WINCO-1153 UC-510

CORROSION IN ICPP FUEL STORAGE BASINS

W. J. Dirk

September 1993

Westinghouse Idaho Nuclear Company, Inc.

PREPARED FOR THE
DEPARTMENT OF ENERGY
IDAHO OPERATIONS OFFICE
UNDER CONTRACT DE-AC07-84ID12435

Corrosion in ICPP Fuel Storage Basins

William J. Dirk
Westinghouse Idaho Nuclear Co. Inc.
1955 Freemont Avenue
P. O. Box 4000
Idaho Falls, Idaho 83415-5217

ABSTRACT

The Idaho Chemical Processing Plant currently stores irradiated nuclear fuel in fuel storage basins. Historically, fuel has been stored for over 30 years. During the 1970's, an algae problem occurred which required higher levels of chemical treatment of the basin water to maintain visibility for fuel storage operations. This treatment led to higher levels of chlorides than seen previously which caused increased corrosion of aluminum and carbon steel, but has had little effect on the stainless steel in the basin.

Corrosion measurements of select aluminum fuel storage cans, aluminum fuel storage buckets, and operational support equipment have been completed. Aluminum has exhibited good general corrosion rates, but has shown accelerated preferential attack in the form of pitting. Hot dipped zinc coated carbon steel, which has been in the basin for approximately 40 years, has shown a general corrosion rate of 4 mpy, and there is evidence of large shallow pits on the surface. A welded type 304 stainless steel corrosion coupon has shown no attack after 13 years exposure.

Galvanic couples between carbon steel welded to Type 304 stainless steel occur in fuel storage yokes exposed to the basin water. These welded couples have shown galvanic attack as well as hot weld cracking and intergranular cracking. The intergranular stress corrosion cracking is attributed to crevices formed during fabrication which allowed chlorides to concentrate.

Key Words: Nuclear, Fuel, Storage, Basins, Aluminum, Carbon Steel, Stainless Steel, Welds, Galvanic, Stress Corrosion, Cracking, Chlorides, Nitrates, Water

I. Background

The Idaho Chemical Processing Plant (ICPP), located at the Idaho National Engineering Laboratory near Idaho Falls, Idaho, is currently operated by Westinghouse Idaho Nuclear Company, Inc., under contract from the Department of Energy. The past mission of the ICPP was as a nuclear fuel reprocessing plant with multiple headend facilities to process aluminum, stainless steel and zirconium clad fuels by acid dissolution. In 1992 the mission was changed from processing nuclear fuel to receiving, storing, and preparing spent nuclear fuels and radioactive wastes for disposition for the Department of Energy. This change in mission required a thorough review of equipment and inspection procedures for long term under-water storage of nuclear fuel.

II. Introduction

The aqueous nuclear fuel receiving and storage basin at the ICPP handles a diverse mixture of nuclear fuel materials. The principal fuel materials in the ICPP-603 basin include: aluminum clad fuel - usually from test and research reactors, stainless steel clad fuels from liquid metal cooled experimental reactors, and zirconium clad fuel from Naval reactors. In addition, there have also been occasional experimental nuclear fuel elements that have been designed to test variations in reactor design, fuel composition, or cladding materials.

In the past, fuel materials have been received from goverment reactors for processing at ICPP. Some of the fuel materials were scrap in which the cladding was compromised. These materials, received in aluminum or stainless steel cans, usually contained, scrap, segments of fuel elements that had been dissected for metallurgical or chemical examination, or fuel elements that were known to have perforated cladding.

The aqueous fuel receiving and storage basin at ICPP 603 is an "E" shaped structure (Figure 1), with provisions for receiving or shipping materials by rail or by truck. The North and Middle basins are 40 feet wide, 60 feet long and 21 feet deep, and covered with a metal floor grating. The North and Middle basins and the connecting transfer canal were constructed in 1951. The south basin section, added in 1957, is an open pool, 41 feet wide, 80 feet long, and 21 feet deep. The basin, as it now exists, is an unlined concrete structure with a capacity of approximately 1.5 million gallons of water.

The North and Middle basin areas are equipped with a trolley and hanger system (Figure 2) from which fuel materials can be suspended underwater as individual fuel units or as items contained in cans or buckets. The south basin is a large open area in which fuels are stored in underwater racks (Figures 3 and 4).[1]

The original basin used a water flow through system which was disposed of on site. Concentrations of contaminants and chloride were slightly above that of the well water feed. This mode of operation was discontinued in 1966 when the basin went to a closed loop system. Operation of the basin as a closed system led to concentration of both radioactive and non-radioactive substances. A treatment system to remove radioactive contaminants was installed and made operational in 1973; however, ionic constituents continued to buildup. Biological growth, in the form of algae, resulted in the loss of clarity and acted to increase activity buildup. In order to control the algae, sodium hypochlorite, chlorine, and iodine were added separately as an algicide. Concentrations of chloride rose to approximately 800 ppm by 1976. A study was conducted on the existing conditions, after which several alternative treatments, as well as water quality specifications were recommended. A system to reduce the concentration of chlorides and other contaminants in the water was installed and operated for 40 days in 1976. This system employed reverse osmosis (RO) treatment of the incoming basin water makeup and evaporation of the RO reject stream by an augertype evaporator to convert the high salt solution to a damp solid which was collected in drums for disposal. During this period, the chloride was reduced to approximately 360 ppm. The RO unit was not operated from 1977 to 1980 due to high radiation exposure to maintenance personnel, caused primarily by frequent breakdown of the evaporator. The RO unit operated periodically from 1981 to 1983, during which time the chloride concentration was reduced to the 80-90 ppm level. Currently the algae is controlled by use of ultraviolet lights, and levels of chloride are controlled by using makeup water with very low chloride content. Periodic transfers of basin water to the process equipment waste evaporator (PEW) has helped to reduced the chloride concentration to its current range of 54-60 ppm by dilution.[2] Table I lists current water chemistry.

III. Discussion

The change from fuel processing to a facility to handle fuel storage, dispositioning of fuel, and waste management has placed an increased emphasis on the integrity of the CPP-603 basin facility, equipment, and stored fuel. In the past, fuels which experienced fuel cladding degradation were removed and processed before any major problems could occur. Today, those same types of conditions must be addressed for long term storage and ultimate disposition. In addition, equipment that have been exposed to the high chlorides in the basin water must be reevaluated for service life. Analysis of the carbon steel hangers from the trolley system, which support the fuel and fuel buckets, has shown their integrity to be questionable. Corrosion in the form of general attack, galvanic attack and stress corrosion cracking have been identified as possible modes of failure. All of the fuel and fuel buckets in the North and Middle basin have been redundantly rigged using stainless steel cables to prevent fuel from falling due to potential hanger and bucket failures. The current schedule is to remove all fuel from the North and Middle basin by the end of 1996 and the South basin by the end of year 2000. The intent of this paper is to present the identified problems and provide a lessons learned approach to be applied to other aging nuclear facilities.

Lack of documentation of equipment fabrication has complicated the implementation of the best methods of corrosion control. Equipment fabricated during the 1950's through the 1970's used existing techniques and did not always have as-built drawings showing how the item was fabricated. Baseline measurements were not taken to provide information for end-of-life estimates based on material losses. Equipment would have to be pulled from the basin, measured, and minimum thicknesses back calculated to estimate the remaining service life. In the early 1950's through the 1970's design packages often were not reviewed by technical personnel experienced in corrosion processes. There were instances when carbon steel hangers were welded with stainless steel weld metal, thus introducing a galvanic couple. Equipment design did not address the problem of corrosion due crevices formed in fabrication of equipment. In addition, basins contained many different types of metals requiring different approaches for corrosion control which resulted in a compromise for water quality controls. For instance, pitting of aluminum by chloride was moderated by the use of the nitrate ion.[3,4] This was monitored using a nitrate to chloride ratio. Stainless steel is passivated by the nitrate while the corrosion of carbon steel is accelerated at low pH values. In order to maintain corrosion rates at an acceptable level the basin water pH was maintained in a range of pH 5 to pH 8.5.

The types of attack found in the CPP-603 basin have been identified as galvanic corrosion, pitting corrosion, stress corrosion cracking, crevice corrosion, and deterioration of concrete. These types of corrosion and their effect on equipment was previously discussed in CORROSION/81 paper 167; however, additional information has been obtained by metallurgical examination and underwater video camera. [1]

Corrosion Coupons:

Stainless steel and aluminum corrosion coupons have been installed in the south basin. A welded stainless steel tie plate, representing the "Tie-Plate" for the stainless steel fuel storage racks, has been inspected on a semi-annual basis for 13 years (Figure 5). During each inspection period the coupon has been evaluated for stress corrosion cracking using a fluorescent dye penetrant examination. In addition, ultrasonic thickness measurements have been made periodically. Results are shown in Table II.

Two types of aluminum corrosion coupons have been installed in the south basin. The first type uses an expanded metal mesh to duplicate the screens on the aluminum racks. The second type of coupon uses a woven wire mesh to duplicate the screens on previous aluminum racks. These coupons were designed with plate material, pipe material, and crevices. Figures 6 through 11 show the chronological progression of corrosion of these coupons. These coupons have been inspected every 6 months and have seen an exposure of 10.6 years. Aluminum has shown a general attack of 1.5 mpy with preferential attack in the form of pitting and crevice attack. Ultrasonic thickness measurements are shown in Table III and Table IV for the expanded aluminum mesh and wire mesh aluminum corrosion coupons.

Hanger Corrosion:

Failure of one of the hooks on a double trunion hanger (Figure 12) in 1992 led to increased inspection of existing hangers supported by the monorail system. There are three types of hangers used in the North and Middle basin. The first is a welded Type 304 stainless steel hanger with a single hook. One of these hangers was tested to failure and a section of the welded 5/8 inch hook and hanger assembly was metallurgically evaluated. There was no indication of significant attack of the stainless steel at any point. Ultrasonic thickness measurements showed no indications of general attack after 17 years of exposure when the immersed section was compared to the section above the water line.

The second type of hanger was constructed of a 1/2-inch thick by 2-inch-wide carbon steel bar with a 5/8 inch Type 304 stainless steel eye piece welded in a notch cut into the end of the bar (Figure 13). The carbon steel had been previously galvanized to increase the service life, however, there was very little zinc galvanizing left. Ultrasonic thickness measurements made on the carbon steel bar showed a general thickness loss of 0.106 inches after 24 years exposure to the basin water. The area where the stainless steel rod was welded into the carbon steel bar showed evidence of attack in the heat affected zone parallel to the weld. This is indicative of galvanic attack. This hanger was sectioned and metallographically examined. Figure 14 shows a description of where the hanger was sectioned and Figure 15 shows a representation of the sectioned piece. The cross section of the hanger (Figure 14-B) shows incomplete penetration of the weld resulting in a crevice on both sides of the stainless steel rod. This crevice was filled with corrosion product and allowed chloride ions from the basin water to concentrate. Figure 16 shows an example of chloride stress corrosion cracking of the Type 304 stainless steel bar which initiated near the heat affected zone. Other types of cracks were noted, but have been attributed to hot cracking during fabrication. An example of these type of cracks are shown in Figure 17. A second sample was cut from the bumper section of the carbon steel hanger (Figure 14-C). The bumper is important in keeping nuclear fuel separated for nuclear criticality safety. Since the carbon steel had been heavily attacked, it was necessary to evaluate the carbon steel welds to determine their structural strength. The metallographically mounted cross section of the welds showed some corrosion product, the remaining weld showed sufficient weld integrity to prevent loss of the bumper section due to a normal impact (Figure 18). A third section was cut from the bumper cross piece where it was welded to the main carbon steel bar (Figure 14-A). This section showed that the carbon steel was welded with a stainless steel weld rod. Hot cracking of the stainless steel weld occurred in this section (Figure 19)

The third type of hanger examined was the double trunion hook type (Figure 12). Two hangers were examined. The first in a routine inspection showed that both hooks had fallen off in service under a no-load condition near the junction of a stainless steel to carbon steel weld. Drawings indicated that there was a step down at this point where a separate section of the 3/8 inch thick hook which was welded with a 1/8 inch fillet weld on one side to the 1/2 inch thick carbon steel hanger. The question to be resolved was whether the hook failed by galvanic attack or attack of the small fillet weld. In actuality, the joint was an open butt weld, not a fillet weld (Figure 20). A second hanger was removed from the basin and a section involving the stainless steel to carbon steel weld and the open butt weld was cut out (Figure 21). The results indicated that the failure occurred because of general corrosion of the carbon steel weld. Galvanic attack of the carbon steel caused by the bi-metallic couple with the stainless steel was not a factor.

Fuel Corrosion :

There is a requirement to inspect a representative sampling of each type of fuel can stored in the CPP-603 basin every eighteen months. In the past, this visual inspection was performed using underwater lights and binoculars through 20 feet of water. Zirconium clad fuel and Stationary Medium Power Reactor #1 (SM-1) fuel in stainless steel cans showed no visible attack (Figure 22). Aluminum clad fuel and fuel in aluminum cans showed moderate to heavy oxide buildup indicating pitting attack of the aluminum. The aluminum inspection was limited to a visual inspection since there was not a hot cell available to do a close up inspection. A hot cell is a special cell which is designed for remote work and provides shielding of radioactive materials to prevent personnel exposure to radiation. In 1992 the technology of underwater camera systems progressed to the point where an acceptable picture for viewing could be captured on video tape. With the acquisition of a very small underwater camera it became possible to lower the camera into a fuel storage bucket and view the fuel contents. Space Nuclear Auxillary Power (SNAP) fuel were stored in aluminum cans. Examination confirmed breaching of the alumium cans due to pitting corrosion as exemplified by the buildup of heavy corrosion product. In addition, it was possible to see the bottom of the aluminum can in contact with the stainless steel bucket. At this point, galvanic corrosion had occurred in conjunction with internal corrosion of the aluminum can, allowing some of the fuel pins inside the can to be exposed. Accelerated corrosion of the aluminum can appeared to occur after the first observed perforation of the aluminum can. Movement of the fuel under controlled conditons caused the can to break apart at the point where the aluminum can came in contact with the stainless steel divider (Figure 23). The results of this inspection has led to a full video taping of all fuel in the

North and Middle basins and is being expanded to the fuel in the storage racks in the South basin.

Concrete Corrosion:

The visible portions of the concrete basin structure are examined on an annual basis for indications of surface deterioration at the liquid air interface, and any cracking of all visible surfaces. A core sample was taken to evaluate any migration of chloride into the concrete which could reach the rebar. A vertical core was drilled parallel to the basin wall to obtain concrete at the water level and to obtain a rebar sample. This core was then evaluated for concrete deterioration and the potential for rebar corrosion.[5] There was no indication of chloride attack on the rebar sample, however, chloride levels found above the water line were measured at 0.104 weight percent chloride of the concrete. While it is possible for corrosion of steel at this level of chloride, the moisture content required to propagate corrosion of the rebar in the concrete has been reduced by evaporation. Sulfate levels were found to be low, in the range of 0.18 to 0.29 weight percent. The low level of sulfate in the cores make it unlikely that disruption of the concrete due to sulfate attack will occur in the future.

IV. Conclusion

The ICPP-603 fuel storage basin has operated successfully for over 40 years using carbon steel, stainless steel, and aluminum as materials of construction. Continued long term use of this facility would require major equipment change out to maintain the safe operation required for long term fuel storage. In support of the new mission, the ICPP-603 fuel storage basin will remain in service for 6 to 7 additional years to implement canning and removal of the remaining fuel.

Information derived from operation of the ICPP-603 fuel storage basin was used in design of the new state of the art stainless steel lined fuel storage basin ICPP-666. This basin was designed to use high purity water and ultraviolet lights for sterilization of the water and is expected to meet the requirements for long term fuel storage.

Lessons learned during the detailed inspection of equipment in the CPP-603 fuel storage basin which apply to other existing fuel storage basins and design of new storage basins are:

1. Equipment designed for long term aqueous exposure should utilize corrosion resistant materials, and minimize crevices and as many galvanic couples as possible.

2. Compatible type fuels should be stored in the same basin. For example, stainless steel clad fuel and zirconium clad fuel should be stored together, but not with aluminum types.

3. Aluminum clad fuel should be stored only for short times in aqueous fuel storage basins and should be transferred to dry fuel storage as soon as possible to mitigate the potential effects of pitting.

4. Control of chloride levels and contaminants in the parts per billion (ppb) range may be required for long term aqueous storage.

5. For new construction, a good quality control program is required for traceability of materials and an as-building program to provide good base line data for future reference. This goes hand in hand with an engineering program that has identified the criteria necessary to determine end of life of operating equipment.

6. Concrete fuel storage basins should be designed with linings to allow better water quality control and ultimately reduce corrosion of fuel and equipment.

Acknowledgements

The author would like to acknowledge the metallographical guidance from Mr. Brad C. Norby and the laboratory assistance of Ms. Lucy L. Littleton in preparing and interpretation of the metallurgical samples.

References

1. C. A. Zimmerman, "Control of Corrosion in Aqueous Nuclear Fuel Storage Basin," Corrosion/81, paper 167, April 1981.

2. Report from Ion Exchange Associates, Inc. to Westinghouse Idaho Nuclear Co., "Evaluation of CPP-603 Basin Water Treatment System," pages 1-3, dated May 12, 1993.

3. Böhni, H. and Uhlig, H.," Environmental Factors Affecting the Critical Pitting Potential of Aluminum," J. Electrochemical Society, 1969, page 116 : 906

4. Report from James M. Montgomery, Consulting Engineer, Inc. to Allied Chemical Corporation, "CPP-603 Fuel Storage Basin Water Quality Study " dated June 28, 1974, pages 13-23.

5. Draft Report from Wiss, Janney, Eistner Associates, Inc. to Westinghouse Idaho Nuclear Co., "CPP-603 Basin Concrete," dated April 30, 1993.

Table I

CPP-603 Water Chemistry

pH	CL^- (PPM)	NO_3^- to CL^- Ratio	Conductivity (μMHOs/CM)
8.1	53.4	3.26	637

Table II

Ultrasonic Thickness Comparisons for the CPP-603 Type 304 Stainless Steel Tie Plate

Location	4/4/80	10/9/91	3/27/92	10/19/92	4/14/93
1	0.245 inches (0.622 cm)	0.244 inches (0. 620 cm)	0.242 inches (0.615 cm)	0.245 inches (0.622 cm)	0.248 inches (0.630 cm)
2	0.247 (0.627)	0.247 (0.627)	0.247 (0. 627)	0.248 (0.630)	0.253 (0.643)
3	0.249 (0.632)	0.246 (0.625)	0.247 (0.627)	0.248 (0.630)	0.252 (0.640)
4	0.245 (0.622)	0.244 (0.620)	0.243 (0.617)	0.243 (0.617)	0.247 (0.627)
5	0.359 (0.912)	0.354 (0.899)	0.367 (0.932)	0.359 (0.912)	0.357 (0.907)
6	0.356 (0.904)	0.344 (0.874)	0.354 (0.899)	0.355 (0.902)	0.347 (0.881)
7	0.350 (0.889)	0.339 (0.861)	0.351 (0.892)	0.349 (0.886)	0.345 (0.876)
8	0.351 (0.892)	0.366 (0.930)	0.356 (0.904)	0.349 (0.886)	0.344 (0.874)

Notes: Ultrasonic thickness tolerances are $\pm$ 0.003 inches (0.076 cm).
Total exposure of the "Tie Plate" in CPP-603 basin water is 14.7 years.
Locations 1-4 are plate material. Locations 5-8 are channel bar material.

Table III

Thickness Measurements of CPP-603 Aluminum Corrosion Specimen #1

Expanded Metal Mesh

10/21/82	10/9/91	3/27/92	10/19/92	4/19/93
0.125 Inches (0.319 cm)	0.118 Inches (0.300 cm)	0.119 Inches (0.302 cm)	0.122 Inches (0.310 cm)	0.125 Inches (0.318 cm)
0.125 (0.318)	0.116 (0.295)	0.121 (0.307)	0.123 (0.312)	0.122 (0.310)
0.290 (0.737)	0.287 (0.729)	0.283 (0.719)	0.291 (0.739)	0.288 (0.732)
0.274 (0.696)	0.296 (0.752)	0.266 (0.676)	0.288 (0.732)	0.297 (0.754)
0.125 (0.318)	0.115 (0.292)	0.120 (0.305)	0.121 (0.307)	0.123 (0.312)
0.126 (0.319)	0.121 (0.307)	0.119 (0.302)	0.121 (0.307)	0.123 (0.312)
0.283 (0.719)	0.286 (0.726)	0.272 (0.691)	0.271 (0.688)	0.285 (0.724)
0.297 (0.754)	0.279 (0.709)	0.289 (0.734)	0.288 (0.732)	0.272 (0.691)

Note: 1. Tolerances for plate 0.109-0.140 inches (0.277-0.356 cm) thick is $\pm$ 0.0045 inches (0.011 cm).

Table IV

Thickness Measurement of CPP-603 Aluminum Corrosion Specimen #2

Wire Mesh Screen

10/21/82	10/9/91	3/27/92	10/19/92	4/19/93
0.124 Inches (0.315 cm)	0.115 Inches (2.92 cm)	0.121 Inches (0.307 cm)	0.128 Inches (0.325 cm)	0.120 Inches (0.305 cm)
0.124 (0.315)	0.118 (0.300)	0.121 (0.307)	0.121 (0.307)	0.123 (0.312)
0.293 (0.744)	0.289 (0.734)	0.287 (0.729)	0.291 (0.739)	0.292 (0.742)
0.298 (0.757)	0.281 (0.714)	0.287 (0.729)	0.276 (0.701)	0.269 (0.683)
0.125 (0.318)	0.117 (0.297)	0.120 (0.305)	0.122 (0.310)	0.122 (0.310)
0.124 (0.315)	0.115 (0.292)	0.120 (0.305)	0.121 (0.307)	0.122 (0.310)
0.285 (0.724)	0.289 (0.734)	0.276 (0.701)	0.278 (0.706)	0.280 (0.711)
0.276 (0.701)	0.279 (0.709)	0.274 (0.696)	0.286 (0.726)	0.290 (0.737)

Note: 1. Tolerances for aluminum plate 0.109-0.140 inches (0.277-0.356 cm) thick is $\pm$ 0.0045 inches (0.011 cm).

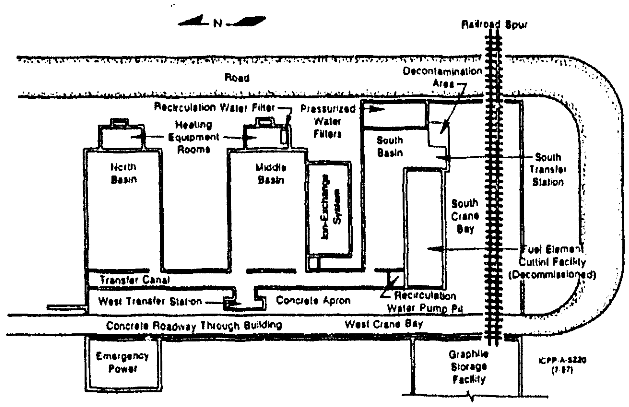

Figure 1- ICPP Aqueous Fuel Storage Basin

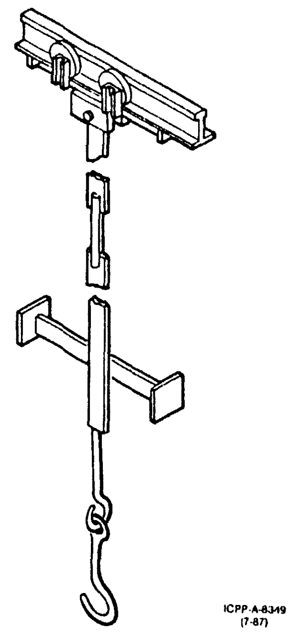

Figure 2 - Trolley and Hanger Assembly

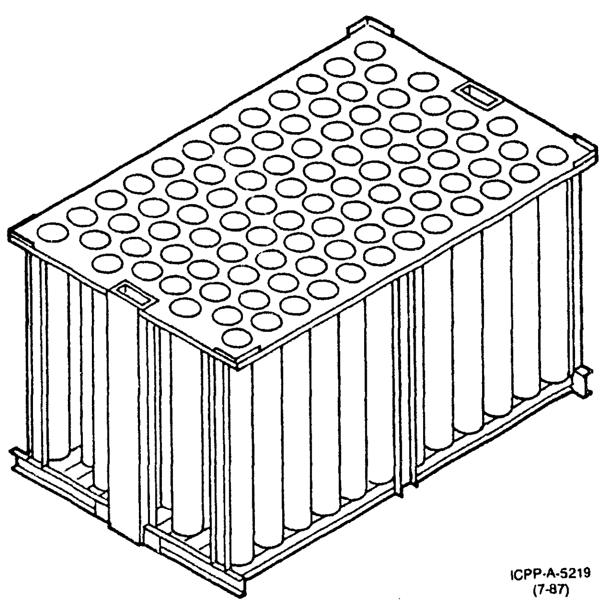

Figure 3 - Aluminum Fuel Storage Rack

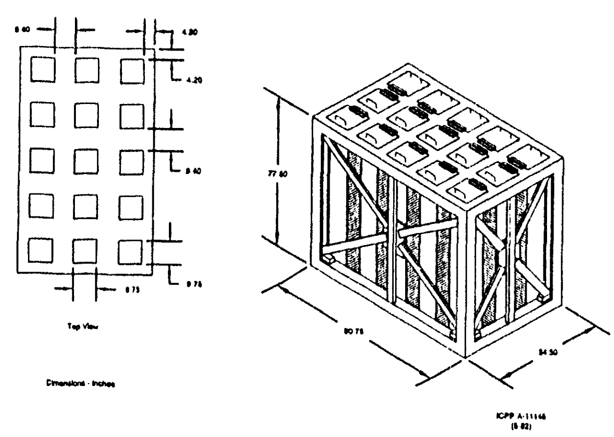

Figure 4 - Stainless Steel Fuel Storage Rack Type RK-SF-900

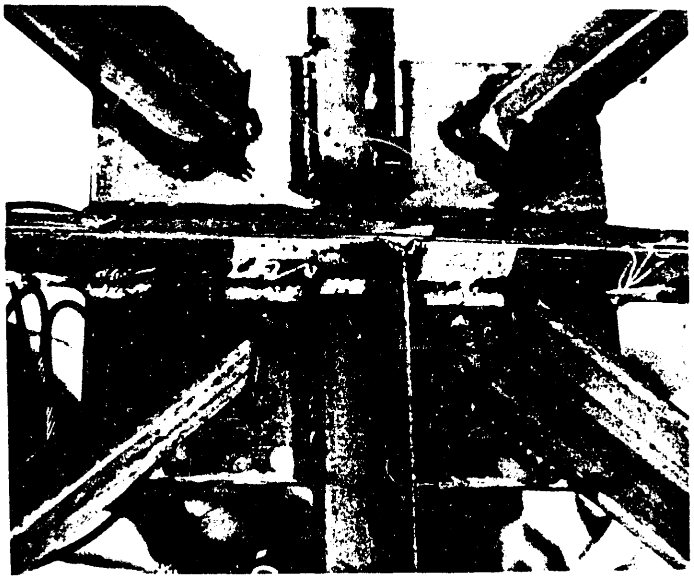

Figure 5 - Stainless Steel "Tie-Plate"
13 Years Exposure

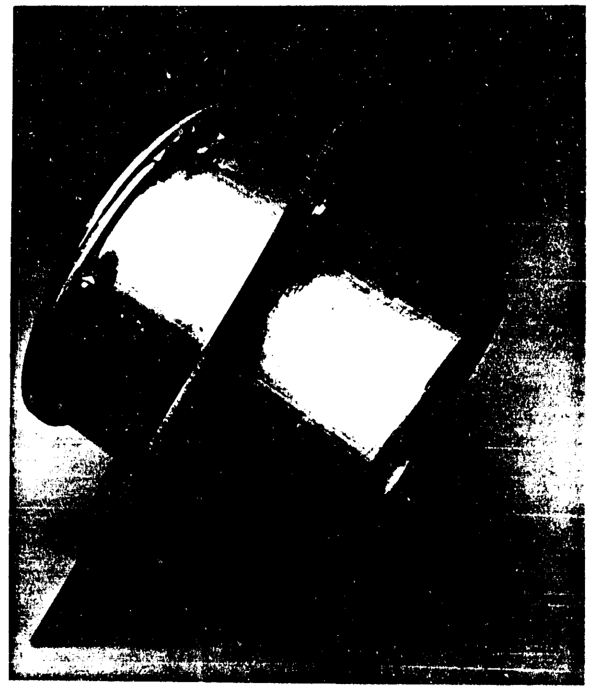

Figure 6 - Aluminum Coupon
Before Exposure

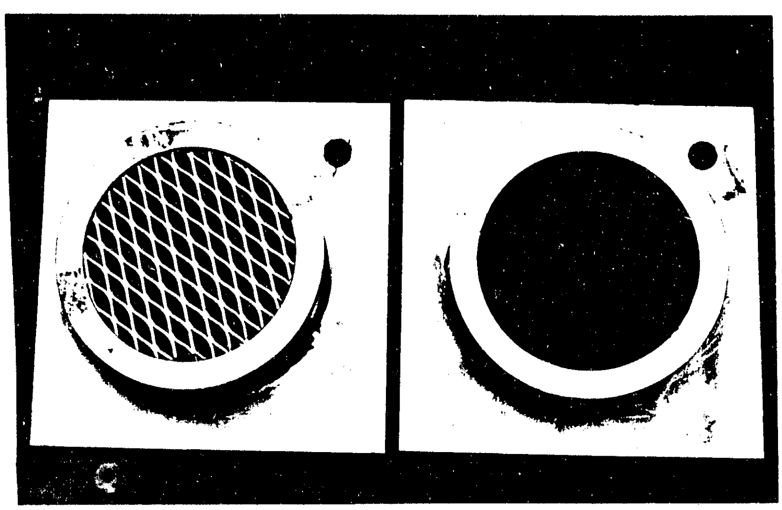

Figure 7 - Expanded Metal and Wire Mesh Aluminum Coupon before Exposure

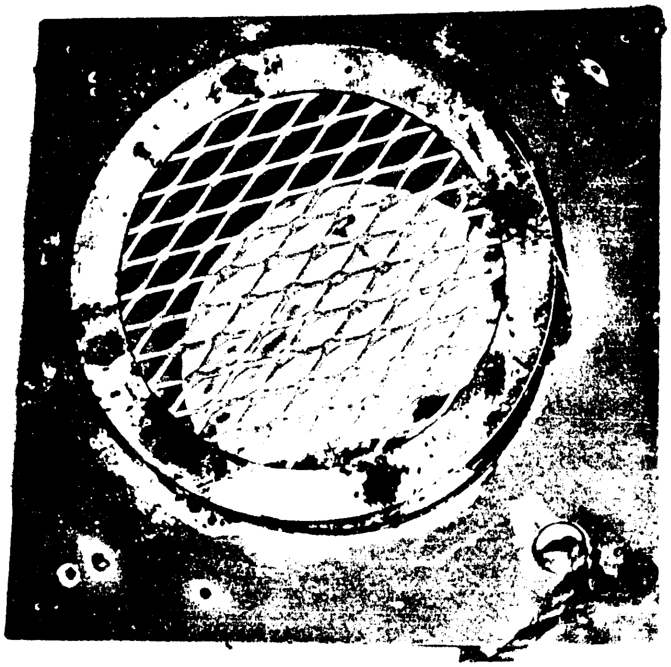

Figure 8- Aluminum 6 Years Exposure

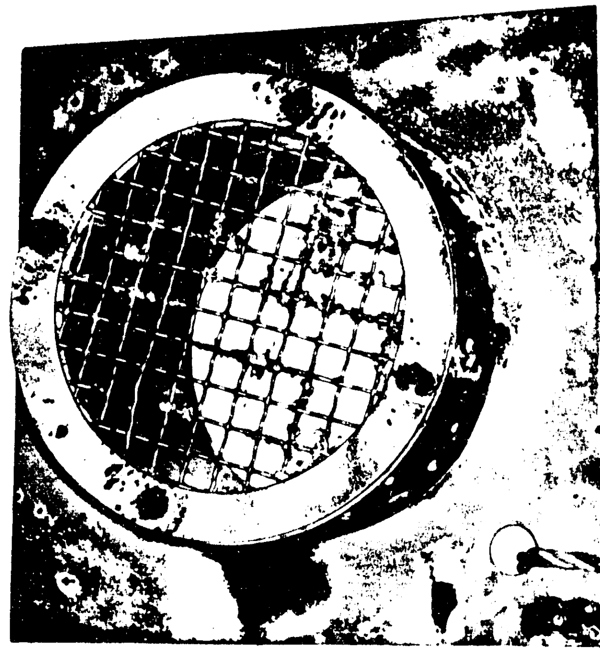

Figure 9 - Aluminum 6 Years Exposure

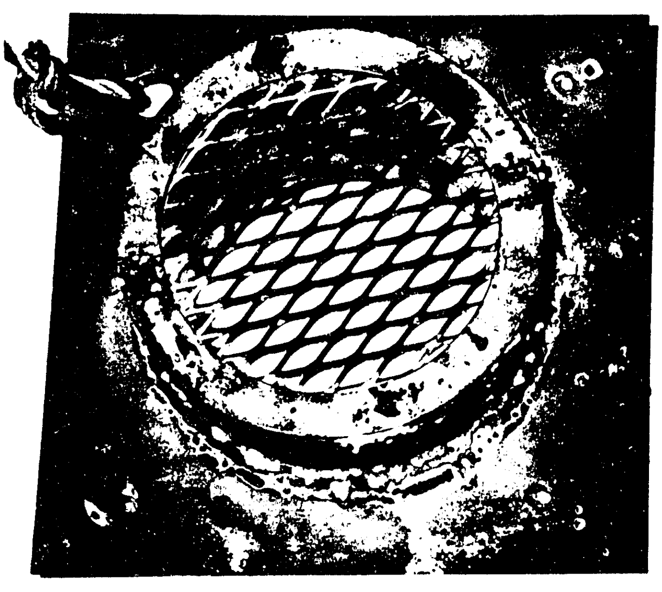

Figure 10 - Aluminum 10 Years Exposure

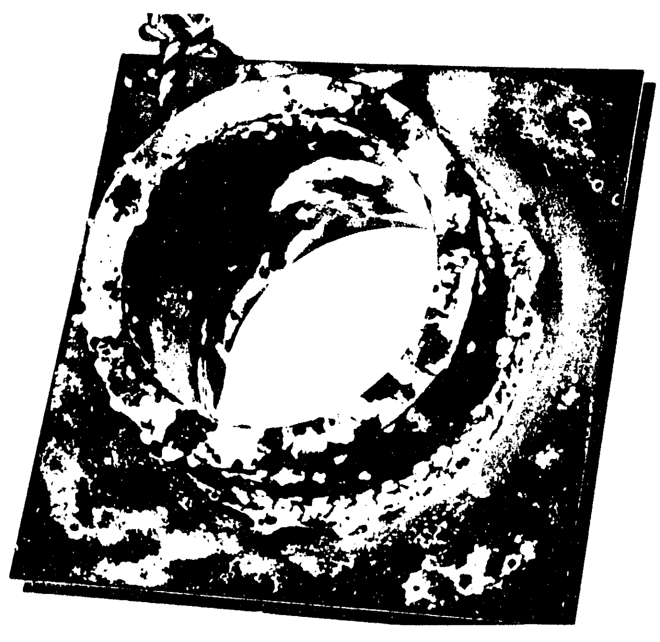

Figure 11 - Aluminum 10 Years Exposure

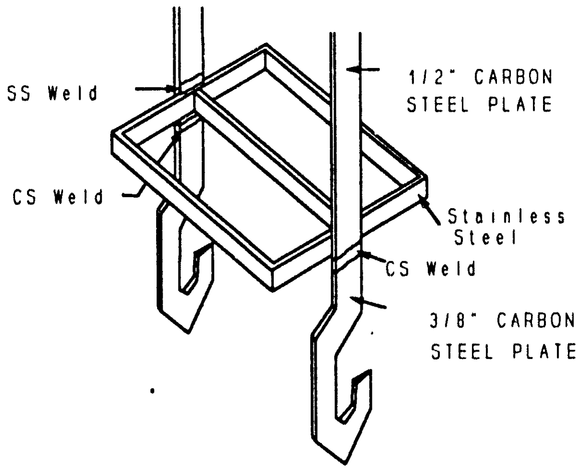

Figure 12 - Double Trunion Hook

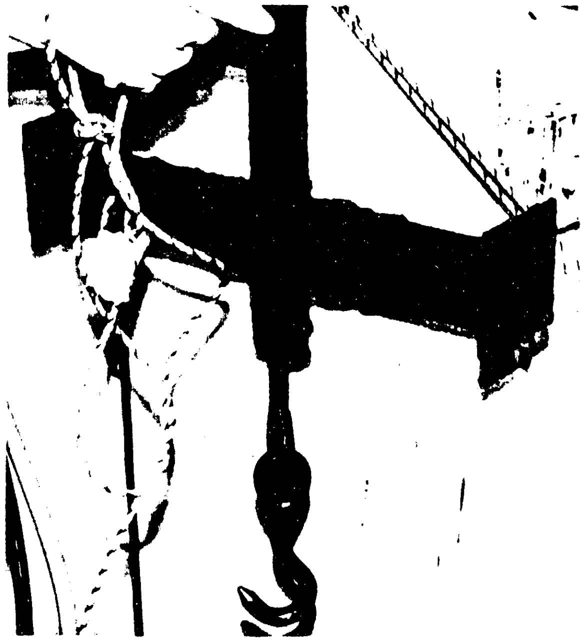

Figure 13- Single Carbon Steel Hanger Stainless Steel Hook

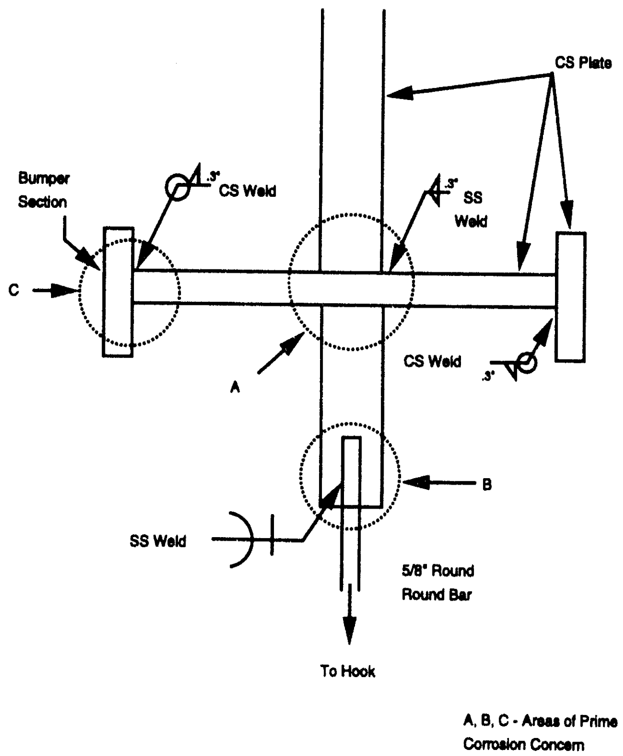

Figure 14 - Single Hanger Assembly

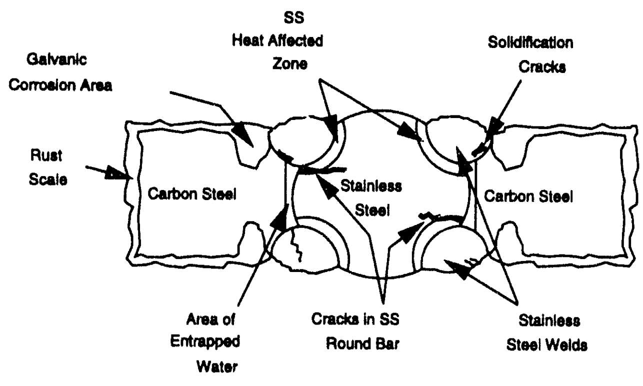

Figure 15 - Cross Section of Single Hook

Figure 16 - Intergranular Crack of the Type 304 SS 5/8 inch Single Hook Welded Bar-100X

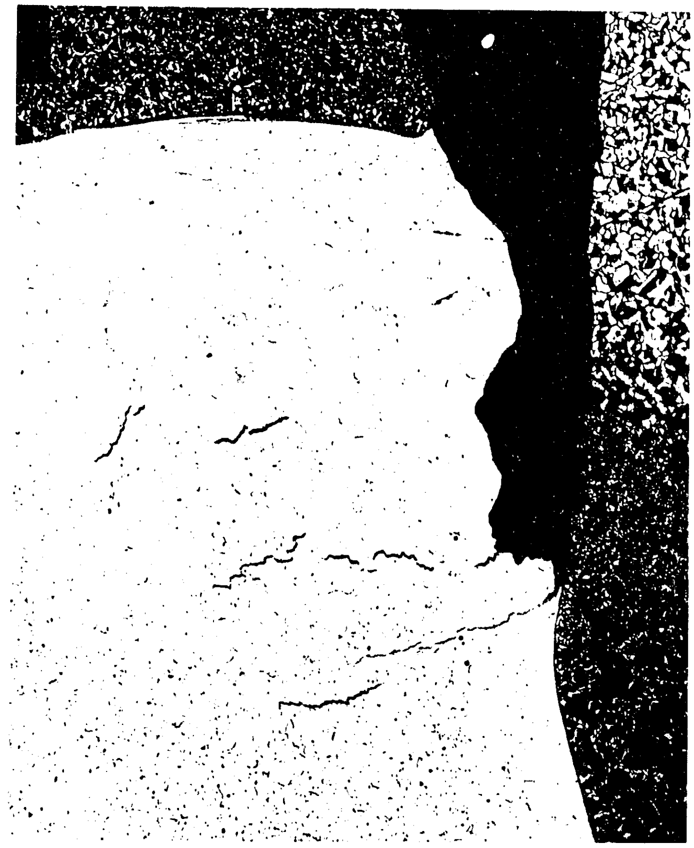

Figure 17 - Solidification cracks of the Stainless Steel Bumper Weld - 50X

Figure 18 - Galvanic Attack of the Type 304/Carbon Steel Weld

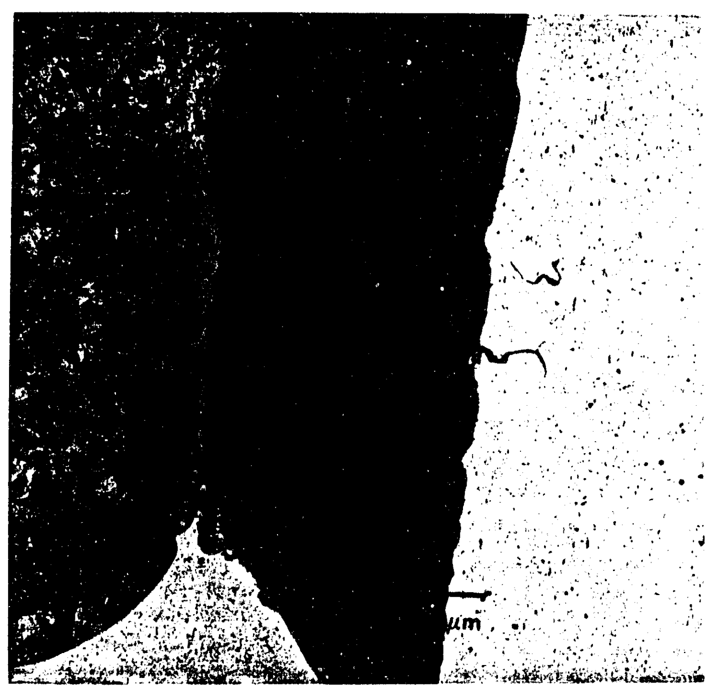

Figure 19 - Section of the Double Trunion Hook Welds

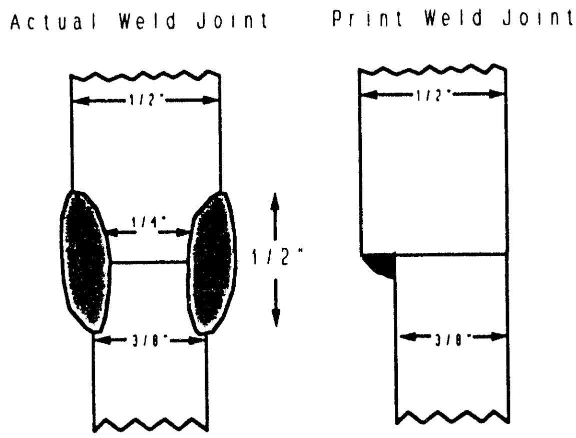

Figure 20 - Double Yoke
Open Butt Weld

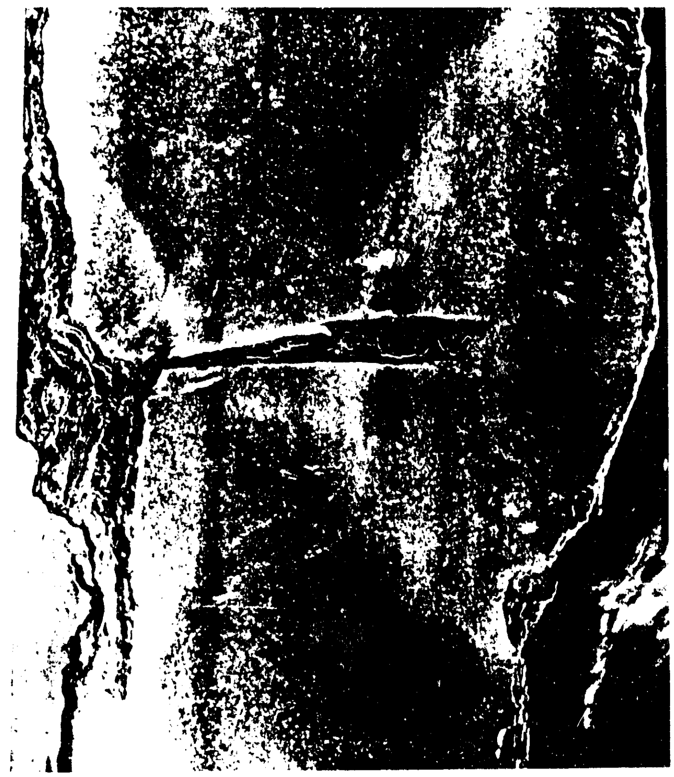

Figure 21 - Double Yoke Butt
Weld

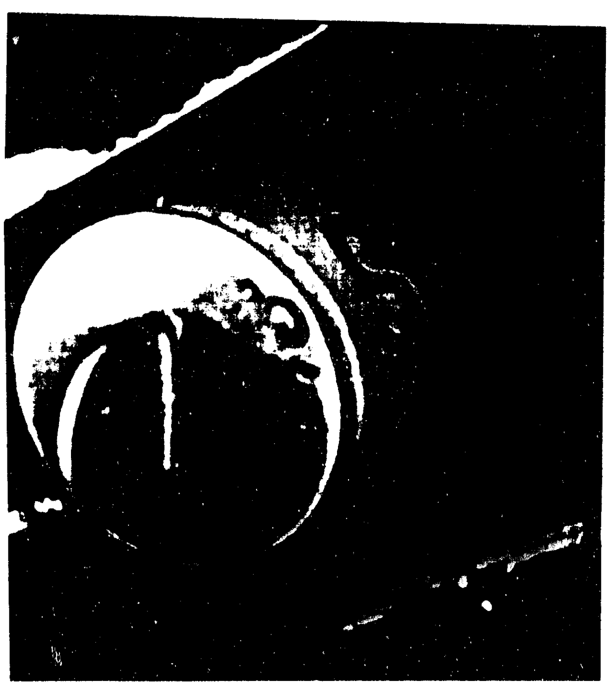

Figure 22 - SM-1A Stainless
Steel Fuel Can

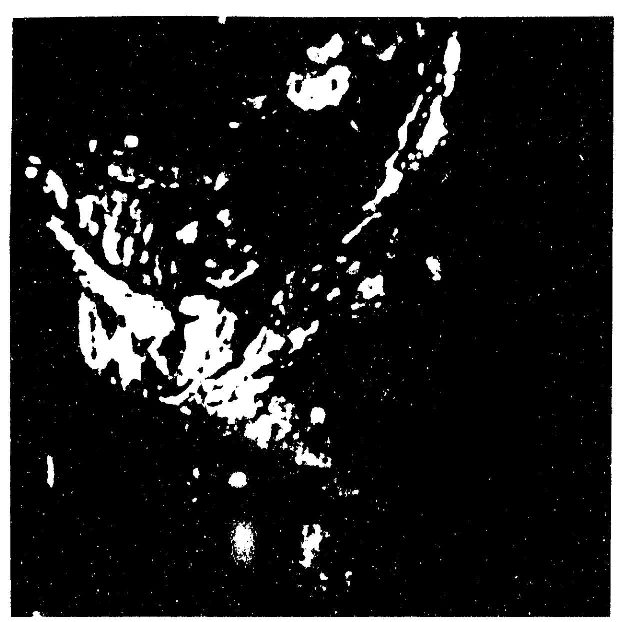

Figure 23 - SNAP Aluminum
Fuel Can

DATE

FILMED

4/21/94

END