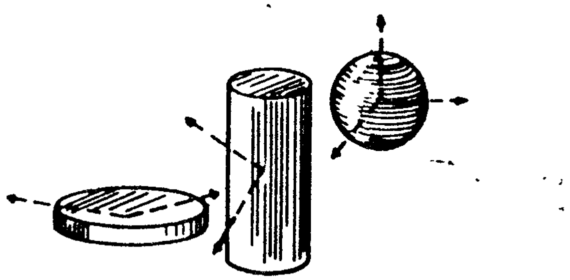

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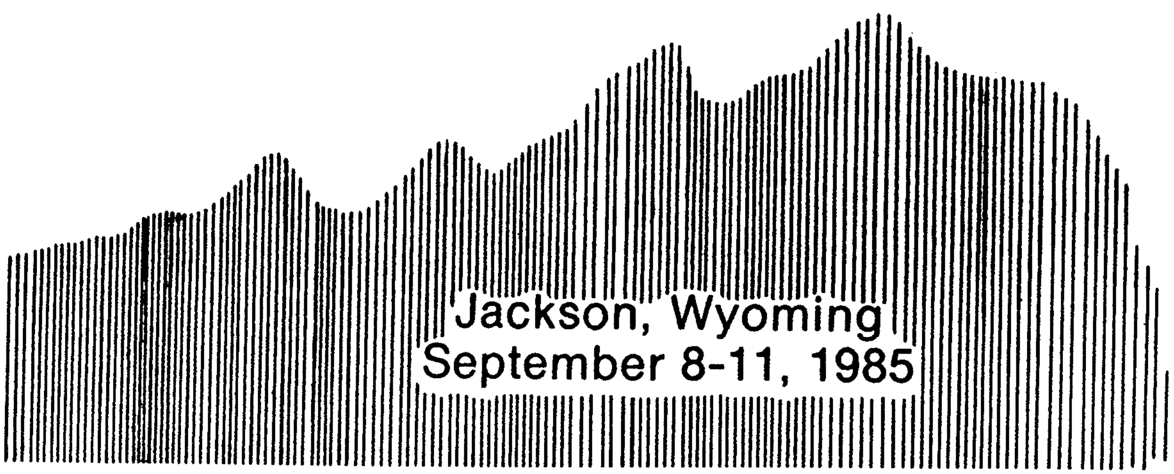
CRITICALITY SAFETY IN THE STORAGE OF FISSILE MATERIAL

PROCEEDINGS OF A TOPICAL MEETING



American Nuclear Society
Idaho Section
Nuclear Criticality Safety Division

A SURVEY OF FISSILE SOLUTION STORAGE METHODS: CHAMPION THE POISONED TUBE TANK

Dr. Robert E. Rothe
Rockwell International
North American Space Operations
Rocky Flats Plant
P. O. Box 464
Golden, CO 80402-0464

The storage of fissile materials poses many special problems for safety engineers representing several different aspects of safety. The difficulties are intensified in a large-scale production plant where very large volumes of highly corrosive fluids need to be stored with unquestioned confidence in safety - especially nuclear criticality safety. Additionally, these liquids sometimes are laden with insoluble fissile material in suspension or weakly dissolved salts susceptable to precipitation.

A number of methods for the safe storage of such liquids are described and evaluated. Some date back to the dawn of the nuclear age; but others are somewhat novel. General regions of applicability for the various methods are also addressed.

Rockwell International's plant at Rocky Flats, Colorado has safely handled large amounts of such liquids for over three decades. The cost of the method used and other considerations suggest the continued search for improved methods. One method - the Poisoned Tube Tank - emerges as a candidate with high potential for many future applications. Rockwell International has designed its first such tank for service. This tank will be critically safe, even under a variety of conditions; and it combines reasonable initial cost with an expected low opertaing and inspection cost. The tank should be installed by the end of 1985.

INTRODUCTION

Safety in the nuclear industry - especially Criticality Safety - is of paramount importance. One area of this safety concern involves liquids such as plutonium and uranium solutions encountered in various chemical processing and waste handling operations. The storage of these solutions is a problem that triggers the attention of safety engineers in nuclear processing plants around the world. The concerns are many. These liquids are radioactive, usually quite corrosive, capable of contaminating people and things, valuable (requiring tight accountability controls), and - worst of all - capable of inadvertent accumulation into a prompt critical configuration. This last safety consideration, NUCLEAR CRITICALITY SAFETY, is the primary concern of this paper. These solutions must be processed, transported, and stored safely such that a prompt critical configuration is never attained or even approached closely. People's lives depend upon quality safety evaluations in this area.

History has revealed that nuclear criticality accidents are seldom associated with normal operations of a system. After all, the system was designed not to be critical under these conditions. Most such accidents throughout the world and across the decades have occurred because unanticipated, out-of-the-ordinary operations have led to critically unsafe conditions. The ability to anticipate and then evaluate the safety of credible accident conditions is a most important attribute of a Criticality Safety Engineer.

Many methods have been proposed for handling fissile solutions in critically-safe fashion over the four decades since the industry began. Each of these methods have their areas of applicability; but other situations exist where their use would be extremely impractical. Consider, for example, storing fissile solution in individual, small bottles which are critically safe regardless of their shape. An analytical laboratory which assays these liquids for their fissile element content would welcome receiving samples in these small bottles. Even large numbers could be handled safely in a planar array if the thickness of the effective slab formed were critically safe. By contrast, a production plant needing to store thousands of gallons of fissile solution would hardly consider for a moment a planar array of small containers. The space requirements would be prohibitively expensive, and the fissile solution would not be readily accessible for productive use.

The storage of large volumes of fissile solution poses many special problems. The method selected should meet several criteria. First, it must be cost effective, although not necessarily the cheapest. Usually, this translates into a nearly maximized storage capacity for the floor space available. Throughout this paper, the percentage of floor space safely available for the storage of fissile solution is referred to as "the floor space efficiency". A second criterion is that the method selected should be easily maintained and trouble free. This suggests that inspections should not require access to the interior of the tank or the removal of massive amounts of shielding or other materials. A minimum number of welds on the tank is another valuable asset. Experience reveals that leaks occur at welded joints more often than at an unwelded portion of a tank. Fourth, the method should possess good mixing properties and minimal tendency to accumulate sludge. Industrial solutions are noted for suspended impurities which can precipitate, requiring tank clean-out. A final and most important criterion is that the selected method shall be critically safe even under all credible accident conditions. People make mistakes; a "safe" tank which attains criticality through a predictable human error is useless

CONCENTRATION CONTROL

The nuclear safety of this method depends upon the fact that the amount of fissile material contained in the solution is so small that k_∞, the neutron reproduction factor for an infinite volume of the solution, is safely less than unity. The critical values of this parameter ($k_\infty = 1.0$) are about 8.5 g ^{239}Pu/liter and 13 g ^{235}U/liter; so the only concentrations for which this method might be considered adaquately safe are necessarily much below those values. Concentration control should never be used for the criticality safety of liquids containing any more fissile material than that contained in more contaminated waste waters. The inadvertent cross-connection of the wrong liquid into a tank designed for "low-level fissile solution" is an ever-present real danger. An equal danger is the gradual building of precipitates containing fissile material. These could disperse if disturbed - as during a clean-out operation - and exceed the critical concentration. Note, however, every nuclear installation is ultimately faced with the use of this method of control as the end-of-the-line waste waters are finally discharged to their waste treatment facility for liquid,

At Rocky Flats, no contaiminated liquids may be released to a critically unsafe vessel until several conditions are met. First, the solution is collected in a critically safe tank and sampled. Redundant samples must show that the concentration is so low that the fissile material mass limit allowed for the critically unsafe tank, 200 g, would not be achieved by that addition. In one example, a critically unsafe 4000 liter tank having this 200 g limit is not allowed to receive any solution in excess of 0.05 g Pu/liter. A final precaution is that two valves in the line connecting the two tanks are both physically locked closed. One valve is found at the output of the critically safe tank; the second at the input to the critically unsafe tank. In spite of these very tight physical and administrative controls, Criticality Safety Engineers still pay considerable attention to these tanks

SOLUBLE POISON

Fissile solutions which also contain adequate amounts of dissolved salts of certain elements can be rendered critically safe. These elements include boron, cadmium, and other elements having large thermal neutron absorption cross sections. The danger is precipitation If the absorber collects at the bottom of the tank, criticality can occur quite easily in the insufficiently-poisoned liquid above it. The use of soluble poisons should never be implemented in the nuclear industry as a means of criticality control. Even two elements, such as both boron and cadmium, as redundent soluble absorbers does not seem adequate. This redundancy has been employed at some nuclear installations who recognize that the danger of plating out or precipitating one or the other is real. This method also assumes that the probability that any single chemical operation might cause both poisons to precipitate is acceptably small. Although no nuclear criticality accident can be traced to precipitation of soluble poisons, the practice still appears dangerous. Rocky Flats does not permit this method as a means of criticality control in any operation. In addition to the precipitation hazard, the method is plagued with the problem of knowing that the absorbers are present through any kind of visual inspection. Finally, the liquid needs to be processed, extracting the dissolved absorbers, before it may be used for its intended purpose.

PENCIL TANKS

Criticality safety is assured by the geometrical design of these tanks. An example of a pencil tank is shown in Figure 1 prior to its installation. A sufficient number of neutrons escape from the considerable surface area that criticality cannot occur within the long, thin solution region regardless of concentration. Collectively, arrays of these tanks can be rendered safe by rigidly maintaining large separations between adjacent tanks. While the spacing allowed between elements of a small array of pencil tanks does depend upon the number of tanks in the array, a typical, compact, small-number array at Rocky Flats would find four tanks fabricated of 5-inch diameter, schedule 40 pipe (5.04-inch inside diameter) located on 18-inch centers. This limit, of course, assumes full water reflections around the tank farm because that is a conservative approximation to the more likely concrete reflection from nearby walls. This example is only 6% efficient in the use of floor space; and yet, such an array of 7-foot-tall tanks would still contain 110 liters of solution. Thus, such an array of these tanks is a practical and economical method of storing moderate-sized volumes of fissile solution. A very large number of pencil tanks would probably not be practical even if floor space efficiency were not a problem. The large number of welds and valves could introduce a leak problem, which would counter-balance otherwise attractive features of the method.

Many years ago, a fissile solution storage vessel based on pencil tanks was designed at Rocky Flats which attempted to improve the floor space efficiency while maintaining other positive qualities of a pencil tank farm. A model of this vessel is shown in Figure 2. The proposed would contain almost 600 liters in a 10-foot-square floor space, about one-tenth the efficiency of a Raschig-ring-filled tank. This design has not been implemented at Rocky Flats.

SLAB TANKS

These tanks, similar to pencil tanks, depend upon neutrons escaping from their large surface area for criticality safety. Arrays of slab tanks will also be safe if they are spaced adaquately far apart. Figure 3 shows a pair of portable slab tanks rigidly mounted in carrages which assure the needed spacing. These tanks were once used at Rocky Flats; but they are no longer in service.

The Critical Mass Laboratory at Battelle's Pacific Northwest Laboratories stores its fissile solution in a compact, permanently situated, slab-tank farm where the space between adjacent tanks is filled with laminations of neutron-moderating plastic and neutron-absorbing cadmium metal sheets. Their design has been in service for a quarter of a century. It is 35% efficient in the use of floor space, and this cannot be improved upon much without significant compromises in safety. Each waist-high tank is about 6 m long and has a capacity to store 400 liters of solution.

Rockwell International prefers to avoid using slab tanks at their Rocky Flats Plant because of the possibility that walls may bulge under hydrostatic pressure or from other causes. The reactivity dependence upon thickness is very sensitive and a small bulge could be quite serious. The square pattern of dark areas visible on each of the tanks shown in Figure 3 are "stay rods" welded between the two faces and designed to prevent bulging.

The few slab tanks used into the 1970's at Rocky Flats, were restricted to a 2 inch interior thickness and had to be spaced such that they were only 8% efficient in the use of floor space.

RASCHIG-RING-FILLED TANKS

This method is the most common example of that which might be termed "fixed neutron absorber". Here, nuclear safety is assured by the presence of a large number of uniformly-distributed, discreet, and insoluble objects containing a strong neutron absorber. These objects, randomly placed but filling a tank, occupy a certain fraction of the tank's capacity; but fissile solution may then safely occupy the remainder. Figure 4 shows a small-sized tank fully loaded with Raschig rings and ready to be placed into service. The Raschig rings used at Rocky Flats are cylindrical annuli of borosilicate glass (about 14 weight-percent B_2O_3), with concentric diameters of 38 and 25 mm, and a length of 44 mm. See Figure 5.

Long the standard method of storing large volumes of fissile solution at the Rocky Flats Plant, Raschig-ring-filled tanks are the most efficient in the use of floor space of the methods so far discussed. Even though a typical large tank may contain tens of thousands of such objects, still 65% of the tank's capacity is available for the storage of fissile solution.

At present, more than 200 of these kinds of tanks exist at Rocky Flats with confidence in their ability to provide criticality safety. From the beginning, the potential for glass to break (even hardened glass) and/or for glass to be etched away by strong corrosive agents created a concern over the continued serviceability of these rings. In answer to that need, a program of inspection was instituted. The nature of these inspections has evolved over the years to the following:

- A visual inspection of the ring level at the top of the tank to assure that the tank remains completely full.

- A sampling of rings from both the top and bottom of the tank. Four rings are selected from each location; and both sets must pass the same dimensional tolerance test as new rings fresh from the factory. This test proves that the rings have not thinned. They must also pass a dynamic mechanical test called the "tumble test", designed to demonstrate that the rings have not lost their structural soundness.

- Each ring-filled tank is emptied of fissile solution and scanned with a gamma-sensitive detector. The purpose of this inspection is to locate possible accumulations of plutonium- or uranium-bearing precipitates within the tank. Even Raschig rings are not adequate to render a tank critically safe for any arbitrarily-high concentration of fissile material in a wet medium.

- Each ring-filled tank is also "calibrated" by adding increments of a known volume of calibration fluid (usually water or acid) to a previously emptied tank. By comparing the height observed for each increment with the original calibration curve, the inspector hopes to detect regions within the tank where accumulated sludge displaces calibration fluid or where broken glass may have left an unpoisoned void.

The above inspections are largely based upon the requirements of and American National Standard document ANSI/ANS-8.5-1979, "Use of Borosilicate-glass Raschig Rings as a Neutron Absorber in Solutions of Fissile Material". Every ring-filled tank at Rocky Flats is inspected with a frequency ranging from every few months to once every few years, depending upon the severity of the corrosive liquid which normally occupies that tank.

The cautious nuclear safety expert will recognize that each of the above inspections, taken alone, have the potential to suggest false conclusions. The visual inspection, for example, may reveal a full tank; but, in reality, rings may have broken within the tank, forming a void. The shape of these rings does permit an interlocking effect and the formation of a "bridge" within the tank. As a second example, measurement uncertainties exist with the calibration inspection such that the propagated uncertainty in reading and analyzing the data coupled with real deviations in linearity of the height-vs-volume curve (introduced by side ports, variations in ring packing density, and tank fabrication) could mask the perturbation sought.

In spite of the apparent shortcomings of the individual inspections, nuclear safety of ring-filled tanks is maintained because all the inspections are performed - and then interpreted - in conjunction with one another. Furthermore, any recognized potential weakness of an inspection procedure is compensated for by a conservative approach to the interpretation of the data. For example, a tank would be cleaned of sludge well before the gamma survey instrument indicated the allowable limit had been reached because of the recognized low precision of the method. Finally, the procedures for each of the inspection programs are continually being improved. Many years ago, the tank calibration procedure called for a least-squares fit to a linear regression curve relating tank height to calibration volume. Thus, all of the data influenced - even though weakly - every portion of the curve, a property of the regression technique. On one non-fissile test of the method, performed in the early 1970's, a 14-liter spherical void was intentionally placed in a large-diameter tank; and its presence remained undetected in the data analysis. The current procedure has been improved such that the residuals of the least-squares fit are compared to similar data taken at the time the tank last received a loading of new rings. The graph relating these residuals to the height is often referred to as the "finger print" of a particular loading of rings and is much more sensitive to small changes within the field of rings.

The cost of implementing this Raschig ring inspection program reveals that this method is deceptively expensive, while new rings are relatively inexpensive (50 cents each), the average cost for Raschig ring replacement at Rocky Flats in 1980 was $40,000 per tank. The labor involved in removing plutonium-contaminated glass from within a plutonium-contaminated tank accounted for 70% of that cost. The cost of new rings accounted for only 14%, and expenses incurred in waste disposal totaled another 11%.

Even this cost would be acceptable on a plant-wide basis if only a few tanks needed new rings each year. Unfortunately, that proves not to be the case. In 1980, fourteen tanks required ring changes at a total cost of $550,000. Over one 13-year period, almost half the ring-filled tanks at Rocky Flats had to have new rings for one reason or another.

A study of the reasons behind Raschig ring changes reveals that tanks needing more frequent changes are usually those containing a strongly corrosive, high concentration plutonium solution and/or those with a high potential for sludge accumulation. The economic conclusion is that ring-filled-tank storage is probably not the best method for these kinds of solutions. Fortunately, solutions of this nature represent a comparatively small percentage of the fissile solution handled at Rocky Flats. Most solutions are quite compatable with long-term storage in Raschig-ring-filled tanks; and this fact is reflected in a reduced inspection frequency, thereby decreasing cost.

In conclusion, Raschig rings will continue to serve Rocky Flats for the safe storage of large volumes of certain fissile solutions; but an improved method is being sought for use with more corrosive liquids.

ANNULAR TANK

Fissile solution may be stored in a tank composed of two concentric cylindrical shells of different diameters with solution occupying the space between. Criticality safety is assured by controlling the thickness of the solution region. A pair of nested annular tanks - part of an experimental program conducted at Rockwell International's Critical Mass Laboratory - are shown in Figure 6. Annular tanks are relatively inexpensive to build because the design is so simple. Rockwell International recently purchased three such tanks for use in the plutonium processing plant. The average cost was $5300 (1984), and the average capacity was 270 liters. By comparison, the Raschig rings alone for a ring-filled tank of 270-liter capacity would cost $3500, the labor to install them would add about $10,000, and the tank itself would cost a few thousand dollars more.

The amount of welding required to fabricate a tank for any storage method is an important consideration. Tanks which contain corrosive liquids are known to be more susceptable to pin hole leaks at welded joints than elsewhere because corrosive solutions, especially fluorides, are much more likely to attack metals which have been metallurgically modified by the heat of welding. Annular tanks require only about double the amount of welding required to fabricate a ring-filled tank, and the welds are readily accessible for repair should a leak develop. By comparison, a pencil tank farm of the same capacity as a single ring-filled tank has about eight times the amount of welding.

Annular tanks have not been in service long enough to determine if sludge accumulation is a problem. Even though solution flow is expected to be quite laminar (decreased sludge deposition over the years), the very thin, annular design of such a tank suggests that cleanout of sludge might be difficult.

Some early studies on the homogenization characteristics of an annular tank suggest that mixing is quite good especially if the inlet nozzle is aimed tangentially around the tank. Mixing characteristics, however, will also be understood better after additional years of experience.

Rockwell International employs annular tanks in specific applications where intermediate-sized volumes need to be contained. the method is not very efficient in the use of floor space for large quantities of solution. for example, two sizes of tanks in use at Rocky

Flats (40-in. and 60-in. diameter) are between 4% and 5% efficient. The annular thickness allowed is only 1.4 in. and a 6-foot-tall tank of the larger diameter contains about 365 liters of fissile solution. The floor space requirement, however, is more than 6 feet square.

The greatest deterrent to an improved floor space efficiency using the annular tank design is the inability to allow thicker solution regions while maintaining nuclear criticality safety. This thickness could be increased - with no loss of safety - by inserting within the inner shell a neutron absorbing medium. This material will absorb many fission neutrons before they traverse a chord length and cause further fissions in the solution. The principal advantage is that the neutron absorbing material, unlike Raschig rings, is not in contact with the fissile solution. This simplifies inspection of the absorber if, indeed, inspection is ever required other than to assure its continued presence.

Before allowing such internally poisoned annular tanks for the safe storage of high-concentration fissile solution, criticality safety experts would need to establish physical and administrative controls to assure the aborber's presence. The internal absorber is so effective that its absence could lead to a prompt criticality if the proper fissile solution were introduced to an unprotected annular tank. Experiments performed at Rocky Flats1 revealed that the annular solution region thickness could be at least doubled and still remain subcritical provided a neutron absorbing annulus was situated inside the annular tank. In one experiment having a 2.8-in.-thick plaster annulus containing 2.8% natural boron, very little increase in multiplication was observed as the tank filled with high concentration fissile solution. Criticality occurred at a fissile solution depth of 0.94 meter when this internal absorber was removed.

POISONED TUBE TANK

The last method discussed - the poisoned tube tank - is a blend of many positive qualities of other methods with very few potential shortcomings. It is easily competetive with Raschig-ring-filled tanks from the perspective of floor space efficiency, and it should prove much less costly to inspect and maintain.

A poisoned tube tank may be described as a boiler-tube heat exchanger enclosed by a metal shell forming a tank. The fissile solution is allowed to occupy the space within the tank but outside uniformly spaced boiler tubes. Criticality safety is assured by filling the hundreds of boiler tubes with long, thin, rods containing a strong thermal neutron absorbing material. Fabrication costs are surprisingly low - despite the tanks complex appearance (see Figure 7) - because the basic technology needed dates back to the invention of the steam locomotive. Tank inspection costs are also expected to be low because the neutron absorber elements remain uncontaminated throughout their life in normal use.

Rockwell International plans to evaluate this method further at its Rocky Flats Plant. An extensive program of criticality experiments was completed in 1984 and a first poisoned tube tank for use in the plant has been designed. The tank is currently being fabricated by an outside vendor and should be in service by the end of 1985. If it proves successful, the poisoned tube tank may find areas of applicability at the plant for the storage of large volume of corrosive, concentrated fissile solution. Still, other methods will continue to serve their special applications. Raschig-ring-filled tanks will continue to be used where high floor space efficiency is required and the solution being stored is compatable with the method. Annular tank and pencil tank farms will continue to be used wherever only intermediate volumes need to be stored.

This first tank has been engineered under the auspices of several different safety organiations, as well as considering the needs of the user group. The final design agreed upon (and described in the following paragraphs) is critically safe, is reasonably inexpensive to build, should be as free as possible of the tendency to accumulate precipitated solids, and is expected to be relatively maintenance-free over decades of exposure of corrosive fluids to welded joints. This last expectation is based upon the fact that heat exchanger fabrication technology has been well developed, boiler tube weldments will be machine welded, and other fabrication details to be discussed later. Still, this tank is not touted as the final design for all future Rocky Flats applications; future tanks will benefit from the experience gained from this first tank.

This tank will be a 410-liter-capacity vertical cylindrical tank with flat, but sloped and parallel, top and bottom elliptical disks. The steeply sloped bottom (15°) aids the elimination of precipitates; the top is sloped parallel to the bottom so all absorber rods will be the same length. Three hundred boiler tubes are arranged in a square pattern. They, too, are vertical and, therefore, parallel to the tank's wall. The boiler tubes are commercial, cold drawn, annealed and pickled, seamless type 304 stainless steel tubing in the 1¼" by 11 gauge size. Tubing was used (rather than pipe of similar wall thickness) because the dimensional tolerances established by the industry for the fabrication of tubing are a factor of two better than for pipe. This is an important factor considering the method, described later, of fixing the boiler tubes into the tank's top and bottom plates. The square pattern was selected rather than a triangular array because it was more compatible with the computational code used to design criticality safety into the tank, thus reducing uncertainties in that important area. (More recent versions of the same code would permit the calculation of a triangular array with equal ease.) The number of tubes was chosen to yield a lattice spacing between adjacent boiler tube elements for which the computed value of k_{eff} remained much less than unity for the most reactive fissile solution under normal use, and additionally, remained confidently less than unity for the same solution even under a reasonable set of assummed accident conditions. The lattice spacing selected also depends upon the composition of the absorber rods, especially the atomic density of the strong neutron absorber, often boron. The spacing selected is additionally conservative in that it was designed for use with a second choice absorber for which the boron content was less than that of the material selected.

This tank will use a boron-loaded rubber known as Neutro-Shield T.M. for the neuton absorbing rods. This product was created especially for this project as a manufacturing modification to a pre-existing material sold by the same manufacturer. It is a silicone-based rubber that contains about 50% (by weight) boron carbide homogeneously distributed throughout the rubber. The natural boron content is 0.60 g B/cm^3 averaged over the entire length of the rod. The diameter of the rods is large enough to fill the boiler tube yet permit easy insertion and removal. Each rod is a little longer than the length of the boiler tube and extends above it to permit easy removal by hand for inspection. A simple "keeper bar" welded across a row of open-bottomed boiler tubes prevents the absorber rod from passing through the tube to the floor. A flexible rubber was chosen because ceiling height in production areas would not always permit the removal of a rigid rod.

The boron content chosen is close to the maximum that can be included in the rubber. Boron carbide, though more expensive than other boron-rich compounds, was selected as the neutron abosrbing ingredient because it is 78% boron and chemically inert as an additive to the rubber.

The design of the bottom of the poison tube tank deserves specific discussion here because two designs were considered. Rocky Flats selected the "pass through" design, shown to the left in Figure 8. This design was favored over the sealed end cap design because an assummed leak in a weld would pass solution to the floor - permitting early detection - rather than contact the rubber. The rubber is known to be attacked by strong acid, and the concern is that the boron carbide either might precipitate or float to the top of a dissolved rubber rod. Early tests revealed a tendency for the rubber merely to swell and become gelatinous, but these were inadequate to assure that a redistribution of the boron carbide would never occur.

This Rocky Flats poisoned tube tank was designed to be critically safe even under the accident scenario that a small bundle of absorber rods is inadvertently omitted during loading or not returned following an inspection procedure. The lattice spacing has been made small enough such that the tank will be safe even in this situation. Criticality safety experts at other facilities will need to establish their own criteria as to the number of absent rods allowed before criticality might occur.

The method chosen to join the boiler tubes into the tank's bottom plate is one which offers the greatest possible assurance against leaks. The method is known as "roller expanding" and is illustrated in

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T.M. - Trademark of Bisco Products Incorporated, 1420 Renaissence Drive Park Ridge, Illinois 60068

Figure 9. The joint begins with a tube slid into a reamed hole in the plate. The gap between the two should be both small and constant, which is the reason that tubing is preferred over pipe of the same nominal wall thickness. Then, a hardened-steel taper is hydraulically forced into the tubing, expanding the metal wall and causing it to flow into every pore of the mating hole. Roller expanding requires the use of a thicker plate than would be required for a simple welded joint between tube and plate. Grooves cut into the plate as shown in Figure 2 improve the seal. A finished, roller-expanded joint may then be back-welded for even further protection. In principle, this weld joint should never come in contact with corrosive fluids. The first Rocky Flats poisoned tube tank will feature back-welded, roller-expanded connections in the tank's bottom plate, but only welded connections at the top.

Many other absorber materials were considered for the Rocky Flats tank before the Neutro-Shield material was finally selected. Important factors entering into this consideration for a number of other materials are discussed below:

1. Powders containing a high percentage of boron could be poured directly into boiler tubes if their bottoms were capped in some fashion, or they could be encapsulated into thin-walled tubes which slide, in turn, into the boiler tubes. The principal concern here is that powders may settle and could leave an unpoisoned region near the top of a tank. Administrative controls needed to monitor this problem might be expensive. The encapsulated method would again require adequate clearance to the ceiling. Some candidate powders are described in Table 1 below:

Table 1. Neutron Absorbing Powders

Mineral	Absorber Element	Cost and (Safety) Assessment
boron carbide	78%	expensive
anhydrous boric acid	31%	inexpensive
borax	22%	inexpensive
colemanite/ulexite	11%	very inexpensive
cadmium oxide	88%	expensive (hazardous)
gadolinium oxide	87%	expensive

2. Rigid rods which naturally contain thermal neutron absorbing materials could be used. Pyrex-glass rod stock is a common, relatively inexpensive material, but it only contains about 4% boron. Polyvinyl-chloride (PVC) rod is quite inexpensive and contains about 56% chlorine; but this element has only a 33-barn thermal neutron absorption cross section compared to the boron cross section of 760 barns.

Chlorinated polyvinylchloride (CPVC) is much more expensive and the chlorine has only been increased to 62%. In both plastics, however, the cross section is just too low to use for the storage of high concentration fissile solution.

Some of the powders (but not all) in Table 1 could be added to a matrix material and formed into rigid rods containing adequate amounts of neutron absorbers. One example of a matrix material would be plaster. Plasters can usually accept up to 50% additives; thus the effective percent absorber for such a mixture would be reduced below the value given in Table 1 by the dilution ratio. A few preliminary attempts have been made to develop a method to sinter, pelletize, or otherwise form powders into rigid rods, but these have largely not met with a great deal of success. The principal problem in the use of these rigid rods would be the ceiling clearance requirements already addressed. The use of several, shorter, segmented rods has been rejected at Rocky Flats because of the possible omission of a segment caused by an oversized segment becoming wedged within a tube during loading. The resulting unpoisoned region would be difficult to detect.

CONCLUSION

The poisoned tube tank shows a great deal of promise as a viable method for the storage of large volumes of highly corrosive fissile liquids. The method is comparable with others in initial cost; but inspection costs are projected to be much smaller than some other methods. No new technology is required before designing a poisoned tube tank. Heat exchanger technology is well established; and materials for use as neutron absorber rods are readily available. The rubber product Neutro-Shield and borosilicate glass are two examples.

Rockwell International plans to install a poisoned tube tank at its Rocky Flats Plant by the end of 1985. Experience gained during installation and the early years of operation will be most helpful in evaluating the method.

All of the other methods discussed will continue to have their areas of applicability. Annular tanks provide a very useful storage method for intermediate sized volumes. Laboratory samples will continue to be collected in small bottles.

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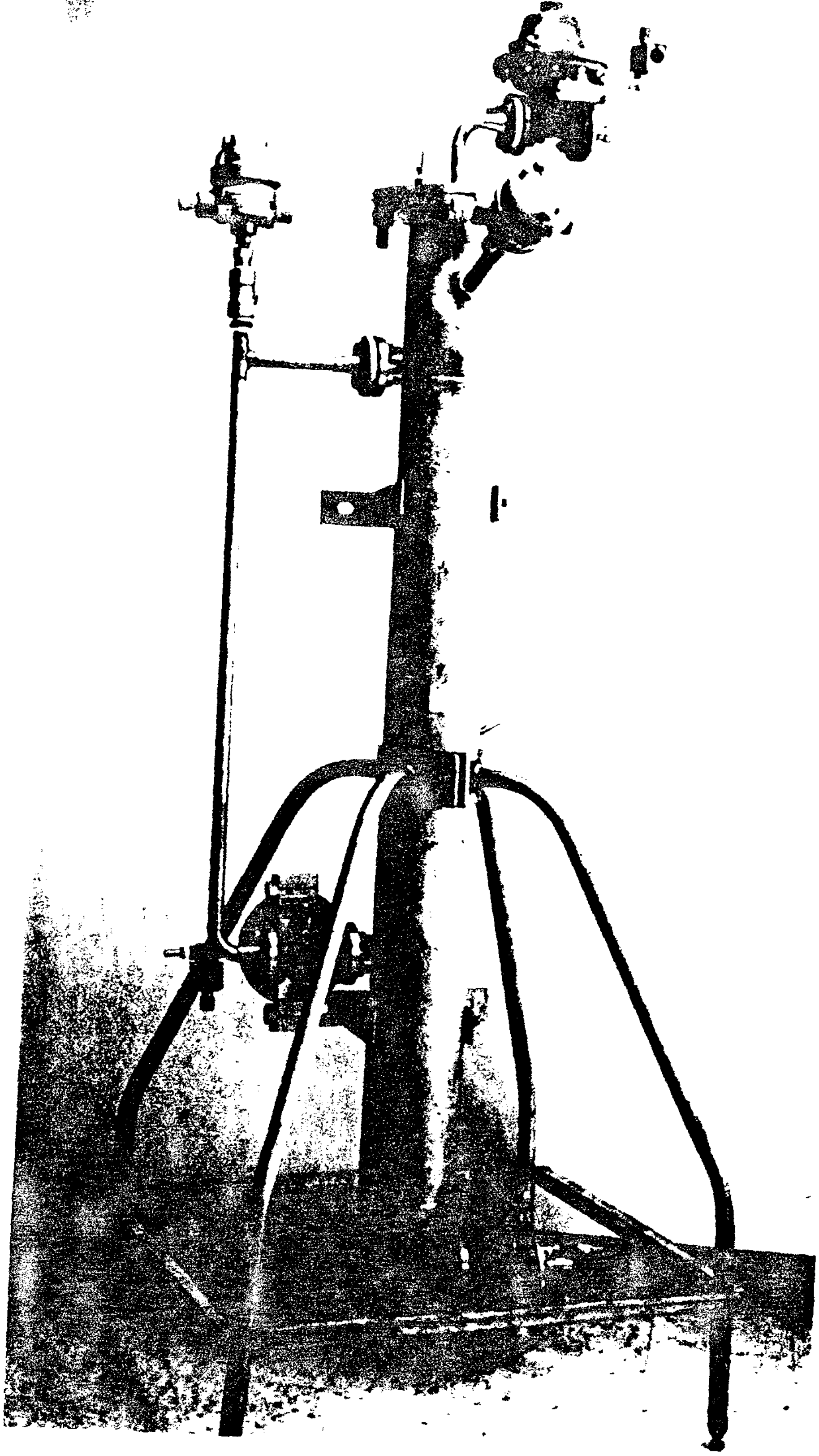
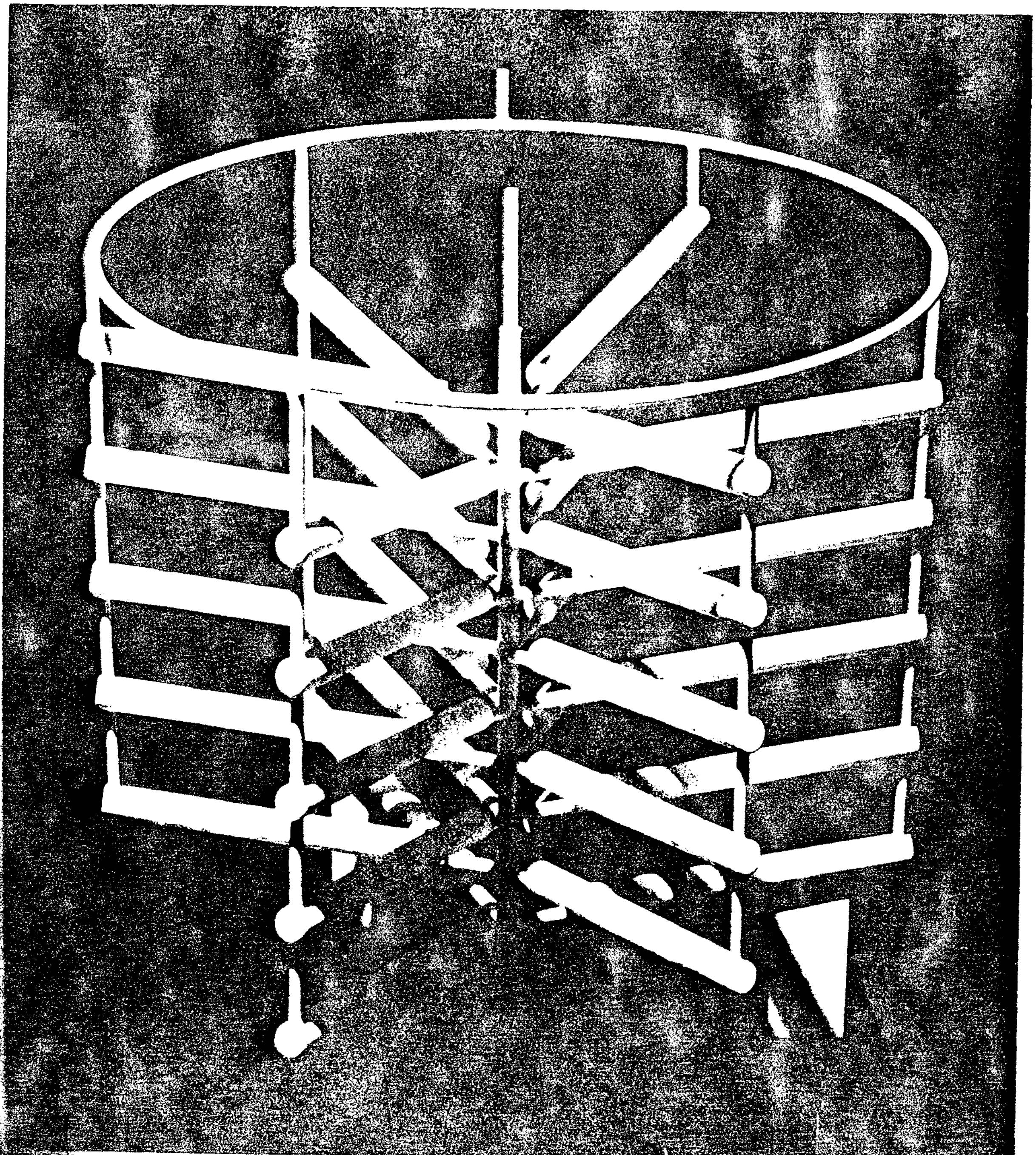


Figure 1. A Pencil Tank Prior to Installation. The cradle would be removed before bolting to a wall.



A Proposed Storage Method Composed of Many Pencil Tanks. This method has not been implemented at Rocky Flats.

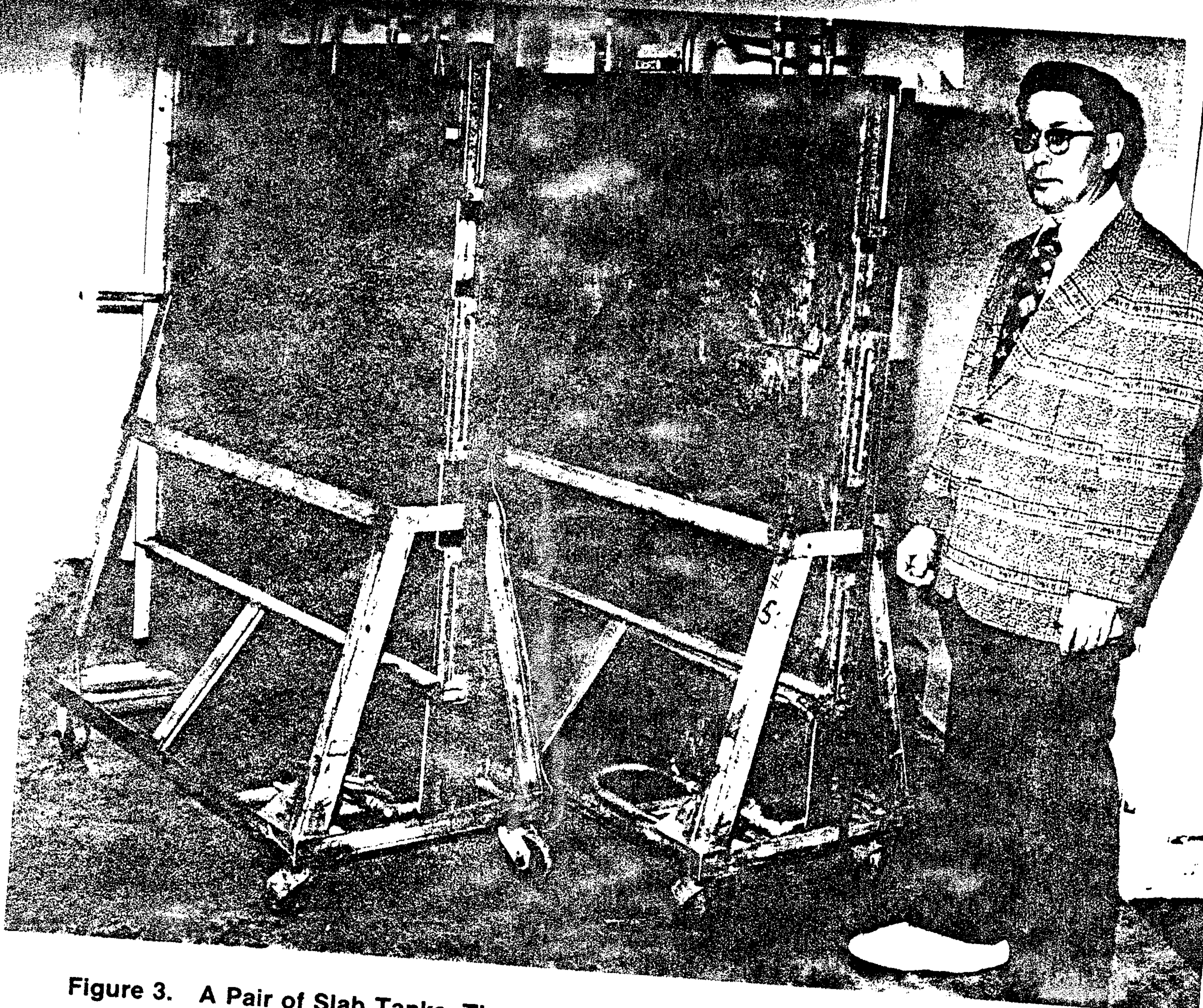


Figure 3. A Pair of Slab Tanks. The portable cradles provided critically safe spacing.

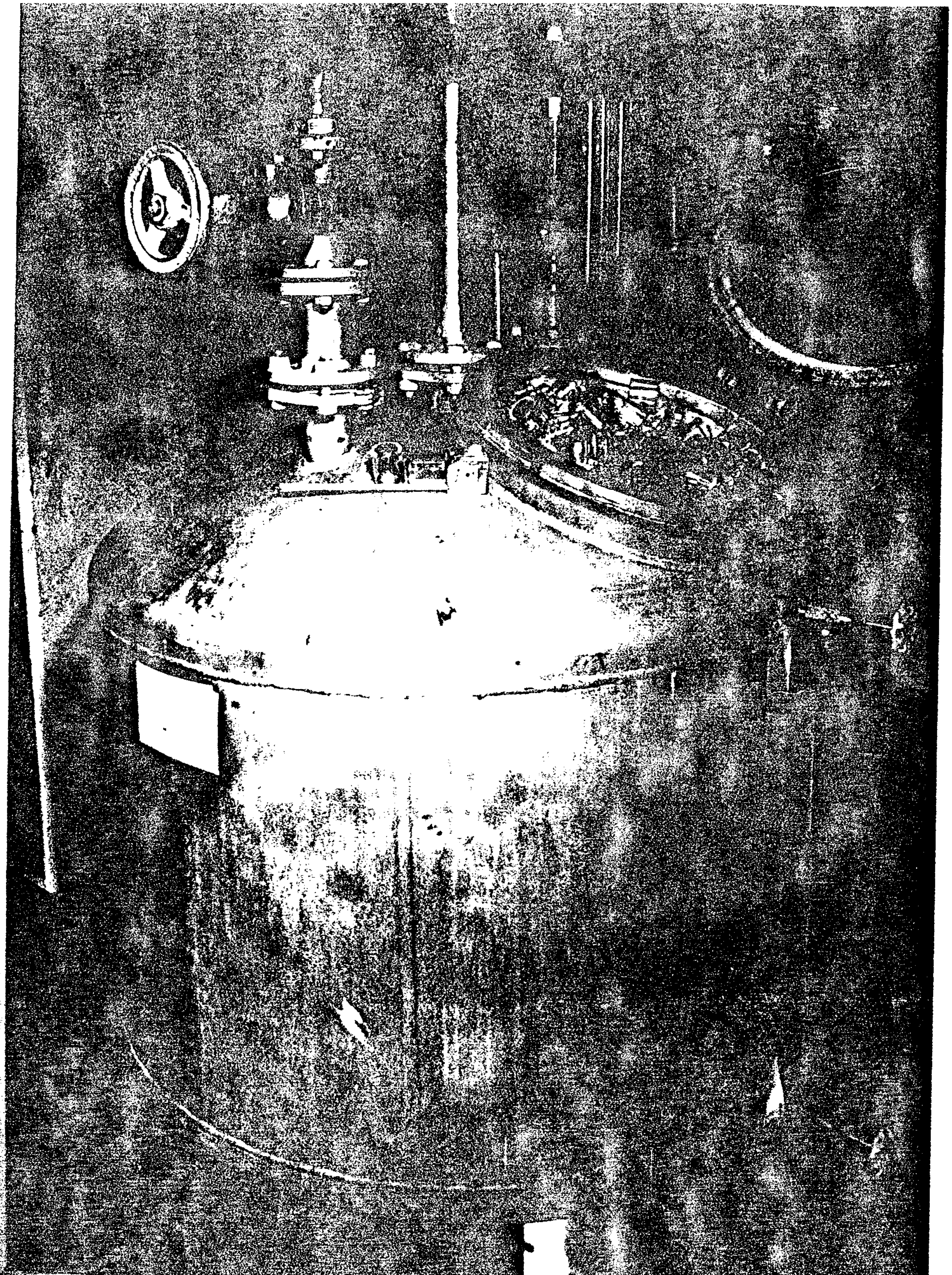


Figure 4. A Raschig-Ring-Filled Tank.

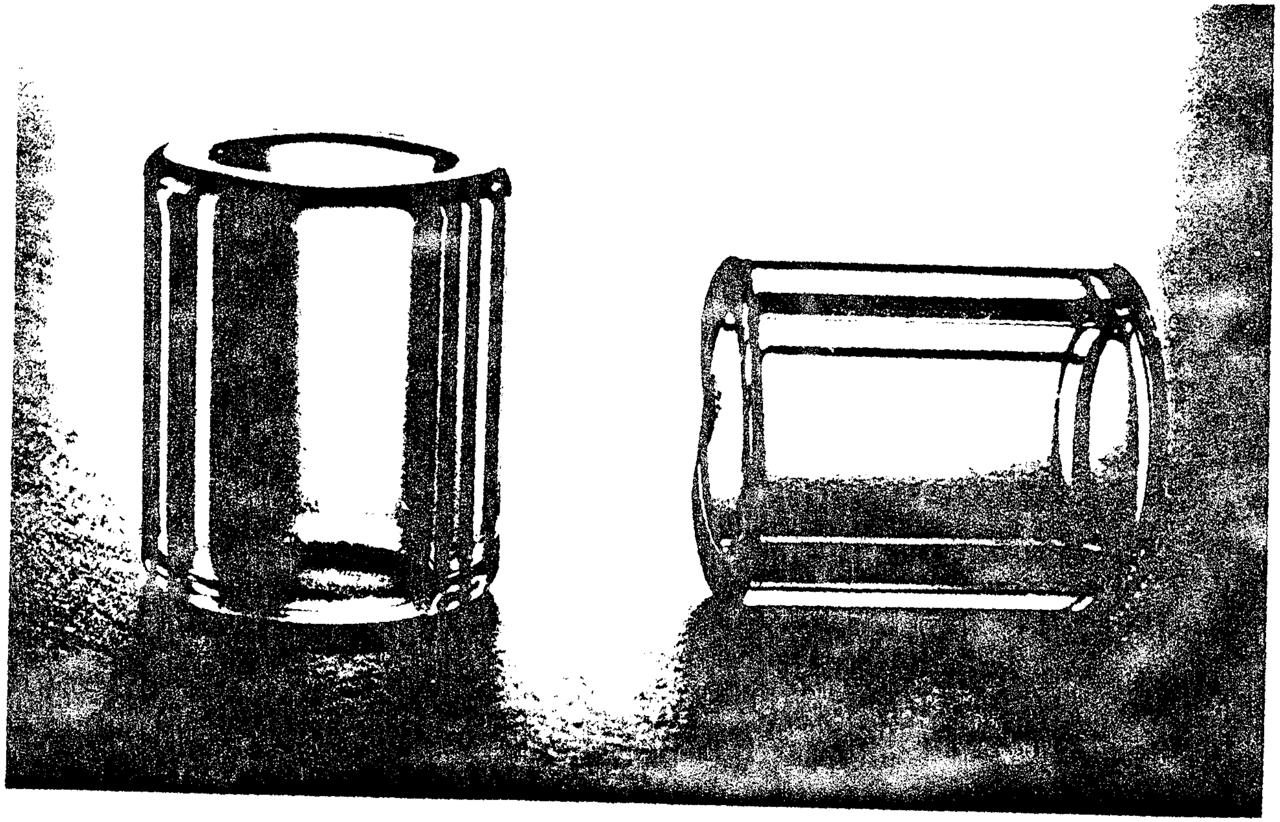


Figure 5. Raschig Rings.

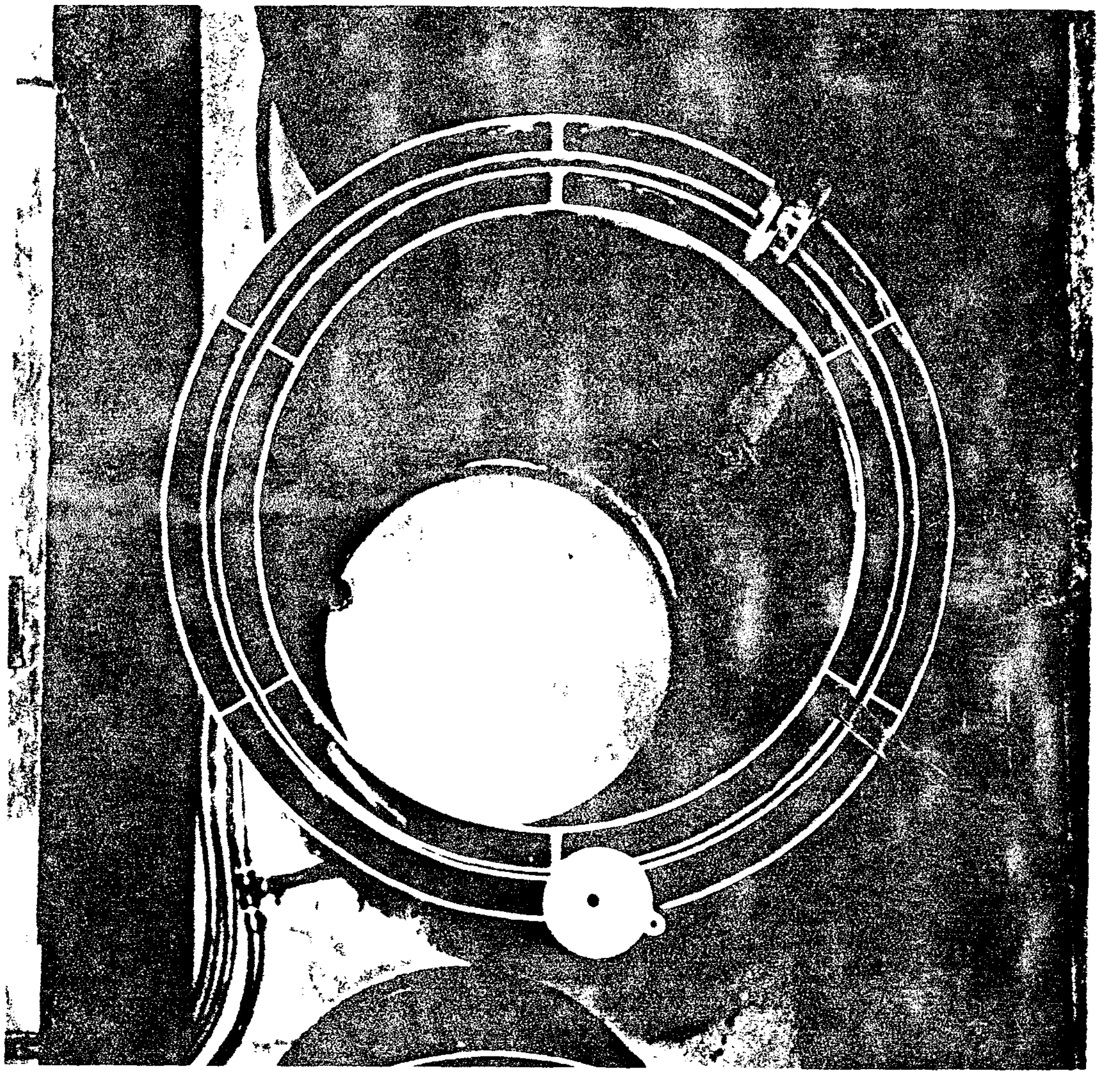


Figure 6. A Pair of Nested Annular Tanks. These were used for a series of critical experiments designed to evaluate the safety of the method. Normally, annular tanks would not be nested.

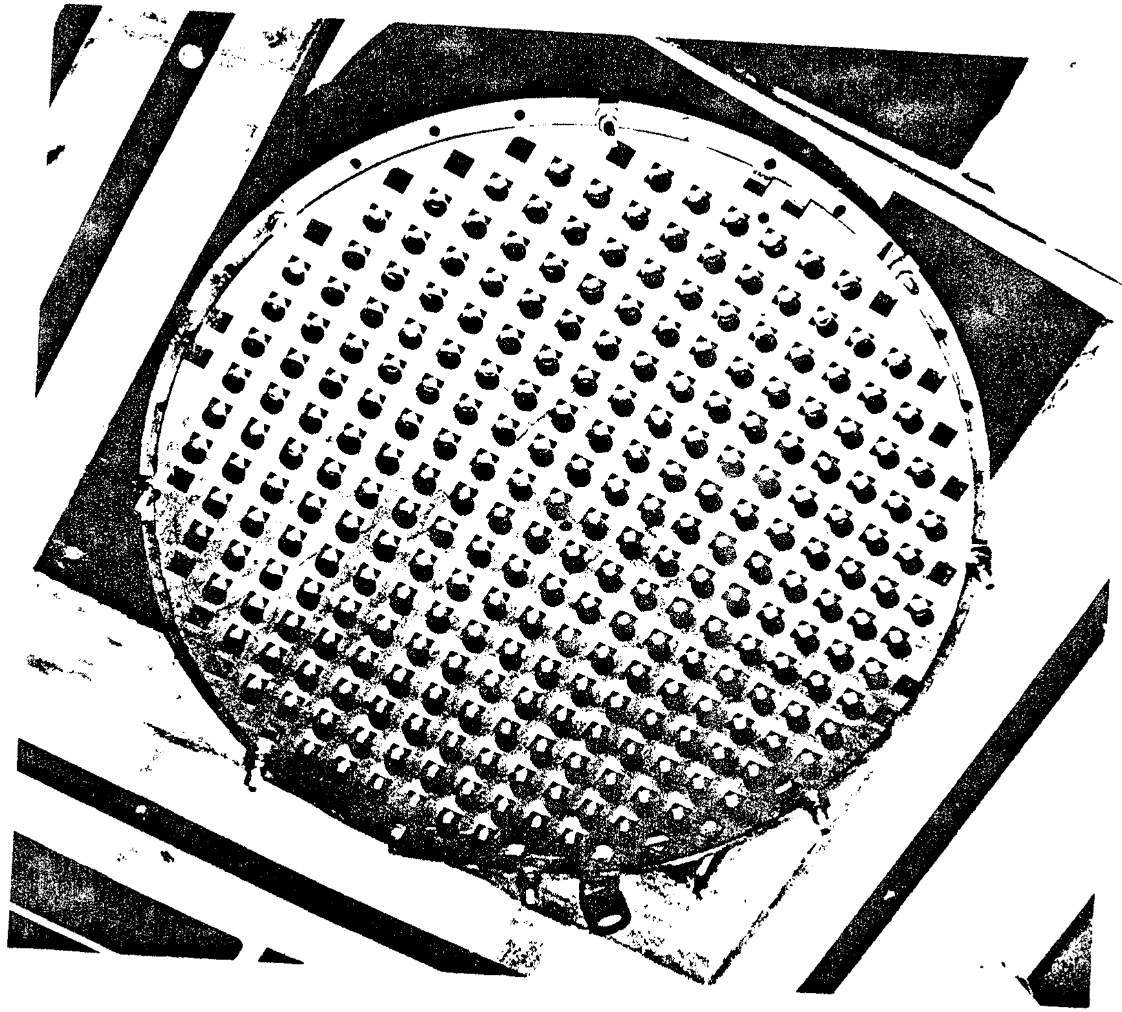


Figure 7. A Poisoned Tube Tank. This tank was used for a series of critical experiments designed to evaluate the safety of such a method. Normally, tubes would be seal welded into the top of the tank.

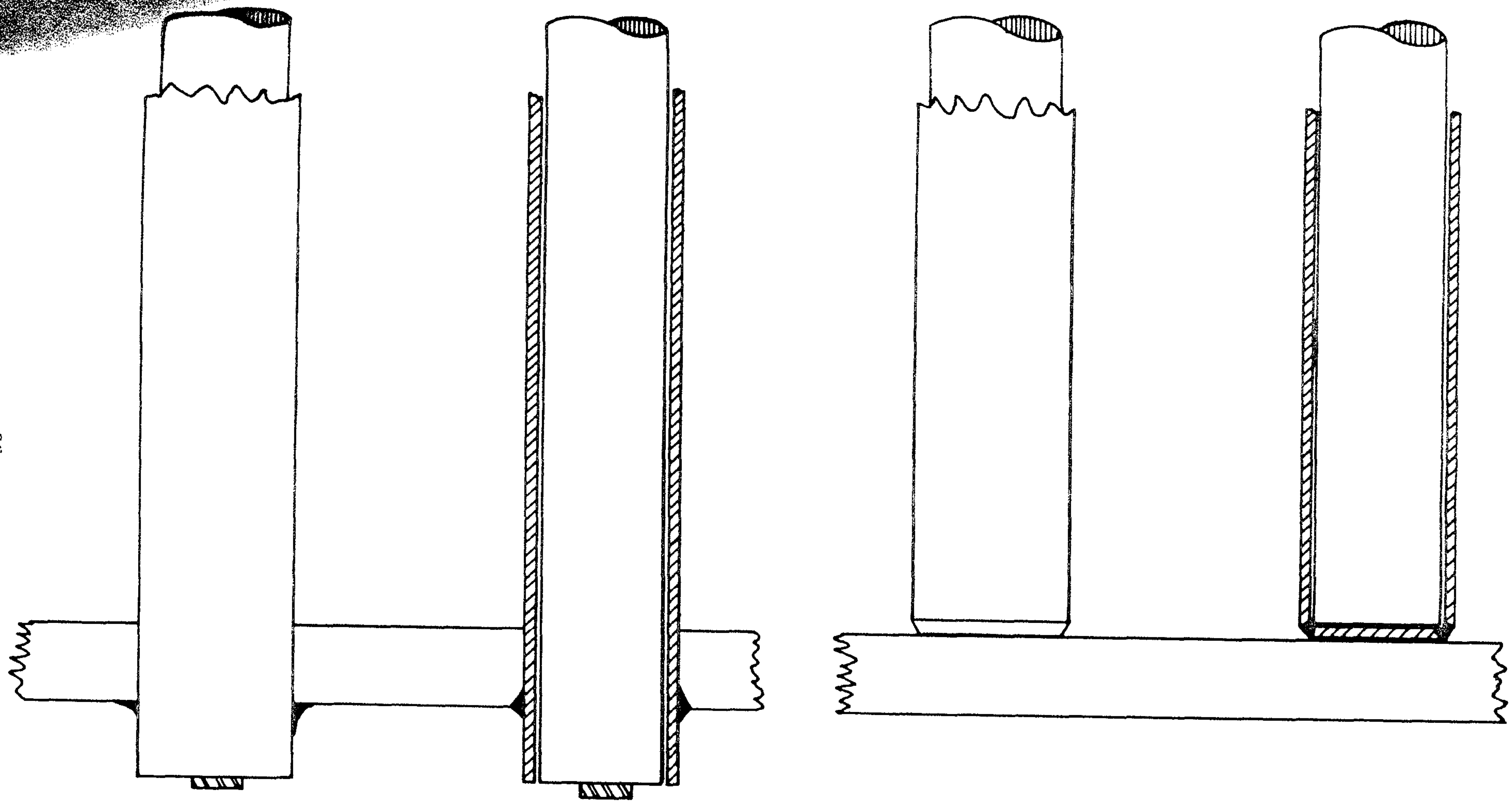


Figure 8. Two tank bottom designs. The left hand pair shows a "pass through" heat exchanger; the other pair shows a sealed end cap design. For both pair, the right hand portion is shown in section.

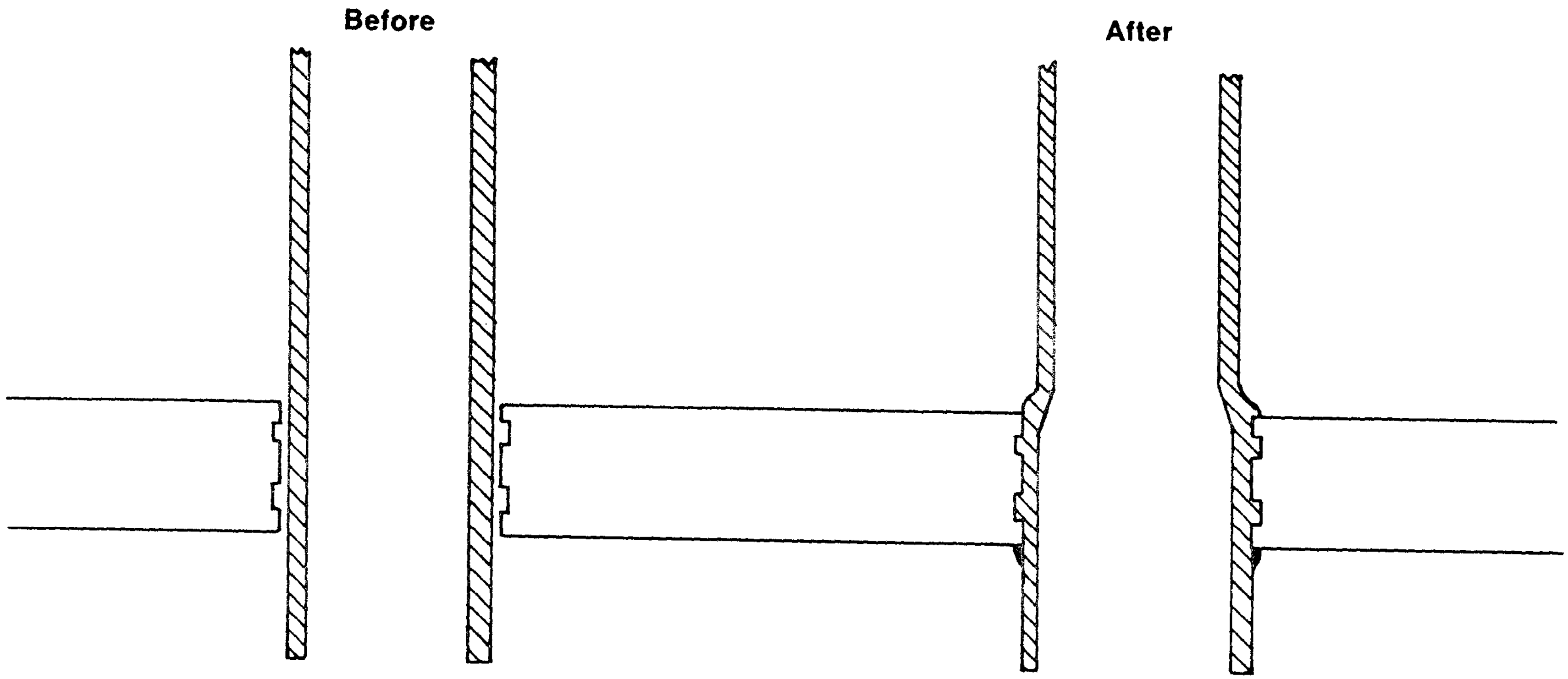


Figure 9. The roller expanding process for joining tubes to a thick metal plate. The left tube is shown slip fit into the hole. The right tube is shown after the roller expansion operation.