latter incident was made famous by Hollywood in a movie "Fatman and Little Boy.")

In both of these accidents, the neutron leakage terms were abruptly changed.

3. Process Accidents:

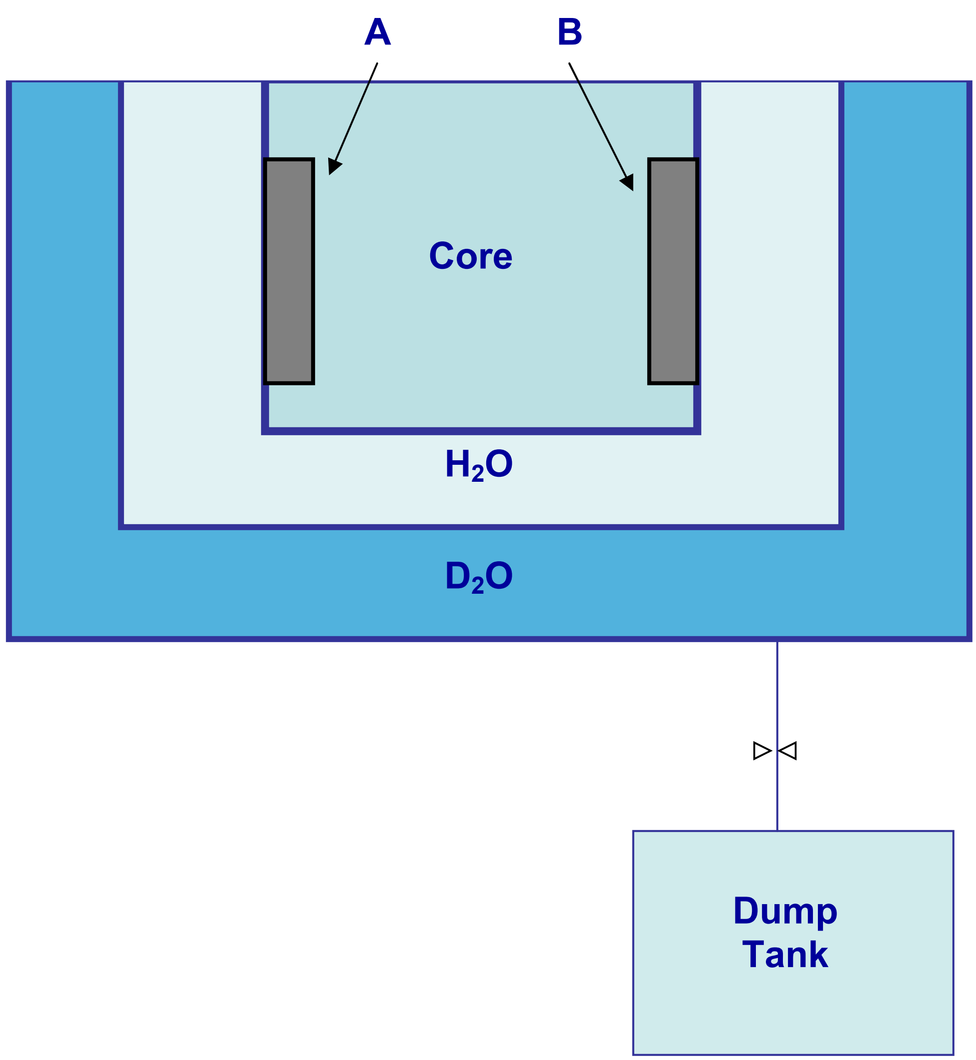
Several process accidents are described by Kneif in the book, Nuclear Criticality Safety: Theory and Practice. See Chapter 3, pp. 13-28. Some of these will be discussed in class.

4. Reactor Accidents:

a) SL-1: The SL-1 reactor was located in Idaho and operated for research purposes. One of its control rods became stuck and the reactor was shut down. Two technicians, both on the night shift, were assigned to fix the problem. One bent over the stuck rod and pulled on it. It suddenly came free and the force of the pull caused it to come completely out of the core. This was enough to make the reactor critical. The previously stuck rod was ejected by the subsequent steam explosion and it pinned the technician to the top of the SL-l's containment building. The other technician died from radiation injuries.

The accident was caused by a sudden change in the thermal utilization. It led to a rule that reactors be designed so that the withdrawal of any single rod could not make the reactor critical. The SL-1 accident occurred in the early 1960s.

b) Research Reactors: A more recent (1988) accident occurred in a research reactor. The configuration is shown below



The core is light-water moderated and heavy-water reflected. The reactor was shutdown for a fuel shuffle. That is, fuel would be rearranged within the core so as to equalize burnup. To ensure that the reactor would be subcritical, the heavy water reflector was to be drained to a dump tank. Two operators were assigned to do the work. In order to save time, they decided not to dump the reflector. One then removed an element from position A with the intent of moving it across the top of the core to position B. As the element passed over the top of the core, a blue flash occurred. The operator who was moving the fuel died, the other survived.

In this case, the leakage from the element was large when it was at the core perimeter. But as it was moved across the core top, leakage decreased.

5. Lessons:

a) Advance preparation is essential. This should include the writing and careful review by independent experts of procedures as well as the performance of walkthroughs.

b) Strict adherence to the written procedures is essential.

c) Personnel who will be performing the work should be trained on the reasons for the procedures. Safety depends on everyone's realizing why each step and each procedure is essential.

d) Work should always be independently double checked.

e) Establishment of a safety culture where everyone integrates safe practice into the routine work is essential.