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Safety Evaluation of Soda-Acid Fire Extinquishers

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National Bureau of Standards
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Failure Analysis Report

Prepared for
Bureau of Engineering Safety
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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Acting Director***

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SUMMARY

A safety evaluation of soda-acid fire extinguishers was carried out. One extinguisher which exploded was photographed at low magnification, and three extinguishers removed from service were evaluated by metallographic examination and by pressurization tests. The objective of these evaluations was to determine if the susceptibility of soda-acid fire extinguishers to catastrophic failure during use were a generic problem.

The fire extinguisher which exploded separated into two pieces via a circumferential tear at the dome end. The path of the tear was through dome metal --- it followed what appeared to be a brazed joint between dome and collar.

One of the three extinguishers removed from service was cut up to facilitate metallographic examination. Definite evidence of interior deterioriation due to deformation and corrosion was found along a circumferential path following a joint between the dome and collar. Visual examination of the other two extinguishers removed from service revealed interior deterioriation in the same region. However, these two extinguishers performed well during pressurization tests --- one withstood 25 pressurizations such as occur during discharge in service, then burst at 850 psig, as compared to the required test pressure of 500 psig. The second extinguisher burst at 700 psig. Failure of both extinguishers occurred by bursting a disk out of the cap.

It was concluded that deterioriation at the dome end is likely to occur in many soda-acid fire extinguishers. Susceptibility to such deterioriation seems attributable to a combination of several factors, including design, use of dissimilar metals, manufacturing practice, handling in service, time in service and frequency of discharge. However, even extinguishers removed from service which exhibited conspicuous interior deterioriation performed satisfactorily in pressurization tests. Hence, the results of this evaluation are inconclusive as regards the question of whether or not the susceptibility of soda-acid fire extinguishers to catastrophic failure is a generic problem.

SAFETY EVALUATION OF
SODA-ACID FIRE EXTINGUISHERS

I. INTRODUCTION:

Reference: Bureau of Engineering Safety, Consumer Product Safety Commission, Washington, D.C. 20207. This investigation was conducted at the request of Mr. S. Greenwald, Office of Consumer Product Safety - NBS, and Mr. James Talentino, Bureau of Engineering Safety, Consumer Product Safety Commission. The request was made on June 26, 1975.

On June 26, 1975, Mr. S. Greenwald, Mr. James Talentino and Dr. Bruce Christ of the NBS Mechanical Properties Section conferred about how to proceed with the evaluation of three used-but-undamaged* soda-acid fire extinguishers which had been left at NBS on June 18, 1975 by Mr. Talentino. Attention was being given to these used soda-acid fire extinguishers because a similar one had exploded in use and resulted in a fatality. The fatality occurred on May 6, 1975 during a fire-fighting demonstration by firemen in the vicinity of San Antonio, Texas (Reference 1). It was reported that the three used fire extinguishers were from a collection which had been voluntarily turned in by owners subsequent to the accident (Reference 1). These three fire extinguishers are identified as follows: Manufactured by Company A, all model SA SG, Numbers G 319542, F 701019 and F 700745.

The fire extinguisher which exploded (Number F 407396) had been left at NBS on June 18, 1975 for some photographing. This fire extinguisher was returned to Mr. Talentino on June 26, 1975. Several photographs of this fire extinguisher were transmitted via memo to Mr. Talentino on July 8, 1975 (Reference 2). Analysis of this failed fire extinguisher was of a preliminary nature, due to a constraint suggested by the Consumer Product Safety Commission for legal reasons, "Do not alter its physical condition or visual appearance in any way." (Reference 3).

According to Mr. Talentino, the objective of the Consumer Product Safety Commission in this matter was to determine if the fire extinguisher failure which led to the fatality were a generic problem for soda-acid fire extinguishers --- the three used fire extinguishers were made available to test in any way which might provide information

* Throughout this report, the phrase "used-but-undamaged" referes to extinguishers removed from service. Details of service history, such as time in service and frequency of discharge are unknown. However, it may be assumed that each extinguisher was discharged annually in accord with instructions on the label fastened to the extinguisher shell.

related to this objective. As a result of the discussion on June 26, 1975, the following course of action was agreed upon:

1. cut up one used fire extinguisher for purposes of metallographic examination, and

2. carry out pressurization such as occurs in service on another used fire extinguisher in an attempt to promote a burst failure.

This report contains a selection of results from the preliminary analysis (Reference 2) which was carried out on the fire extinguisher that led to the fatality. This report also contains results obtained from one used extinguisher which was cut up for purposes of metallographic examination, and results from one used extinguisher which was subjected to pressurization such as occurs in service. Results of hydraulic burst tests are also included. These tests were agreed to between Mr. Talentino and Dr. John Smith of NBS when service-type pressurization did not lead to a burst.

II. BACKGROUND INFORMATION:

The Consumer Product Safety Commission supplied NBS with the following documentation:

1. A copy of a memo to Richard Armstrong, Director, BES from Carl Blechschmidt, Director, Office of Product Defect Identification. Attached to this memo was information about the fatal accident (Reference 1). Also attached was literature about fire extinguishers from the National Association of Fire Equipment Distributiors, Inc. (hereafter referred to as NAFED) (Reference 4).

(ANSI Z171.1-1969) "Standards For Safety - Soda-Acid Fire Extinguishers, dated October 14, 1969 (Reference 5).

Some highlights from this background information are cited below.

A. Accident Report (Reference 1)

1. The fire extinguisher which exploded and caused a fatality on May 6, 1975 had been hydrostatically re-tested in November, 1973. A statement about the re-test pressure was not found in Reference 1.

2. The fire extinguisher which exploded had sprayed water for approximately 10 to 20 seconds before the explosion.

B. Literature From NAFED (Reference 4)

1. Periodic hydrostatic re-test occurs every 5 years for soda-acid fire extinguishers. An "old test pressure = 75% of shell psi

rating" is cited, and a "new test pressure = 100% of shell psi rating" is also cited.

2. This literature provides documentation of numerous failures of soda acid fire extinguishers, as well as foam, water cartridge and loaded stream cartridge extinguishers. It is reported, for example, that 22% of those fire extinguishers made with a stainless steel shell fail the required 5-year retest, and that a larger fraction --- 46% --- of those made with a soldered copper shell fail the retest. Precise figures on the fraction of soda-acid extinguishers which fail in service were not found in the NAFED literature.

3. The 1974 literature from NAFED indicates that soda-acid fire extinguishers have been "discontinued." Apparently, "discontinued" means these extinguishers are no longer made. Nevertheless, many of these extinguishers do remain in service and come up for periodic re-test.

C. Underwriters Laboratories Specification (Reference 5)

1. The construction of a soda-acid fire extinguisher essentially consists of a cylindrical shell, with closures called a dome and a bottom fastened at either end. The dome end consists of the dome (Paragraphs 20, 24F and 24G), a collar (Paragraphs 30-35) and a cap (Paragraphs 47-57), as well as a hose outlet elbow (Paragraphs 41-43) and an interior-mounted strainer (Paragraphs 39-40). The cap is fastened to the collar via threads.

2. The kinds of materials and methods used in the manufacture of soda-acid fire extinguishers are mentioned in Paragraphs 18-22 and 26-30. Joining techniques are described in Paragraphs 27 and 33.

3. Mechanical properties of the materials used for fire extinguisher manufacture are mentioned in Paragraph 24B.

4. Concern about carbide precipitation in the stainless steel shell is expressed in Paragraphs 28, 98G and 98H.

5. Concern about the corrosion behavior of the entire structure is expressed in Paragraph 19.

6. Pressure capacity and rupture pressure of the extinguisher itself are referred to in Paragraphs 23, 24 and 24A.

7. Test methods for evaluating the performance of soda-acid fire extinguishers are described in Paragraphs 85-111.

NOTE: A description of a method for burst testing was not found in the Underwriters Laboratories Specifications.

8. The chemical charge for a soda-acid fire extinguisher is specified in Paragraph 83. For a 2 1/2-gallon extinguisher, the charge consists of

Sodium Bicarbonate --- 1 1/2 pounds ± 1 ounce
Concentrated Sulfuric Acid (specific gravity 1.83) --- 4 fluid ounces ± 1/4 fluid ounce

The functioning of a soda-acid fire extinguisher is as follows:

a. The extinguisher is partially charged by dissolving sodium bicarbonate in water --- this solution is contained in the shell.

b. The charging is completed by installing a bottle of sulfuric acid inside the extinguisher, (See Paragraph 58 for a description of acid bottles). The acid bottle is positioned upright in a support cage (Paragraphs 60-62) at the hose-end of the extinguisher (Paragraph 9). The hose end is at the top when the extinguisher is stored in an upright position.

c. A loose-fitting stopple (Paragraphs 63-65) closes the acid bottle when the fire extinguisher is stored in the upright position.

d. When the fire extinguisher is put into service, the vessel is inverted so that the hose-end is at the bottom. When inverted, acid dribbles from the bottle past the loose-fitting stopple and into the bicarbonate solution. Chemical reaction occurs between the acid and bicarbonate solution which releases gas. It is the pressure of this gas which drives the water solution from the extinguisher. Since there is no valve on the soda-acid fire extinguisher, discharge occurs until it is empty. The gas point is defined as the time when the discharge changes from a liquid to a gas (Paragraph 86).

NOTE: A gasket is used to prevent gas from escaping at the threaded joint between the cap and collar (Paragraphs 56-57). Concern is expressed that the cap not reach the dome when the gasket is removed (Paragraph 32).

NOTE: Instructions on the labels of the four fire extinguishers examined recommend that the extinguisher be discharged annually.

III. FIRE EXTINGUISHER WHICH EXPLODED:

The fire extinguisher which exploded (number F 407396) was delivered to NBS in two pieces --- one piece had separated from the other via a circumferential tear near what appeared to be a brazed joint at the dome end. Figure 1 shows a view of the components of the fire extinguisher which exploded. The cap and collar --- still fastened together at the threaded joint --- appear at the lower left in Figure 1. Attached to the cap-collar assembly is the support cage which holds the acid bottle. The bottle and stopple appear in the center foreground. The outer ring and spoke of the cap handle were probably damaged by the impact when it "blew straight to the pavement" during the explosion (Reference 1, page 2).

Close-up views of the cap-collar assembly appear in Figures 2a-2d. These views show that a ring of dome metal (arrows in Figures 2a and 2b) remains attached to the collar, probably by the joining metal (Paragraph 33 of Reference 5). The significance of the black arrow on the dome metal in Figures 2a and 2b is not clear --- this arrow was on the as-received part. The circumferential tear seems to have occurred entirely in the dome metal, and the path of the tear seems to follow --- at least approximately --- the tip of the joining metal interior fillet which touched the dome metal. Indeed, what appears to be a fin-like projection of the joining metal is pointed out (arrow) at the right center of Figure 2a. The process used to join the collar to the dome --- welding, brazing or soft soldering --- has not been definitely established. Many of the white regions in Figures 2a-2d probably represent deposits of sodium bicarbonate.

A view of the cap-collar assembly which includes some of the fracture surface of the dome metal along an arbitrarily-selected portion of the circumference appears the composite picture, Figure 3. In this picture, which has a three-dimensional character to it, the dome metal as seen at the outside top of an upright extinguisher appears above the side arrows, and the edge of the flange of the collar --- which would normally be inside the extinguisher --- appears in elevation below the side arrows. Appearing as a layer upon the flange is the dome metal --- which disappears towards the top horizon. The fracture through the thickness of the dome metal is shown in elevation, running between the side arrows. The fracture path does not run in a straight line, but follows a rather wavy path. In fact, scallops in the fracture path through the dome metal --- which show up especially well at the right of Figure 3 --- reveal some of the surface of the collar flange which was joined to the dome metal. Terrace-like features which may be ruptured metal or corrosion product show up at the right-most scallop and also at the third scallop from the right. A feature which may be a delamination between the dome metal and the collar metal appears just to the left of center in Figure 3. A smaller possible delamination appears somewhat further to the left. The white regions in Figure 3 may be areas where sodium bicarbonate has deposited. Conditions of photographing made it rather difficult to show up joing metal at the interface between the dome metal and the collar metal.

The circumferential tear which is clearly evident at the top of the dome in Figure 1 is shown in some close-up views which appear in Figures 4a, 4b, and 4c. Conspicuous bulging does not show up anywhere along the circumference. Indeed, the separation seems to have occurred in a uniform fashion along the entire circumference. The wavy path followed by the fracture is clearly seen in Figure 4c. All three figures seem to indicate that the fracture occurred entirely in the dome metal. It is likely that the dome metal is a stainless steel, as suggested by its surface luster, its inability to attract a small, hand-held magnet and the wording of the specification, Paragraph 20 of Reference 5. However, conclusive identification of the dome metal via chemical analysis was not obtained at this stage of the examination.

IV. EXAMINATIONS ON USED FIRE EXTINGUISHERS:

A. Visual Examination

The three used --- but undamaged --- fire extinguishers were examined visually. Table I summarizes the data taken from the retest labels found on these extinguishers. Since retest occurs every five years (Reference 4), these data are helpful in inferring a minimum time in service for an extinguisher. For example, fire extinguisher number F 700745 was last retested in May, 1973, indicating that its minimum time in service up to the date it was turned in in May, 1975 was (5 years + 2 years) = 7 years.

Because the exploded extinguisher failed via a circumferential tear at the dome end, this region on the used-but-undamaged extinguishers was examined carefully. The following observations were made:

Materials - The dome was probably made of stainless steel (Paragraph 20, Reference 5), whereas the collar and cap appeared to be of some different metal --- perhaps brass or bronze, judging from surface luster. A precise indication of the collar metal (Paragraph 30, Reference 5) and the cap metal (Paragraph 47 of Reference 5) was not found in the specification, although "... a material equivalent to the material of the shell" is specified for the collar, and a cap "... of corrosion-resistant material equivalent to red brass or austenitic stainless steel" is specified.

Cap - One cap out of the three examined was missing a quadrant from the ring section which would be gripped to tighten or loosen the cap. The other caps appeared to be undamaged.

All three caps had indentations on the spokes, which could have been caused by a lever inserted between the spokes to assist in torquing operations.

Two caps out of the three had a continuous powdery-looking deposit --- mostly green, but with some blue and white --- on the inside.

The third cap exhibited regions of such a deposit on the inside, but this deposit was not continuous.

All three caps contained rubber gaskets. Two gaskets of the three retained permanent impressions of the collar rim, perhaps from tightly torquing the cap to the collar. The gasket which did not have a permanent impression was associated with the cap which did not have a continuous deposit inside the cap. One of the gaskets was cracked and somewhat deterioriated.

The threads on all three caps appeared to be in good condition. A bluish-green deposit was evident here and there on the threads of all three caps.

Collar - The threads on all three collars appeared to be in good condition. A bluish-green deposit was evident here and there on the threads of all three caps, and in all three cases, this deposit was continuous over the bottom one-or-two threads.

The design of these three extinguishers --- as well as the one that exploded --- is such that a flange on the collar conforms closely with the curvature of the dome. The two components are joined via a welding, brazing or soft soldering process. In the case of all three extinguishers, a continuous circumferential ring of the joining metal was visible on the outside where the dome joined the collar. The bluish-green deposit found on the bottom threads was also evident on this ring of joining metal. A nearly-continuous deposit showed up on one extinguisher --- the same type of deposit showed up only here and there on the other extinguishers.

Dome - A pronounced change in surface luster was evident to the unaided eye on two domes out of the three. This change in luster --- near the bottom inch or so --- ran around the entire circumference; it is probably due to drawing marks.

One extinguisher out of the three exhibited some black streaks --- in the circumferential direction --- in the region of the dome just below the ring of joining metal. The cause of these streaks is not evident.

The outside of the dome was readily examined. A technique for easily examining the inside was developed --- this technique involved using a mirror and a light source on a flexible tube. A system utilizing fiber optics was also employed.

Interior examination with the mirror revealed --- in all three extinguishers --- a continuous circumferential ring of joining metal at the dome-collar interface. White deposits were observed on the collar, on the joining metal and on the inside surface of the dome. In the case of all three extinguishers, occasional

reddish-orange-brown deposits were noted on the dome below the joining metal, and on the joining metal itself. For all three extinguishers, some regions along the ring of joining metal seemed to show short segments of a step or a crack in the joining metal.

B. Metallographic Examination

One of the used but undamaged fire extinguishers --- number F 700745 --- was cut up to provide specimens for metallographic examination. This extinguisher was selected at random from among the three provided.

To prepare metallographic specimens, the dome was sawed off the shell, Figure 5a, and a longitudinal section, Figure 5b, was cut from it. In the longitudinal section shown in Figure 5b, the collar is labeled (A) and the dome wall is labeled (D). Joining metal is between the dome wall and collar --- the outside fillet is at (C), and the inside fillet is at (B). The joint where the dome wall meets the shell wall is at (E).

Evidence of particles from the sawing operation appears in both Figures 5a and 5b. These particles were not removed by a cleaning operation such as brushing or ultrasonic cleaning simply to minimize the possibility of removing corrosion products. The region where the collar joined the dome appeared discolored and corroded, especially near the fillet of the joining metal --- which is shown at B in Figure 5b.

Figure 6 shows the inside of the dome after the longitudinal section was removed. A full circumferential picture of the inside of the dome --- taken before the longitudinal section was cut --- appears in Figure 7. The bottom of the collar shows up as the dark circular ring with whitish stains. The outermost ring of white is the inside of the dome wall. A partial view of the strainer covering the outlet elbow is at the left. The joining metal shows up as a dark circumferential ring between the collar and the dome.

A notable feature in Figure 7a is the circumferential step or crack which shows up between the joining metal and the dome metal. The vicinity of this crack is stained with corrosion product around the entire circumference. Drip-shaped stains appear at the arrows in Figure 7a and 7b. These stains have a reddish-orange-brown color, as is evident in Figure 7c.

Figure 7b shows a close-up view of the stain at A in Figure 7a. The longitudinal section cut from the dome, Figure 5b, was obtained by cutting as closely as possible through this stain. Close-up views of the joining metal, the collar and the dome wall appear in Figures 8a (as polished) and 8b (polished and lightly etched).

The joining metal is not delineated from the collar or dome metal in Figure 8a --- however, delineation is clear in Figure 8b due to the

etching. Rupture of the exploded fire extinguisher --- number F 407396 --- seemed to follow a circumferential path in the dome metal just about where the inside fillet of joining metal meets the dome metal.

It is of interest to note that the outside fillet of joining metal shows a rather irregular profile, suggesting that some corrosion took place. Indeed, it was in this region that the three used-but-undamaged extinguishers showed a bluish-green deposit, which was probably a corrosion product. The outside fillet of joining metal is about 0.35 inches away from the region where the dome metal of fire extinguisher number F 407396 ruptured --- it appears unlikely that the corrosion of the outside joining metal might lead to the type of rupture observed in the dome metal of fire extinguisher number F 407396.

Another region of some interest is the end of the dome metal under the outside fillet of joining metal --- this region is near the label "C" in Figure 8. A close-up of this region after etching --- Figure 9 --- reveals evidence of severe plastic deformation, especially at the tip. The explanation of this deformation is not definite. It may be due to punching forces, assuming that the dome was annealed after forming as prescribed in Paragraph 20 of Reference 5 --- then punched to accommodate the collar. Regardless of the cause of this deformation, it seems unlikely that it --- or the cause of it --- might lead to the type of rupture observed in the dome metal of fire extinguisher number F 407396.

A conspicuous feature in Figure 8 is the large pore at the end of the dome metal near the collar. This pore is evidence of incomplete joining of the dome and collar. However, this feature does not seem to be contributory to the manner in which fire extinguisher number F 407396 exploded.

A less conspicuous feature in Figure 8 than the pore is the rupture of the joining metal in the region where the inside fillet runs along the dome wall --- this region is labeled A. This rupture leads into a crevice between the joining metal and the dome metal --- and the crevice tip seems to be in the vicinity of the region labeled B in Figure 8b. The overall length of the crevice seems to be about 0.20 inches, as compared to an overall length of 0.35 inches between the tip of the fillet and the end of the dome wall. This crevice is of potential importance in understanding the malfunctioning of fire extinguisher number F 407396, since this crevice is near the observed rupture path in the dome metal.

A microscope examination for cracking in the dome metal was carried out on the longitudinal section shown in Figure 8. However, no cracks were detected. This examination was carried out because stainless steel --- which the dome metal might be made of (Paragraph 20 of Reference 5) --- is sometimes susceptible to intergranular corrosion and cracking (Reference 6).

A microscope examination was also carried out to search for evidence of penetration of the grain boundaries of the dome metal by another metal. None was found, however. This examination was carried out because joining metals used with stainless steels may sometimes penetrate grain boundaries and thereby cause embrittlement. (Reference 7).

Returning to the joining metal noted at A in Figure 8, it is evident from the close-up views in Figure 10 that the joining metal at the tip of the inside fillet has ruptured and separated from the dome wall. The step due to separation is probably what leads to the appearance of the circumferential step or crack which was pointed out in Figure 7. The layer of corrosion product --- which appears as a grey-black layer on both the joining metal and the dome metal --- suggests that the rupture of the joining metal occurred before the longitudinal section was cut from the dome. Indeed, the layer of corrosion product is apparently quite adherent, since the layer did not flake away significantly during the cutting process.

Corrosion product growing on the ruptured joining metal seems to have almost closed up the rupture in Figure 10c --- however, despite the apparent impingement of these corrosion products, it is likely that the crevice is still open to the interior of the fire extinguisher. In fact, one plausible explanation of the stains labeled A in Figure 7 is that these stains arise from the gradual seepage of corrosive fluid out of the crevice. Corrosive fluid such as the mixture of sulfuric acid and water containing sodium bicarbonate may be driven into the crevice under pressure when the fire extinguisher is used, then may seep out gradually while the re-charged extinguisher is in an upright position awaiting its next use. It is unlikely that even thorough cleaning could remove all corrosive fluid driven into the crevice by pressurization during use because of surface tension effects as well as the near impingement of corrosion product which is evident in Figure 10c.

Lastly, it is noted that at the higher magnification in Figure 10, as compared to Figure 8, there is still no evidence of cracks in the dome metal. Nor is there evidence of intergranular penetration of the dome metal by another metal.

The crevice evident in Figure 8 --- referred to earlier --- shows a significant amount of corrosion product on the dome metal as well as on the collar metal. Figure 11 is a close-up of the crevice at some point between the regions labeled A and B in Figure 8. In addition to the corrosion product evident in Figure 11, there also seems to be an occasional good matching of the profile of the joining metal and the dome metal --- two examples are indicated by the pairs of arrows. This matching suggests the following sequence of events --- first, the interface between the dome metal and joining metal was ruptured, then corrosive fluid entered the crevice and helped to form the tightly adherent corrosion product.

A comparison of the surface profile of the dome metal on either side of the region labeled B in Figure 8 is informative. The two pits

at B in Figure 8 appear at higher magnification in Figure 12a. The crevice narrows from right to left in this figure. Figure 12b was taken in the region between A and B in Figure 8 where the crevice is wide. On the other hand, Figure 12c was taken in the region between B and C in Figure 8 where a tightly bonded interface is evident. There does not seem to be a significant difference in the surface profile of the dome metal in Figures 12b and 12c. This observation suggests that there was little selective solution of the dome metal adjacent to the crevice, for example, in localized regions such as grain boundaries. Indeed, such a process would lead to conspicuous deep penetrations, and none are evident.

A few final features of the dome metal in the region between the labels A and C in Figure 8 are noteworthy, namely, slip lines in isolated grains and grain boundary precipitates. The grain structure of the dome metal appears in Figure 13a --- the crevice and the corrosion product coating the dome metal are at the bottom. The narrow bands traversing entire grains are probably annealing twins (A in Fig. 13b). On the other hand, wavy lines within individual grains are probably slip lines (B in Fig. 13b). These lines show up especially well in certain grains in Figure 13b. Slip lines form when metals are stressed above their yield point. An example of a profusion of slip lines appears in Figure 9. The slip lines of Figure 13b suggest that individual grains in the dome metal were stressed above their yield point, whereas the bulk of the dome metal itself was not. It may be that these slip lines formed when the interface between the joining metal and the dome metal was ruptured. Consistent with this suggestion is the observation that no evidence of slip lines in isolated grains was found in regions of the dome metal remote from the collar and joining metal. Precautions were taken to assure that these slip lines were not artifacts introduced during polishing of the specimens.

An abundance of the grain boundary precipitates mentioned above appears in Figure 14a. Were a Type 304 stainless steel --- which the dome metal might be made of (Reference 5, Paragraph 20) --- to exhibit such a microstructure, it would be described as "sensitized." Such a microstructure --- which frequently forms in Type 304 stainless steel during welding and brazing operations --- is highly susceptible to intergranular corrosion. A close-up of a few grain boundaries is shown in Figure 14b, where the corrosion product at the dome metal-crevice interface appears at the bottom. A suggestion of a slight penetration of grain boundaries by a corrosion process shows up in Figure 14b, but for the most part, it appears that the tightly adherent corrosion product serves as a protective film to shield the dome metal from further penetration by a corrosion process.

Evidence of grain boundary precipitates such as those appearing in Figure 14 was also found near the joint between the dome metal and the shell metal. However, such evidence was not found elsewhere in the dome metal, suggesting that the heat of the joining operation may have contributed to the formation of the grain boundary precipitates.

C. Susceptibility to Corrosion

The materials at the dome end of the used-but-undamaged fire extinguisher which was cut up --- number F 700745 --- seemed to exhibit tendencies toward corrosion. For example, Figure 15 shows a section of the collar metal near the region labeled D in Figure 8. The surface film of corrosion product is clearly evident. Susceptibility of the joining metal and dome metal to corrosion is evident along the crevice in Figures 10, 11, 13a and 14b. The tendency of the joining metal at the top outside fillet --- C in Figure 8 --- was already pointed out. A close-up of a region near C in Figure 8, Figure 16, shows corrosion product adhering to the surface of the joining metal. The region labeled E in Figure 5b --- where the dome metal overlaps the shell metal --- was examined for evidence of corrosion. Indeed, as shown in Figure 17, some evidence of corrosion appears in the form of the irregular surfaces. Adhering corrosion product was not conspicuous on either the dome metal or the shell metal.

In order to evaluate the susceptibility of the dissimilar metals to galvanic corrosion, the corrosion potentials of the dome metal, the collar metal and the joining metal --- relative to one another --- were evaluated. A solution of sodium bicarbonate in water such as the specification (Reference 5) calls for when charging the extinguisher was prepared. Potential measurements versus a saturated calomel electrode were made. Results appear in the first row of Table II. Then three cubic centimeters of concentrated H_2SO_4 were added to bring the solution to one-half the concentration called for in the specification (Reference 5). This procedure was carried out to roughly simulate the case of acid dribbling from the bottle when the extinguisher is inverted. Potential measurements were again made, with the results shown in the second row of Table II. This procedure was repeated by adding three more cubic centimeters of concentrated H_2SO_4 to bring the proportions of acid and sodium bicarbonate to the full values called for in the specification (Reference 5). Results of potential measurements appear in the third row of Table II.

These measurements show that the joining metal has the greatest tendency to go into solution, whereas the dome metal has the least tendency to go into solution. Thus, when the specified solution is present, and when the metal surfaces are bare, the joining metal and the collar metal will tend to dissolve, whereas the dome metal will not. A possible consequence of these tendencies is that a crevice between joining metal and dome metal might widen at its mouth as a result of galvanic corrosion of the joining metal. Another consequence of this specific process would be weakening of the bond between dome and collar, as joining metal dissolves. Of course, the tendency for galvanic corrosion of an active metal will be altered if a film of corrosion product coats the metal surface.

Because of the presence of many crevices, it seemed reasonable to make some measurements of the susceptibility of the dome metal to crevice corrosion. For experimental convenience, a crevice at the dome metal was simulated by fastening a rubber band around a metallographically-mounted and polished section of the dome metal. The specimen was immersed in the solution remaining after the measurements appearing in row 3 of Table II were made. Potential measurements versus the standard calomel electrode were again made over a period of 8 days. After an initial period of a few hours during which the dome metal exhibited a more negative potential --- the electrode potential was about -0.360 volts --- the potential shifted toward the values appearing in column 1 of Table II. Subsequent examination under the microscope revealed no significant amount of crevice corrosion under the rubber band. Thus, the susceptibility of the dome metal to crevice corrosion seems rather limited.

D. Pressurization Tests

One of the used-but-undamaged fire extinguishers (No. F 701019) was tested to simulate typical service use of a soda-acid fire extinguisher. The extinguisher tested exhibited conspicuous evidence of corrosion around the inside circumferential joint between the joining metal and the dome metal. The objective of this testing was to learn if this fire extinguisher could be made to burst catastrophically, as did the fire extinguisher which exploded in service (Section III). However, a burst did not occur, even after 25 pressurization tests. Consequently, this extinguisher was hydrotested as required during a periodic retest (Reference 4) and was then pressurized to failure. The fire extinguisher chosen for this test series had been in service previously, but no details of its service history were available.

For the tests to simulate typical service use, the fire extinguisher was charged according to procedures specified by Underwriters Laboratory "Standards for Safety-Soda-Acid Fire Extinguisher," UL-7-1969 (Reference 5). The charge consisted of 4 ounces of concentrated sulfuric acid (1.83 specific gravity), 1 1/2 pounds of sodium bicarbonate, and 2 1/2 gallons of water.

The fire extinguisher was charged, upended to discharge and then cleaned by rinsing the inside with water and recharged. This procedure was repeated a total of 25 times during an eight hour time period. For the safety of the personnel conducting this test, the fire extinguisher was located in a safety pit and discharged remotely.

In each discharge test, the pressure build up to full discharge pressure took between 5 and 10 seconds. The water discharge continued for 45 to 50 seconds as required by the Underwriters Laboratory Specification (Reference 5). No indication of improper operation was evident during the 25 testing cycles, and no failure of the fire extinguisher occurred. It should be noted that although this testing sequence simulated the operation of the fire extinguisher during

normal use, it was not practical to allow a long time period between individual discharge cycles such as occurs in normal fire extinguisher usage.

Following the 25 cycles simulating service use, a test was carried out to evaluate the response when the discharge hose was blocked. The discharge hose was sealed off, and the fire extinguisher was cleaned and recharged. The extinguisher was then activated by upending it. No discharge of water occurred and after approximately 10 minutes the discharge hose was unblocked and normal discharge occurred. Although during this test the pressure in the fire extinguisher built up higher than during normal operation, the fire extinguisher did not fail catastrophically. Furthermore, no damage was visable after the test.

This fire extinguisher was then hydrostatically tested, as required every 5 years during the life of a fire extinguisher (Reference 4). The fire extinguisher was pressurized to 500 psig as currently required. Two pressurizations were carried out without failure. The fire extinguisher was then pressurized until failure occurred. At a test pressure of 850 psig, the fire extinguisher failed by bursting a disk out of the cap, as shown in Figure 18. The significant bulging of the fire extinguisher evident in Figure 18 occurred without any conspicuous failure of the fire extinguisher structure. This test indicates that no unacceptable deterioration of this particular fire extinguisher had occurred during normal service, or during the service-simulation tests described above.

A second used-but-undamaged fire extinguisher (No. G 319542) was then hydrostatically tested. This extinguisher was first tested to 500 psig, and the pressure was released. It was then repressurized. Failure occurred at 700 psig by bursting the cap in a manner similar to the extinguisher No. 701019. However, no bulging of the extinguisher side walls was observed at this lower pressure.

V. DISCUSSION:

A. Speculation About Failure Mechanism in Dome Metal of Fire Extinguishers

Results presented in this report indicate that the extinguishers examined are so designed, constructed and handled that interior deterioration may occur along a circumferential path following a joint between dome and collar. Apparently, a long time --- perhaps of the order of years --- may be required for deterioration to reach a critical state leading to failure. Information suggesting that deterioration does indeed occur over a long period of time in a variety of fire extinguisher types is found in the report that 22% of stainless steel shell extinguishers fail the first 5-year retest, 8% fail the second 5-year retest, and between 15 and 40% fail the third 5-year retest (Reference 4). It should be noted, however, that these figures pertain to all kinds of retest

failures, not just failure by a circumferential tear through the dome metal.

Concerning the fire extinguisher which exploded, it had been in service for at least 6 1/2 years, as inferred from the report that this extinguisher had been hydrostatically retested in November, 1973 --- about 1 1/2 years before its catastrophic failure on May 6, 1975 (Reference 1). Thus, for this extinguisher, the 1 1/2 years between retest and failure can be regarded as the time during which interior deterioration reached a critical state leading to failure via a circumferential tear. However, a long time in service is not the only factor on which to base a prediction of fire extinguisher reliability. For example, one of the fire extinguishers used in the pressurization tests, number 701019, had been in service for a minimum of 6 1/2 years (inferred from the retest label --- Table I), yet it performed satisfactorily in the pressurization test. Other factors which might be taken into account besides time in service for predicting fire extinguisher reliability include: design, use of dissimilar materials, manufacturing procedures, handling in service and frequency of discharge.

As noted in Section III, the path of the fracture in the fire extinguisher which exploded followed the circumferential path between dome and collar. Also, no conspicuous bulging was noted. The circumferential tear seemed to have occurred entirely in the dome metal, and the path seemed to follow --- at least approximately --- the tip of the joining metal interior fillet which touched the dome metal. The region of the fracture path in the exploded fire extinguisher is almost the same as the region of interior corrosion found in all the fire extinguishers examined. Hence, it is reasonable to speculate about a corrosion process which might occur in the dome metal that could lead to a failure without bulging. One corrosion process which could plausibly occur in the dome metal is intergranular corrosion of sensitized stainless steel (Reference 6). In fact, the failure of a stainless steel dry powder fire extinguisher via intergranular corrosion has been reported (Reference 8). It should be noted, however, that in the case of the soda-acid fire extinguishers, the actual mechanism whereby failure of dome metal occurs probably cannot be positively identified because failed hardware was not available to evaluate.

Some evidence of dome metal which appeared to be sensitized --- in one of the used-but-undamaged extinguishers --- was presented earlier. Sources of corrosive fluid which can contact the dome metal exist --- fluid forced into the crevice between joining metal and dome metal, and sulfuric acid dribbling from the bottle when a fire extinguisher is inverted. Moreover, vapor from the sulfuric acid may be continuously present in the dome region of a charged fire extinguisher awaiting its next use. Finally, components of the flux used in the joining operation may also contribute to a corrosion process. In order for these corrosive media to act on the sensitized metal, it is essential that

fresh metal be exposed to the corrosive media. Such exposure could occur if hard bumps or high torques applied to the dome metal ruptured any tightly-adherent, protective films on the dome metal -- such bumps or high torques may occur in service.

The combination of corrosive attack of the dome metal --- probably over a long period of time --- and the sudden stress application in the presence of a corrosive fluid when a fire extinguisher is pressurized, may be sufficient to result in fracture of the dome metal. Although the findings in this report indicate that ordinary usage of these soda-acid fire extinguishers might lead to conditions resulting in corrosive attack of the dome metal, direct evidence of such a process has not been found.

In the final analysis, it must be stressed that without the opportunity to submit the failed hardware to metallographic examination, nothing definitive can be said about the failure mechanism in the dome metal.

B. Classification of the Fire Extinguisher Behavior

The purpose of this evaluation of soda-acid fire extinguishers was to determine if the cause of the fire extinguisher explosion discussed in Section II might be related to a generic problem for soda-acid fire extinguishers. Results presented in this report indicate that the dome end of the extinguishers examined is so designed and constructed that deterioration may occur over a long period of time as a result of deformation and corrosion processes. Evidence of such deterioration is corrosion along an interior circumferential path following a joint between the dome and collar. All four of the fire extinguishers which were examined exhibited such deterioration. From this limited sampling, it may be concluded that interior deterioration at the dome end is likely to occur in many soda-acid fire extinguishers. A possible result of this deterioration is catastrophic failure by a circumferential tear through the dome metal when the extinguisher is pressurized. Indeed, the fire extinguisher which exploded (Section III) failed this way. Moreover, analysis of retest results indicates that a circumferential tear is an expected type of failure during retest (Reference 4).

However, extinguishers removed from service which exhibited conspicuous interior deterioration performed satisfactorily in pressurization tests. Hence, the susceptibility of soda-acid fire extinguishers to catastrophic failure is probably related to a critical combination of factors, including design, use of dissimilar metals, manufacturing procedures, handling in service, time in service, and frequency of discharge. Thus, the results of this evaluation are inconclusive as regards the question of whether or not the susceptibility of soda-acid fire extinguishers to catastrophic failure is a generic problem.

VI. CONCLUSIONS:

The principal findings of this investigation are:

1. The fire extinguisher which exploded separated into two parts. It failed by a circumferential tear in the dome metal. The path of the tear followed what appeared to be a brazed joint between the dome and the collar.

2. A longitudinal section through the dome and collar revealed a rupture of joining metal in the region where the inside fillet of joining metal runs along the dome wall. This rupture formed a crevice between the joining metal and the dome metal.

3. Dome metal near the crevice exhibited slip lines in isolated grains and a profusion of grain boundary precipitates.

4. Abundant evidence of corrosion was found at the dome end of the extinguisher. Corrosion was especially conspicuous along an interior circumferential path following a joint between the dome and the collar. Dome metal showed the least susceptibility to galvanic corrosion whereas joining metal showed the greatest susceptibility to galvanic corrosion. Dome metal exhibited very little susceptibility to crevice corrosion.

5. No evidence of cracks or intergranular penetration by dissimilar metal was found in the dome metal near the crevice.

6. Service-type pressurization tests of a used-but-undamaged fire extinguisher showed that an extinguisher with conspicuous evidence of corrosion along the inside circumferential joint between dome metal and joining metal could operate without malfunction for twenty-five such pressurizations. Sealing the discharge line of this extinguisher and activation by upending could not promote a malfunction.

7. Pressurization tests to burst of two used-but-undamaged fire extinguishers indicated that these fire extinguishers could withstand pressures in excess of the specified retest pressure of 375 psi --- these extinguishers withstood 850 psi in one case and 700 psi in the other, without failure of the dome metal. Each extinguisher failed by bursting a disk from the center of the cap.

The following conclusions can be drawn from results of this investigation:

1. The dome end of the soda-acid extinguishers examined are so designed and constructed that deterioration may occur over a long period of time via deformation and corrosion processes.

A possible result of this deterioriation is catastrophic failure by a circumferential tear through the dome metal when the extinguisher is pressurized.

2. Ordinary usage of soda-acid fire extinguishers of a particular design and construction leads to conditions which might result in corrosive attack of the dome metal. However, direct evidence of such attack was not found in this investigation.

3. The susceptibility of soda-acid fire extinguishers to catastrophic failure is probably related to a critical combination of several factors, including design, use of dissimilar metals, manufacturing procedures, handling in service, time in service, and frequency of discharge. Thus, the results of this evaluation are inconclusive as regards the question of whether or not the susceptibility of soda-acid fire extinguishers to catastrophic failure is a generic problem.

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FIGURE CAPTIONS

Fire Extinguisher Which Exploded - Number F 407396

1. View of the fire extinguisher which exploded. The cap and collar assembly at lower left separated from the dome via a circumferential tear. The acid bottle is positioned with the stopple-end up in the wire cage attached to the cap-collar assembly when the extinguisher is ready for service. Note the identifying number stamped on the lower part of the label.

2a. Cap-collar assembly showing the ring of dome metal which remained attached to the collar - arrow at left. A fin-like projection of what is believed to be joining metal appears at the arrow - right center.

2b. Close up of the view in Figure 2a. The hole in the cap facilitates venting during filling for hydrotesting.

2c. Inside view of the cap-collar assembly, showing the collar and some of the fracture surface of the dome metal. Note the white substance, which is probably sodium bicarbonate.

2d. View of the cap-collar assembly almost opposite that shown in Figure 2c, showing more of the fracture surface of the dome metal.

3. Close-up view of the cap-collar assembly showing dome metal and collar metal. The dome metal disappears toward the top horizon. Part of the fracture path through the dome metal is shown in elevation and runs horizontally from arrow to arrow. The collar metal is shown in elevation and runs horizontally across the lowermost portion of the picture.

4a. Close-up view of the circumferential tear.

4b. Close-up view of the circumferential tear.

4c. Close-up view of the circumferential tear.

Fire Extinguisher Which Was Sectioned - Number F 700745

5a. Dome removed from fire extinguisher number F 700745.

5b. Longitudinal section through dome wall showing collar (A), joining metal (B and C), dome wall (D) and joint between dome wall and shell wall (E).

6. Inside view of dome removed from fire extinguisher number F 700745.

7a. Full circumferential view of inside of dome. Note the circumferential step or crack which shows up between the joining metal and the dome metal.

7b. Close-up of a section from Figure 7a near the strainer.

7c. Full circumferential view of inside of dome, showing the reddish-orange-brown coloring of stains near the circumferential step or crack shown in Figures 7a and 7b (color-slide No. 18).

8a. Close-up view of the region where the dome metal joins the collar metal. The interface between the wall of dome metal and the collar metal shows up as the horizontal line running left from A (as-polished).

8b. Close-up view of the region where the dome metal joins the collar metal. The joining metal shows up clearly between the dome metal and the collar metal due to etching. The outside fillet of joining metal is in the region labeled C, and the inside fillet curves between A and D.

9a. End of the dome metal under the outside fillet of joining metal. Note severely distorted grains at end indicating localized distortion.

9b. Close-up of the region of localized deformation in Figure 9a. Note transition from severely distorted grains at left to apparently undistorted grains at right.

10a. Rupture of the inside fillet of joining metal noted at A in Figure 8. Dome metal appears acorss the top (as polished).

10b. Close-up of the ruptured joining metal shown in Figure 10a. Note corrosion product coating the surface of the dome metal and the surfaces of the joining metal (as polished).

10c. Rupture of the joining metal shown in Figure 10a. Note the film of corrosion product and the incomplete closure of the rupture (as polished).

11. Close-up of the crevice between dome metal (top) and joining metal (bottom) at some point between A and B in Figure 8. Note the good matching of the profiles of the dome metal and the joining metal at the arrows.

12a. Close-up of the two pits at B in Figure 8. Dome metal is at the top and joining metal is at the bottom.

12b. Appearance of the crevice between dome metal (top) and joining metal (bottom) to the right of the pits in Figure 12a.

12c. Region to the left of the pits in Figure 12a, showing tightly bonded interface between the dome metal (top) and joining metal (bottom).

13a. Grain structure of the dome metal near the crevice at some point between A and B in Figure 8.

13b. Close-up of some grains appearing just below the center of Figure 13a. The feature at A traversing an entire grain is probably an annealing twin, and the features at B -- which appear in several grains -- are probably slip lines.

14a. Grain structure of the dome metal at some point between A and B in Figure 8. An abundance of grain boundary precipitates lead to the darkened and dotted appearance of grain boundaries.

14b. Close-up of grain boundaries in the dome metal near the crevice, showing evidence of grain boundary precipitates. Note that the film of corrosion product exhibits a slight tendency to penetrate some of the grain boundaries.

15. A section of the collar metal near D in Figure 8, showing surface film of corrosion product.

16. A section of the joining metal near C in Figure 8, showing film of corrosion product.

17. Upper region of lap joint between dome metal and shell metal shown at E in Figure 5b. Irregular surfaces suggest corrosive attack, possibly from corrosive fluid retained in the crevice formed by the lap joint.

Pressurization Tests On Used-But-Undamaged Fire Extinguishers

18. Fire extinguisher number F 701019 pressurized to burst. The extinguisher bulged significantly, but remained structurally intact. Failure occurred at 850 psig when the center section of the cap blew out.

TABLE I

FIRE EXTINGUISHER RETEST DATA
OBTAINED FROM RETEST LABELS

Number	Date of Last Retest	Retest Pressure (psi)
F 700745	May, 1973	375
F 701019	November, 1973	375
G 319542	No Retest Label was found	

TABLE II

ELECTRODE POTENTIALS FOR DOME METAL,
JOINING METAL AND COLLAR METAL
(POTENTIAL AFTER 5 MINUTES VERSUS SATURATED CALOMEL ELECTRODE)

	Metals		
Solution	Dome	Collar	Joining
Sodium Bicarbonate	-0.120 volts	-0.180 volts	-0.440 volts
Sodium Bicarbonate, plus 3 cc Conc. H_2SO_4	-0.145	-0.295	-0.470
Sodium Bicarbonate, plus 6 cc Conc. H_2SO_4	-0.150	-0.334	-0.514

Figure 1. View of the fire extinguisher which exploded. The cap and collar assembly at lower left separated from the dome via a circumferential tear. The acid bottle is positioned with the stopple-end up in the wire cage attached to the cap-collar assembly when the extinguisher is ready for service. Note the identifying number stamped on the lower part of the label. X 1/3

Figure 2a. Cap-collar assembly showing the ring of dome metal which remained attached to the collar - arrow at left. A fin-like projection of what is believed to be joining metal appears at the arrow - right center. X 1

Figure 2b. Close up of the view in Figure 2a. The hole in the cap facilitates venting during filling for hydrotesting. X 1 1/4

Figure 2c. Inside view of the cap-collar assembly, showing the collar and some of the fracture surface of the dome metal. Note the white substance, which is probably sodium bicarbonate. X 1 1/4

Figure 2d. View of the cap-collar assembly almost opposite that shown in Figure 2c, showing more of the fracture of the dome metal. X 1 1/4

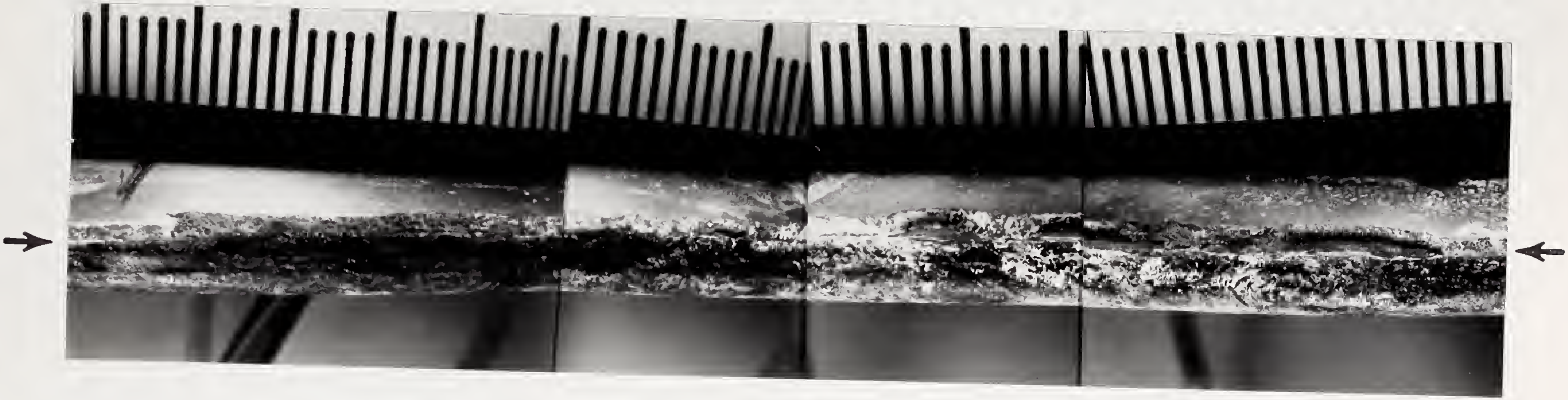


Figure 3. Close-up view of the cap-collar assembly showing dome metal and collar metal. The dome metal disappears toward the top horizon. Part of the fracture path through the dome metal is shown in elevation and runs horizontally from arrow to arrow. The collar metal is shown in elevation and runs horizontally across the lowermost portion of the picture. (One small scale division equals one millimeter.)

Figure 4a. Close-up view of the circumferential tear. X 1 1/4

Figure 4b. Close-up view of the circumferential tear. X 1 1/4

Figure 4c. Close-up view of the circumferential tear. X 3/4

Figure 5a. Dome removed from fire extinguisher number F 700745. X 3/4

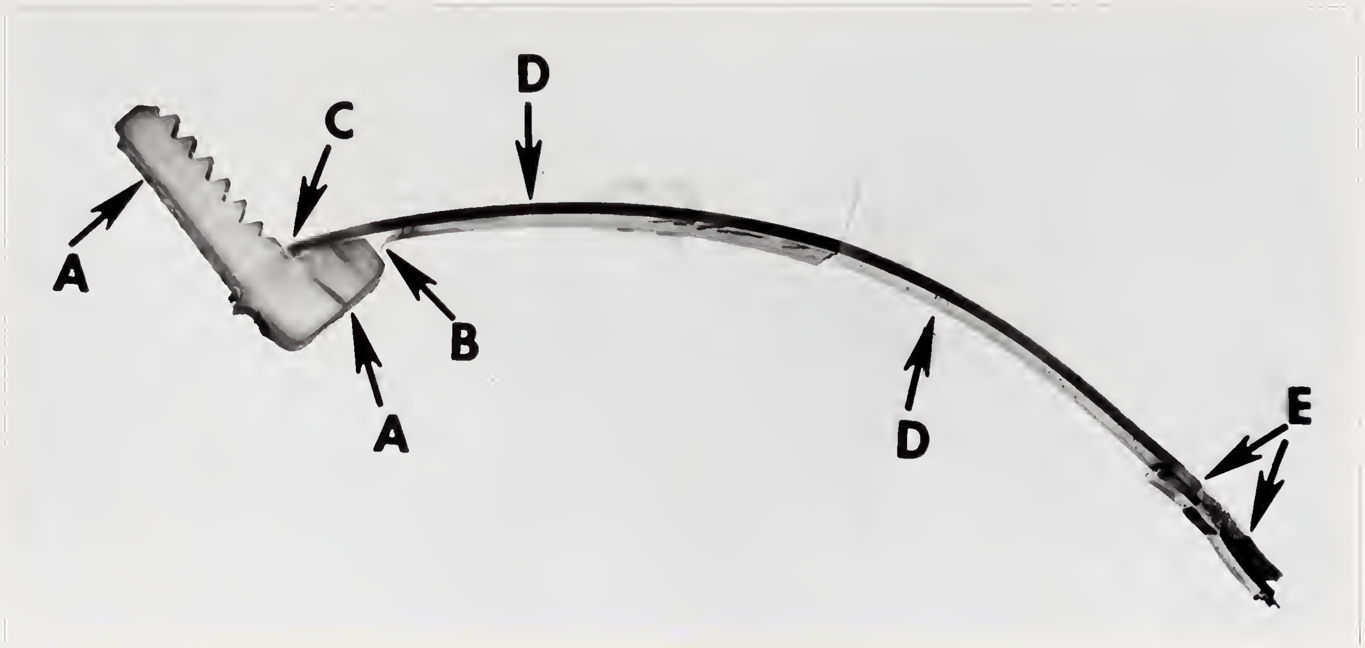


Figure 5b. Longitudinal section through dome wall showing collar (A), joining metal (B and C), dome wall (D) and joint between dome wall and shell wall (E). X 1 1/2

Figure 6. Inside view of dome removed from fire extinguisher number F 700745. X 3/4

Figure 7a. Full circumferential view of inside of dome. Note the circumferential step or crack which shows up between the joining metal and the dome metal. X 1 1/4

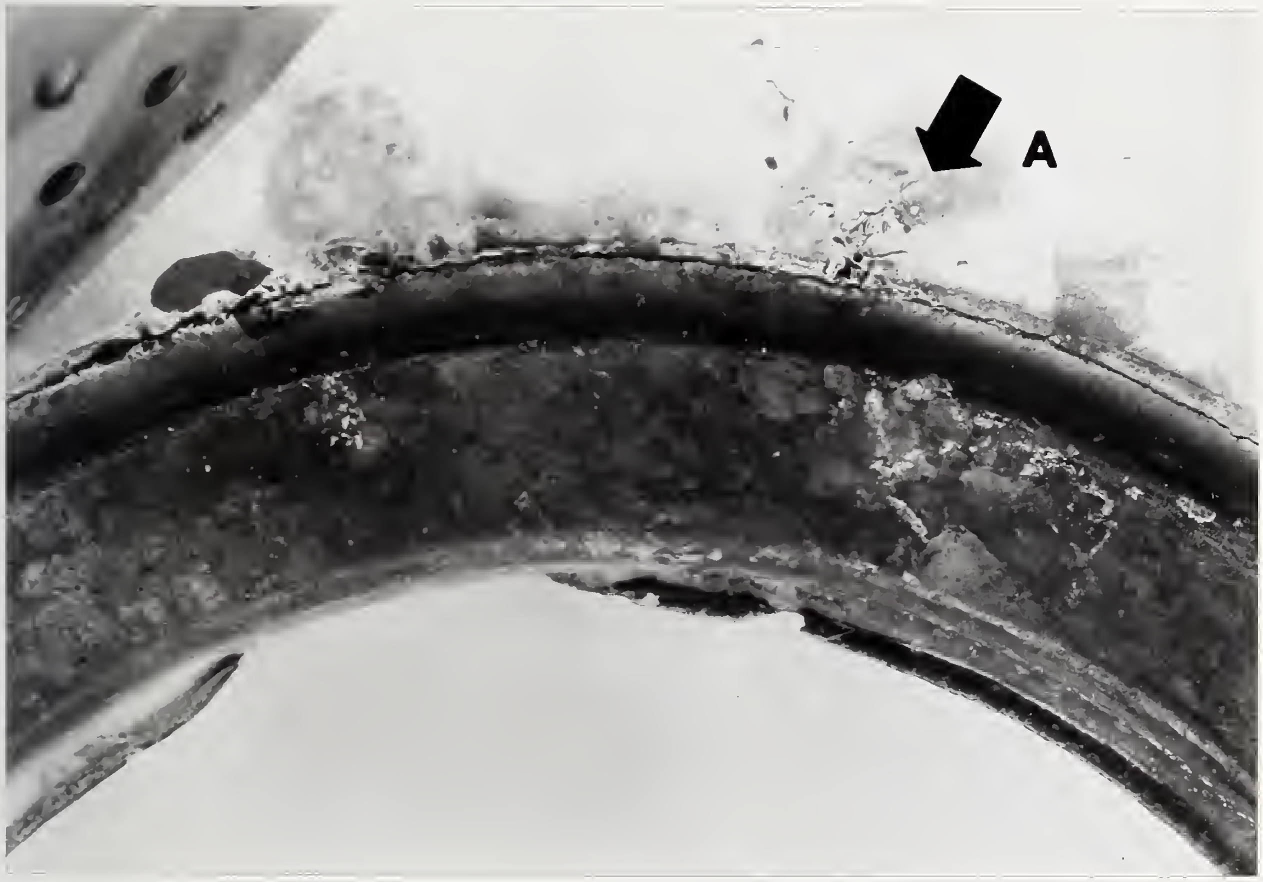


Figure 7b. Close-up of a section from Figure 7a near the strainer. X 2 1/2

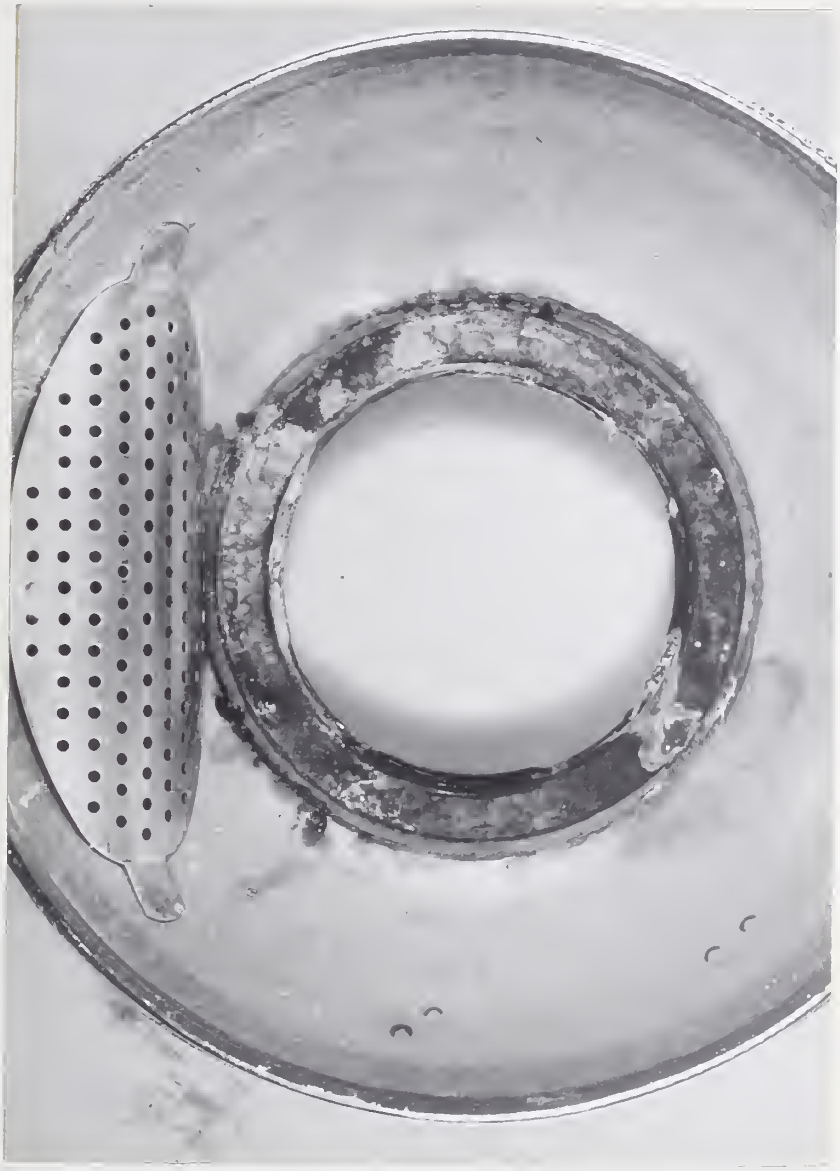
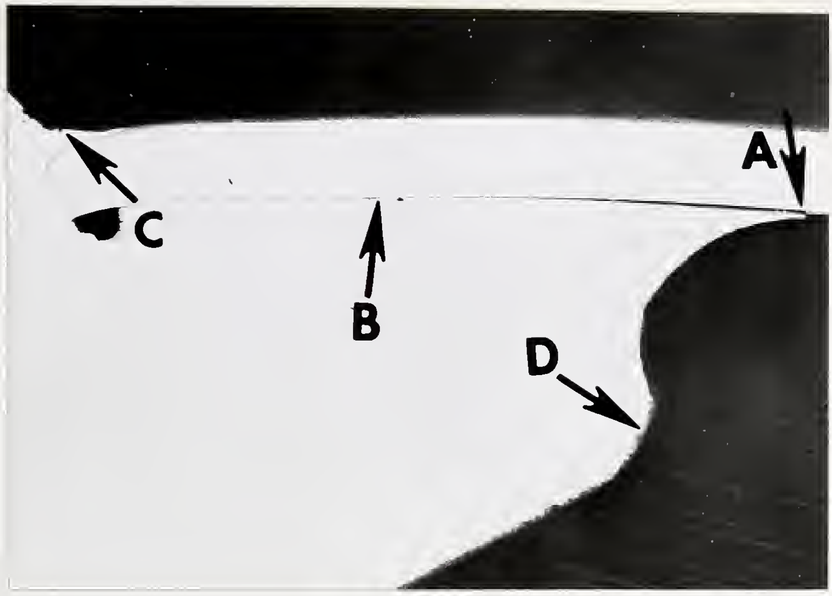
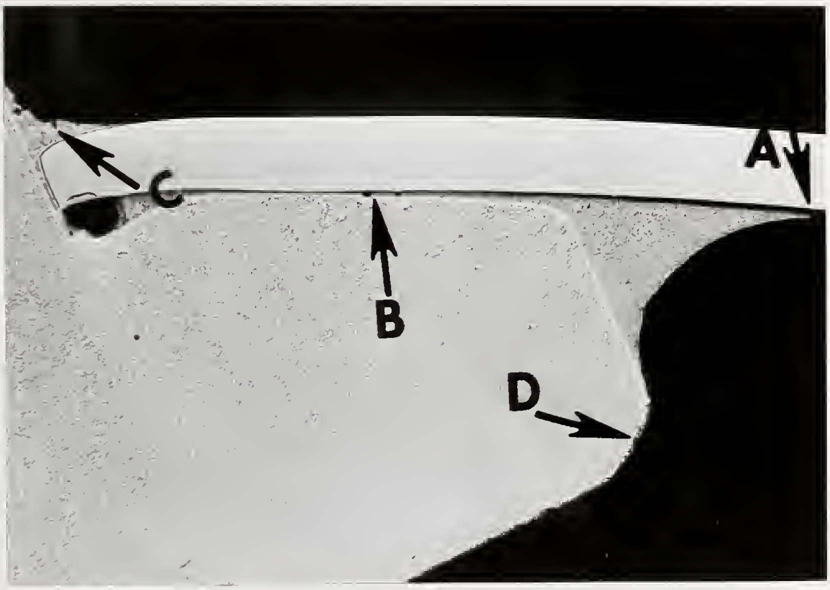


Figure 7c. Full circumferential view of inside of dome, showing the reddish-orange-brown coloring of stains near the circumferential step or crack shown in Figures 7a and 7b. X 3/4



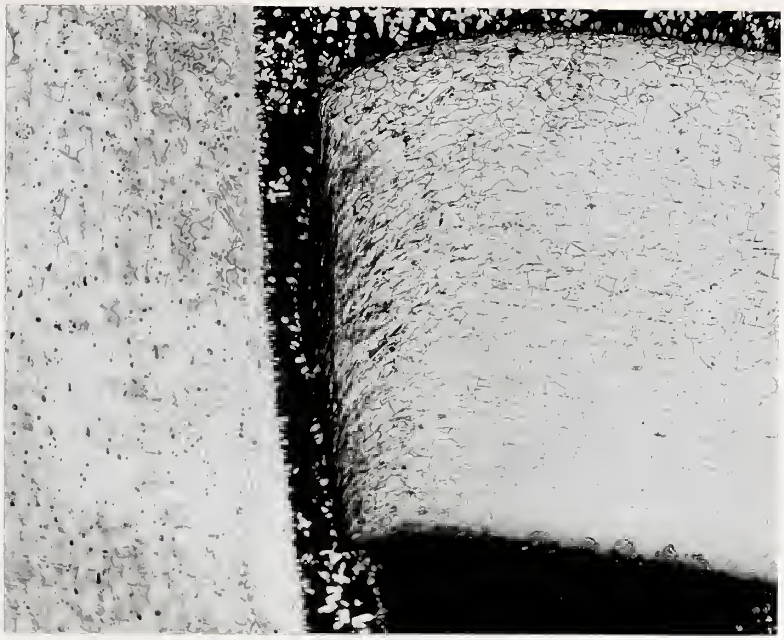
As Polished X 10

Figure 8a. Close-up view of the region where the dome metal joins the collar metal. The interface between the wall of dome metal and the collar metal shows up as the horizontal line running left from A.



Etchant: Glyceregia X 10

Figure 8b. Close-up view of the region where the dome metal joins the collar metal. The joining metal shows up clearly between the dome metal and the collar metal due to etching. The outside fillet of joining metal is in the region labeled C, and the inside fillet curves between A and D.



Etchant: Chromic Acid X 50

Figure 9a. End of the dome metal under the outside fillet of joining metal. Note severely distorted grains at end indicating localized distortion.

Etchant: Chromic Acid X 100

Figure 9b. Close-up of the region of localized deformation in Figure 9a. Note transition from severely distorted grains at left to apparently undistorted grains at right.

As Polished

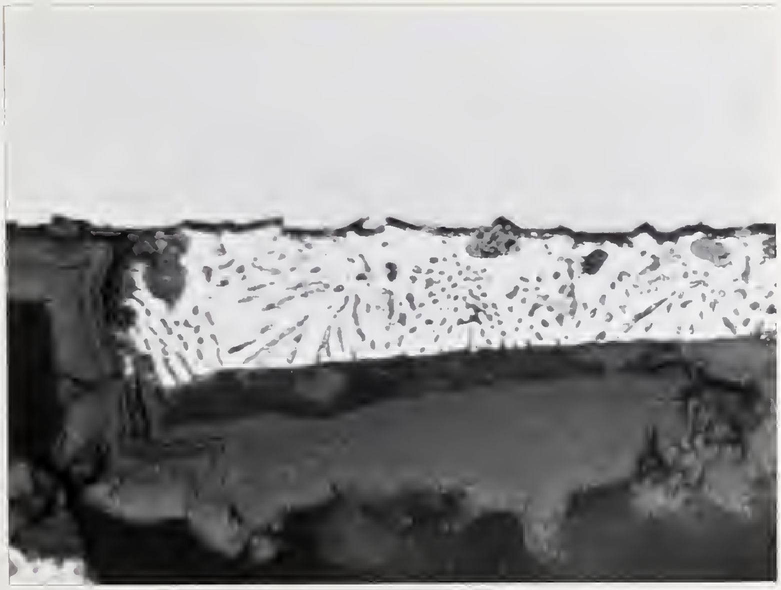
Figure 10. a. Rupture of the inside fillet of joining metal noted at A in Figure 8. Dome metal appears across the top. X 100

b. Close-up of the ruptured joining metal shown in Figure 10a. Note corrosion product coating the surface of the dome metal and the surfaces of the joining metal. X 200

c. Rupture of the joining metal shown in Figure 10a. Note the film of corrosion product and the incomplete closure of the rupture. X 500

(a)

(b)



(c)

As Polished X 500

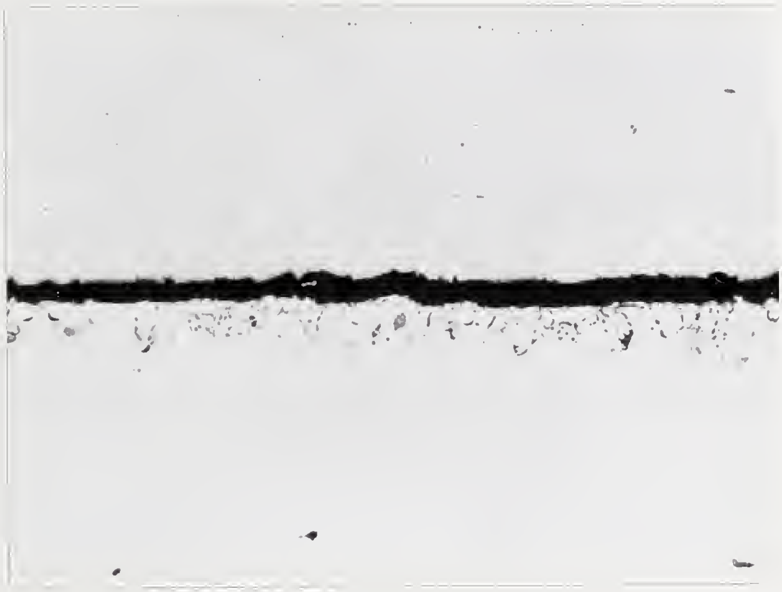
Figure 11. Close-up of the crevice between dome metal (top) and joining metal (bottom) at some point between A and B in Figure 8. Note the good matching of the profiles of the dome metal and the joining metal at the arrows.

Figure 12. a. Close-up of the two pits at B in Figure 8. Dome metal is at the top and joining metal is at the bottom. X 100

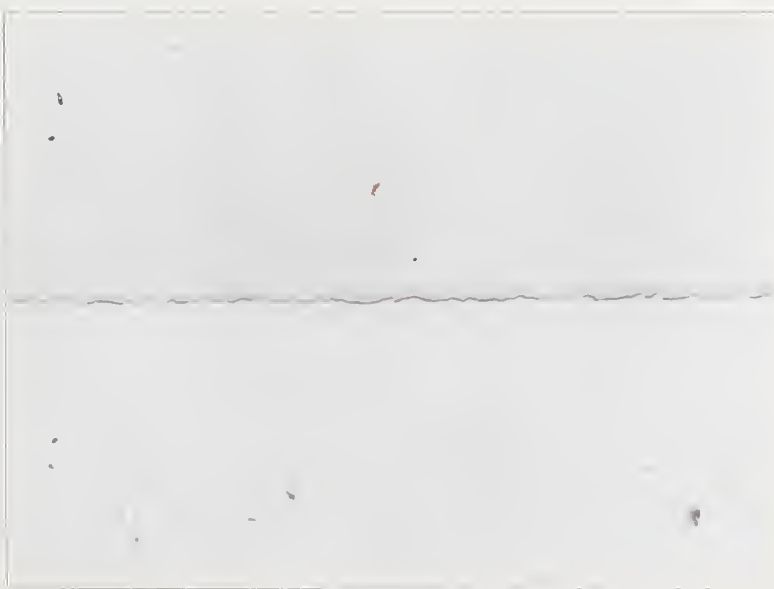
b. Appearance of the crevice between dome metal (top) and joining metal (bottom) to the right of the pits in Figure 12a. X 200

c. Region to the left of the pits in Figure 12a, showing tightly bonded interface between the dome metal (top) and joining metal (bottom). X200

(a)



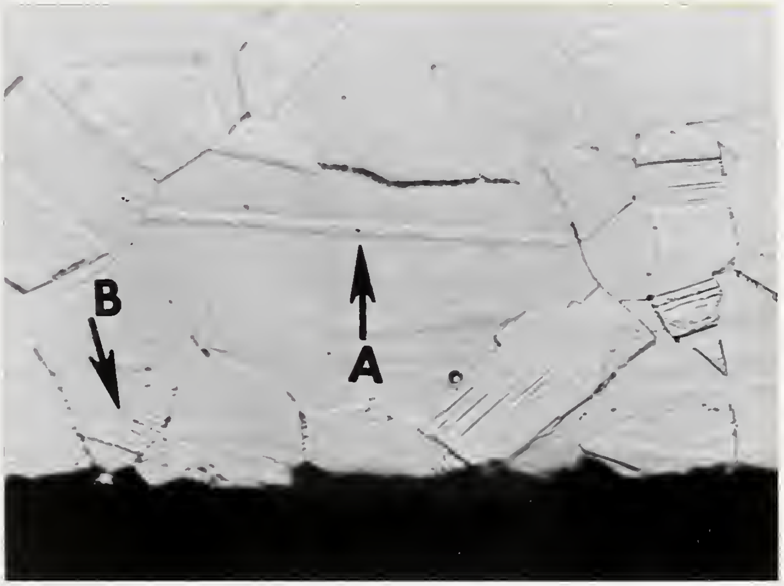
(b)



(c)

10% Oxalic Acid-Electrolytic X 500

Figure 13a. Grain structure of the dome metal near the crevice at some point between A and B in Figure 8.

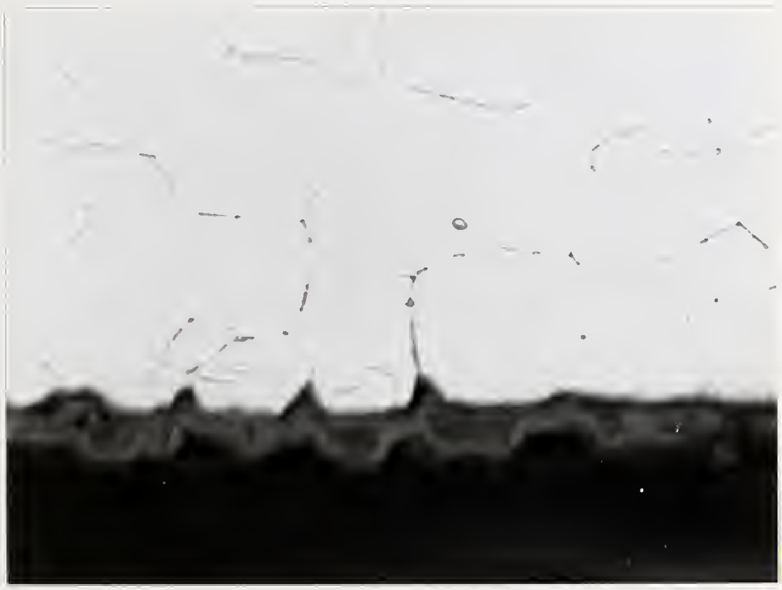


10% Oxalic Acid-Electrolytic X 1200

Figure 13b. Close-up of some grains appearing just below the center of Figure 13a. The feature at A traversing an entire grain is probably an annealing twin, and the features at B --- which appear in several grains --- are probably slip lines.

10% Oxalic Acid-Electrolytic X 500

Figure 14a. Grain structure of the dome metal at some point between A and B in Figure 8. An abundance of grain boundary precipitates lead to the darkened and dotted appearance of grain boundaries.



10% Oxalic Acid-Electrolytic X 1000

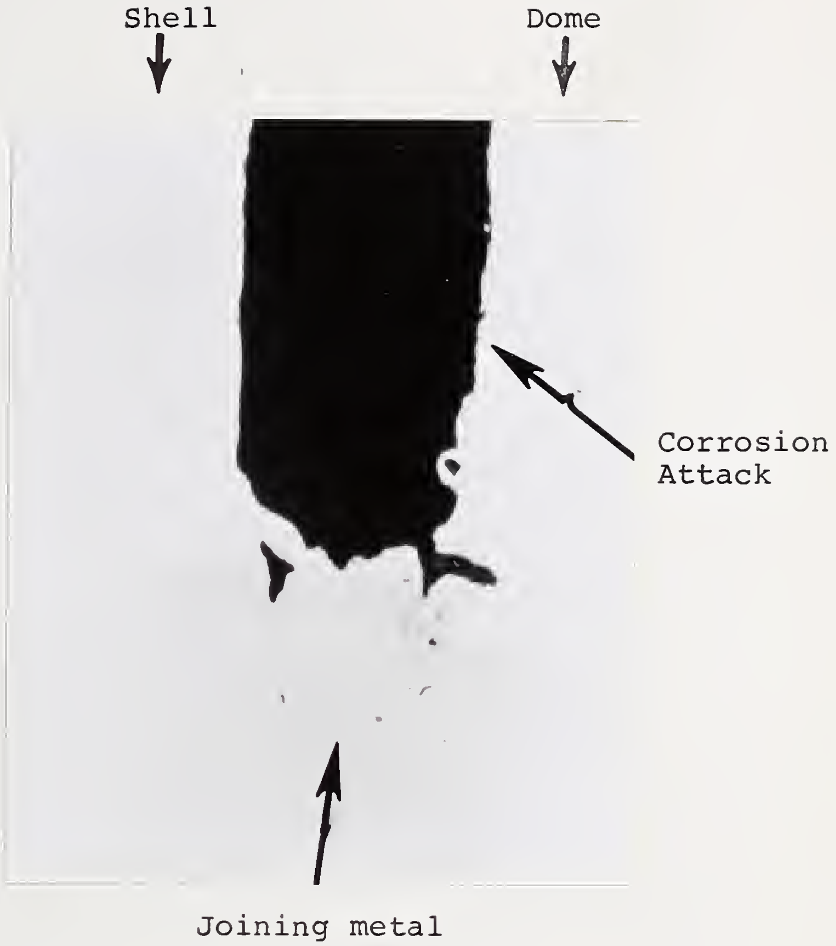
Figure 14b. Close-up of grain boundaries in the dome metal near the crevice, showing evidence of grain boundary precipitates. Note that the film of corrosion product exhibits a slight tendency to penetrate some of the grain boundaries.

As Polished X 100

Figure 15. A section of the collar metal near D in Figure 8, showing surface film of corrosion product.

As Polished X 100

Figure 16. A section of the joining metal near C in Figure 8, showing film of corrosion product.



As Polished X 500

Figure 17. Upper region of lap joint between dome metal and shell metal shown at E in Figure 5b. Irregular surfaces suggest corrosive attack, possibly from corrosive fluid retained in the crevice formed by the lap joint.

Figure 18. Fire extinguisher number F 701019 pressurized to burst. The extinguisher bulged significantly, but remained structurally intact. Failure occurred at 850 psig when the center section of the cap blew out. X 1/3

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A safety evaluation of soda-acid fire extinguishers was carried out. One extinguisher which exploded was photographed at low magnification, and three extinguishers removed from service were evaluated by metallographic examination and by pressurization tests. The objective of these evaluations was to determine if the susceptibility of soda-acid fire extinguishers to catastrophic failure during use were a generic problem. Results indicated that deterioriation at the dome end is likely to occur in many soda-acid fire extinguishers. Susceptibility to such deterioriation seems attributable to a combination of several factors, including design, use of dissimilar metals, manufacturing practice, handling in service, time in service and frequency of discharge. However, even extinguishers removed from service which exhibited conspicuous interior deterioriation performed satisfactorily in pressurization tests. Hence, the results of this evaluation are inconclusive as regards the question of whether or not the susceptibility of soda-acid fire extinguishers to catastrophic failure is a generic problem.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*
Circumferential tear; fire extinguisher; metallographic examination; pressurization tests; safety evaluation; soda-acid

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