# 5.1 YUCCA MOUNTAIN CONTAINER FABRICATION, CLOSURE AND NON-DESTRUCTIVE EVALUATION DEVELOPMENT ACTIVITIES*+

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In this presentation, I will describe our container fabrication, closure and non-destructive evaluation (NDE) process development activities. All of these activities are interrelated, and will contribute to our metal barrier selection activity.

The key design parameters for a tuff environment have been discussed already by Kass and will only be reviewed briefly here. The key points are:

(i) There will be no significant hydrostatic or lithostatic loading of the container.

(ii) The flux of water will be very small (~ 1 mm/a).

(iii) The water is benign. It is basically J-13 well water, i.e., an oxidizing, dilute sodium bicarbonate solution of neutral pH, containing 7 ppm $Cl^-$ and 10 ppm $NO_3^-$.

(iv) The temperature of the borehole wall will attain levels of ~ 250°C over the first 50 to 100 years and then fall to about 97°C over the remainder of the 300-year containment period.



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Our plan is to use a corrosion-resistant material in the form of a cylinder with a wall thickness of ~ 1 cm (2 cm for pure copper). The materials under consideration have been discussed by Kass and include the three austenitic alloys, AISI 304L, AISI 316L and alloy 825, as well as the three copper alloys, CDA 102, CDA 613 and CDA 715. Our targets are:

(a) Controlled, uniform microstructures for the base metal, the weld, and the heated affected zc ˋs (HAZ) of the welds;

(b) Controlled microchemistry;

(c) Low residual stresses;

(d) Small welds and heat-affected zones;

(e) Reliable methods of flaw detection by both surface and volumetric activities.

Figure 1 gives an overview of our container process development activities.

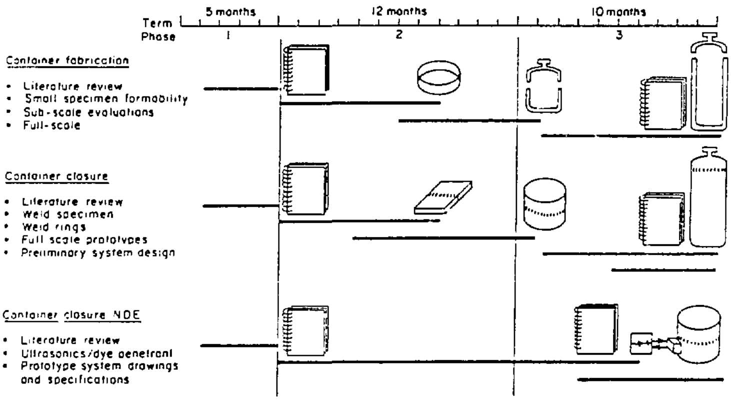


FIGURE 1: Overview of Container Process Development Activities

The first two activities, container fabrication and container closure, are being done by Babcock and Wilcox in Alliance, Ohio, and in Lynchburg, Virginia. The container closure non-destructive evaluations are being developed at Lawrence Livermore National Laboratory. Phase 1 of these activities is essentially complete, and we now have preliminary recommendations which we will pursue in the subsequent phases. Phase 2 will commence in FY 89 (fiscal year). During this phase we intend to construct a number of small specimens in the form of rings (container fabrication) and to look at a number of welded specimens, probably in the form of plates as well as rings (container closure). For the third activity (non-destructive evaluation), we will look at these specimens using ultrasonic and dye-penetration techniques. In particular, we will

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look at areas where problems may arise, such as welded areas, and areas where we expect some deformation. In Phase 3, which should start sometime in FY 90, we will produce reports which are a set of specifications of the three activities, fabrication, closure and evaluation. Then we will construct several prototype containers (fabrication) and demonstrate that we can weld them using the welding technique specified (closure). Finally, we will have to prove that we have succeeded in our fabrication and closure efforts using the specified evaluation techniques.

Now that Phase 1 is complete, I would like to review the recommended procedures and processes for fabricating, closing and evaluating each of our candidate materials. First, I will list the procedures to be studied or evaluated and then I will discuss the specific procedures in a little more detail.

A. <u>304L AND 316L STAINLESS STEEL</u>

(a) <u>Fabrication</u>

Three different fabrication processes will be evaluated. The first process is the closed-end extrusion process followed by cold-working. The second, and probably cheapest process, is to roll and weld. This is a very common fabrication method. Subsequent thermo-mechanical processing to homogenize the microstructure throughout the weld and HAZ will be investigated. Finally, we will investigate the technique of centrifugal casting also with subsequent thermo-mechanical processing. All three processes would end with a final anneal to homogenize the microstructure and reduce the residual stresses.

(b) <u>Closure</u>

Three processes have been recommended. These are:

- plasma-arc welding, which is a high-density arc welding process;
- electron-beam welding;
- friction welding.

(c) <u>Inspection</u>

An ultrasonic technique will be used for volumetric inspection and the dye-penetrant technique for surface inspections. If we end up with coarse-grain welds, then special techniques will need to be developed.

(B) <u>ALLOY 825</u>

As far as fabrication is concerned, we will employ essentially the same fabrication procedures as for the two stainless steels. However, since we anticipate a problem with titanium stabilization, we will not pursue the centrifugal casting technique with this alloy. Instead, we will construct an extruded, welded and cold-worked unit. The three methods of container closure and the two methods of container inspection described above for 304L/316L steels will also be employed with alloy 825.

## (C) COPPER (CDA 102), COPPER-NICKEL (CDA 715), ALUMINUM BRONZE (CDA 613)

With the exception of friction welding, which is a doubtful process with pure copper (CDA 102), the same fabrication, closure and inspection techniques described above will be employed. The centrifugal casting process will be evaluated for the 70/30 copper nickel and the aluminum bronze but not for the pure copper (CDA 102). Problems are anticipated in the fusion welding of the aluminum bronze since it is known to be prone to cracking and phase separation.

## (D) CLOSED-END EXTRUSION PROCESS

The closed-end extrusion process is illustrated in Figure 2. This is a

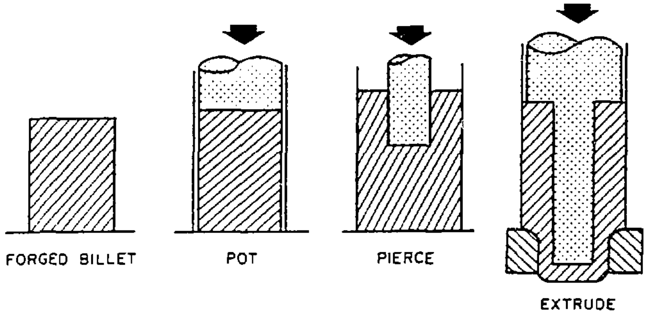


FIGURE 2: Illustration of Closed-End Extrusion Process

simplified series of steps but sufficient to illustrate the process. We start with a forged billet, square it off and place it into a pot, which acts as an external guide. Then we squeeze the billet down, pierce it with a ram, and push it through the guide. The container is extruded in the required form. The benefits of this process include the forged microstructure and the absence of both a long-seam weld and a lower-head weld. The welds are homogeneous, which means they should be less susceptible to localized corrosion that can often initiate at inhomogeneities.

## (E) CENTRIFUGAL CASTING PROCESS

Figure 3 is an illustration of a centrifugal casting machine, which is

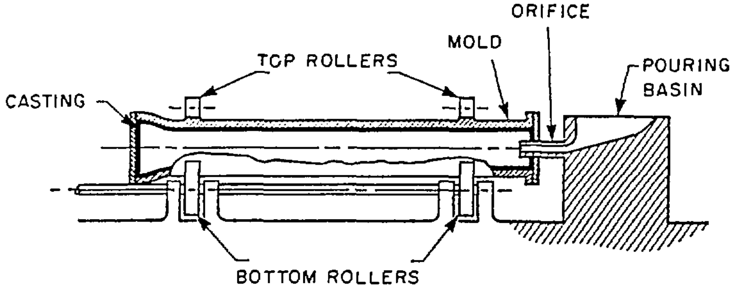


FIGURE 3: Illustration of Centrifugal Casting Machine

simply a rotated mold. It requires an axisymmetrical shape and a pouring basin to add the molten material. This process is low cost compared to the closed-end extrusion method and commercially available. The material should possess a dense clean microstructure and the container would have a low ovality and no long-seam weld.

The cold-working process to be investigated to break up the dendritic columnar weld structure and the radial columnar structure anticipated with centrifugal casting is illustrated in Figure 4. This method, which involves an external roll extrusion using two rollers and two rings on bearings would be followed by several heat-treatment steps as required. The cylinder would rotate with an internal mandrel and the external

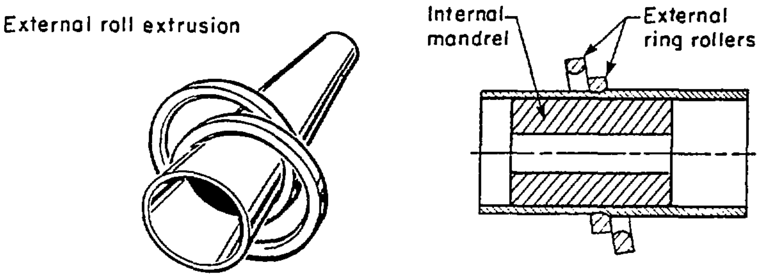


FIGURE 4: Illustration of Process for Cold-Working Cylinders

rollers push down on the walls of the cylinder making them a little thinner. The advantages of such thermo-mechanical working are mainly microstructural. The material would possess a random grain orientation with a uniform grain size, and the welds would undergo recrystallization. The cylinder would also possess improved tolerances. This thermo-mechanical process could be applied to containers formed by any of the methods described above.

(F) PLASMA ARC WELDING (PAW)

Figure 5 shows a conceptual design for the plasma-arc welding process, supplied by Babcock and Wilcox (B and W). The method is derived from the GTA (Gas Tungsten Arc) process, the main difference being that it is a high-energy plasma process with currents possibly greater than 100 A. The process is highly directional and can penetrate to significant depths. It has many advantages, including:

- Low- to medium-heat input. We may forego these advantages in order to achieve the deep penetration and high productivity possible with the high-energy beam.

- The equipment is versatile, allowing both arc and keyhole welding. In keyhole welding you penetrate through the weldment. You attain equilibrium between the plasma and the weld puddle. This enables you to produce a weld much faster than you could with the GTA process.

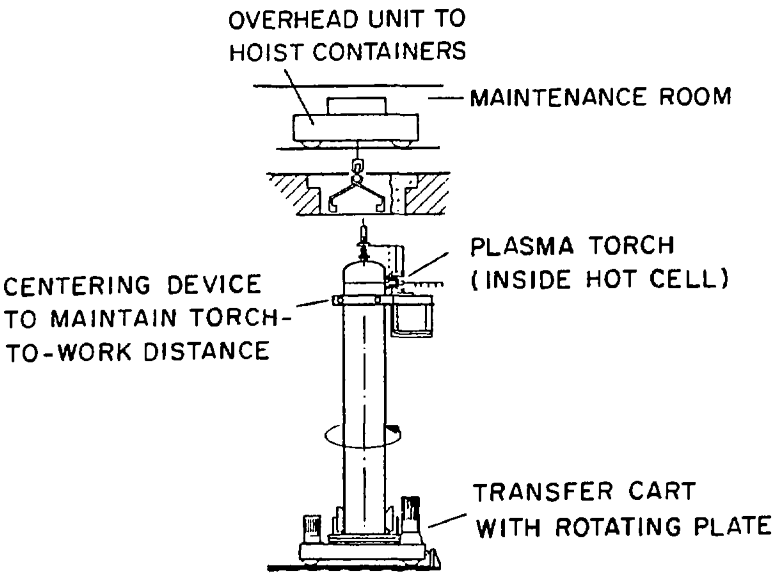


FIGURE 5: Illustration of Plasma-Arc Welding Machine

- No filler is necessary with keyhole welding.
- Repair welding can be done with the same process.
- The equipment is relatively low cost.

Figure 5 shows the PAW arrangement within the hot cell with the waste emplaced. The container is shown standing vertically, though it could be placed horizontally if desired. The centring device is required to maintain the torch-to-work distance. The plasma torch must be inside the hot cell. Also shown is the overhead unit to hoist the containers, and the transfer cart. Located outside the hot cell would be the power supply, control console, cooling system, and shielding gas.

(G) ELECTRON BEAM WELDING (EBW)

Figure 6 shows the B and W conceptual design for the electron beam welding process. This process is probably more familiar to you. One disadvantage that we have with our welding procedure is that we intend to fill the containers with argon. The electron-beam welding process can accommodate this, but you do not get the narrow beam and small heat-affected zones (HAZ) that would be achieved by welding in a vacuum. The major benefits of the electron beam welding process include:

- Small HAZ and fusion zone;
- Relatively low residual stresses and distortion;
- Welds are easy to inspect;

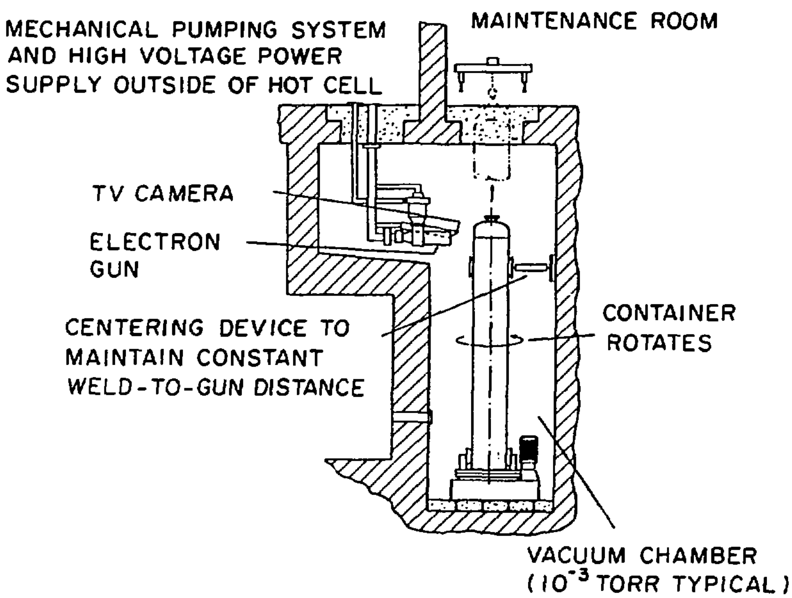


FIGURE 6: Illustration of Electron-Beam Welding Machines

- It is a fast welding process;

- Welds can be repaired without machining;

- No filler metal is required;

Inside the hot cell the container would be placed within a vacuum chamber and rotated while the electron gun and T.V. camera remain stationary. To achieve welding with the normal atmospheric pressures required with argon present, a specially modified electron gun will have to be used.

(H) FRICTION WELDING (FRW)

The friction welding process, which is a solid-state joining process that produces coalescence using the heat developed between surfaces - one surface stationary, while the other rotates - has the following metallurgical benefits: small HAZ, small fusion zone with no melting, minimum risk for second phases, and low residual stress. This method is illustrated in Figure 7.

The major process benefits of this method include its simplicity and ruggedness, and the fact that the parameters are easily controlled. A motor and flywheel are located above the hot cell and are coupled to the top-head. The flywheel is rotated and the top-head is brought into contact with the container body using a thrust plate for upset force. To avoid torque generated during welding, you need a centring and blocking system as shown. The benefits of this process include:

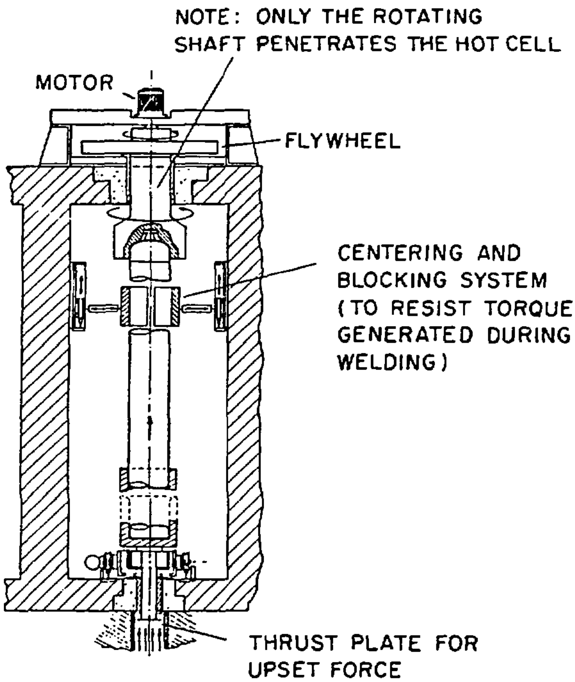


FIGURE 7: Illustration of Friction-Welding Machinery

- Small HAZ and fusion zone (without melting);
- Low residual stresses and distortions;
- Easy to inspect;
- Maintenance inside the hot cell is easy and infrequently required;
- There are very few welding variables to monitor; and
- Welding is rapid.

## (I) NON-DESTRUCTIVE EVALUATION

A conceptual design for a non-destructive evaluation system is shown in Figure 8. This system would be inside the hot cell. It is equipped with a turntable fitted with two arms: one for the dye penetrant system, the other for the transducer array. A benefit of this system is the simple mechanical arrangement with an optimized coupling, although the coupling remains to be demonstrated. This coupling may present a problem since we want to avoid significant amounts of water within the hot cell. There are other benefits to this system, including:

- We expect to detect flaws of between 1% and 10% of the wall thickness;

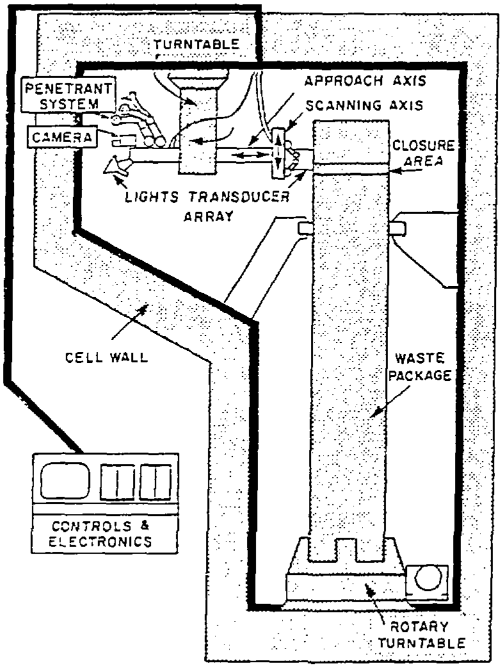


FIGURE 8: Illustration of Non-Destructive Testing System

- Flexibility of inspection of a selected joining process;

- The possibility of combining this evaluation system with our closure system in order to minimize transport of the container. This could be achieved by having a plasma-arc torch on the same turntable.

At Livermore, during Phase 2 of our program, we intend to utilize the UTB (ultrasonics test bed) facility. This is a state-of-the-art robotics system, with 14 axis, multitransducer capability. By using this system we hope to demonstrate its capabilities for our requirements before having to specify the final design of our remote hot cell facility.

In summary: in the completed Phase 1 of our program, we have screened a number of candidate processes for fabricating, closing and testing our containers. We have chosen three fabrication, and three closure methods for further evaluation in Phase 2. For inspection purposes we will use ultrasonic and dye penetrant techniques. In Phase 3 a specific fabrication/closure process will be chosen for an advanced conceptual design. On the basis of these studies, and our corrosion evaluation, we will choose the most appropriate alloy.

CROSTHWAITE Why do you intend to backfill your container with argon?

RUSSELL We would like to consider the zirconium fuel cladding as a barrier and the argon will add corrosion protection.

Also, our temperatures are high, and we wish to avoid oxidizing the cladding.

CROSTHWAITE — If you have to backfill, why don't you use helium instead of argon, so that you can simultaneously perform a helium leak test?

RUSSELL — Since argon is a heavier atom, it is a little easier to use.

KASS — Argon is cheaper than helium. However, we have not chosen a particular inert gas. Helium could be used.

CROSTHWAITE — In your discussion of non-destructive evaluation methods you only discussed weld inspection. Do you intend to do a leak test?

KASS — We are not planning to do such a test, but if required to, we will.

INTERRANTE — Backfilling to a fraction of an atmosphere with a heavy gas like argon may be sufficient for your purposes.

RUSSELL — That is a distinct possibility.

INTERRANTE — Do you really need to backflush with argon? Won't you have sufficient corrosion protection for the cladding, etc., simply by excluding oxygen during welding? After all, you then seal the container without further ingress of oxygen.

KASS — We have not fully analyzed the situation. However, since we will be getting a wide variety of fuel to dispose of, some of it could be wet. A combination of wet fuel and a partial pressure of oxygen would attack the fuel. Also water radiolysis inside the cladding could produce oxidizing conditions. We need to analyze the situation before we decide whether a partial atmosphere of argon is sufficient.

CROSTHWAITE — Why do you have to take credit for the zirconium cladding?

KASS — In our overall performance assessment we have included a term to take credit for the cladding in our code. We don't need to invoke the cladding as a barrier in order to meet our requirement of 300 years of containment. However, I see no reason not to take credit for it.

STAHL — In our assessment we assume that some of our containers will be faulty but will succeed in passing our inspection. Consequently, we assume that ~ 5% of our containers will fail in the first 300 years. Hence, we take credit for the cladding in order to prevent release of the fission products still present after such a time period.