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OAK RIDGE NATIONAL LABORATORY

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ORNL/TM-13162

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# Abstract


The Gaseous Diffusion Plants, or GDPs, have significant amounts of a number of metals, including nickel, aluminum, copper, and steel. Aluminum was used extensively throughout the GDPs because of its excellent strength to weight ratios and good resistance to corrosion by $UF_6$.

This report is concerned with the recycle of aluminum stator and rotor blades from axial compressors. Most of the stator and rotor blades were made from 214-X aluminum casting alloy. Blades were replaced during equipment upgrades, after compressor failure, or as a result of routine evaluations. Used compressor blades were contaminated with uranium both as a result of surface contamination and as an accumulation held in surface-connected voids inside of the blades. The blades remained contaminated even though they were acid washed prior to storage in fiber drums.

A variety of GDP studies were performed to evaluate the amounts of uranium retained in the blades; the volume, area, and location of voids in the blades; and connections between surface defects and voids. Evaluations and inspections were focused primarily on improving quality and longevity of blades and on providing a basis for estimating uranium inventories within GDP equipment. Based on experimental data on deposition, uranium content of the blades is 0.3%, or roughly 200 times the value expected from blade surface area. However, this value does correlate with estimated internal surface area and with lengthy deposition times.

Based on a literature search, it appears that gaseous decontamination or melt refining using fluxes specific for uranium removal have the potential for removing internal contamination from aluminum blades. A melt refining process was used to recycle blades during the 1950s and 1960s. The process removed roughly one-third of the uranium from the blades. Blade cast from recycled aluminum appeared to perform as well as blades from virgin material. New melt refining and gaseous decontamination processes have been shown to provide substantially better decontamination of pure aluminum. If these techniques can be successfully adapted treat aluminum 214-X alloy, internal and, possibly, external reuse of aluminum alloys may be possible.

# 1. Introduction

First generation gaseous diffusion plants, or GDPs, are scheduled for decontamination and decommissioning. As shown in Table 1.1, these plants contain substantial amounts of radioactively contaminated scrap metals, including iron, aluminum, copper, and nickel. The Department of Energy is evaluating methods for decontaminating and recovering these metals. Due to excellent strength-to-weight ratios and good resistance to corrosion by process gas, aluminum alloys were used extensively throughout gaseous diffusion plants for process equipment components, compressors, and fans.

**Table 1.1. Estimated radioactive scrap metal streams from diffusion plants[a]**

| Category | Oak Ridge, 1000 tons | Paducah, 1000 tons | Portsmouth, 1000 tons | Total, 1000 tons |
|---|---|---|---|---|
| Ferrous metals/steel[a] | 103.7 | 74.0 | 91.4 | 269.1 |
| Aluminum/copper | 8.5 | 6.1 | 7.6 | 22.2 |
| Copper wire, tubing, valves | 17.6 | 11.7 | 15.0 | 44.3 |
| Monel pipe, valves[b] | 1.7 | 1.2 | 1.5 | 4.4 |
| Nickel | 22.1 | 15.9 | 19.8 | 57.8 |
| Miscellaneous[c] | 22.1 | 15.9 | 19.8 | 57.8 |

[a]Excludes structural steel remaining in decontaminated structures. [b]Monel contains 27% copper, 68% nickel, and 2-3% iron. [c]Includes instrumentation. Source: National Research Council 1996a.

As shown in Table 1.2, more than a thousand stages were employed at each gaseous diffusion plant. Thousands of axial compressors very similar in structure and operation to jet engines were used to increase gas pressure between diffusion stages. As in jet engines, compressors were equipped with aluminum rotors and stators containing large numbers of replaceable aluminum blades. Blade size and shape varied according to position in the assembly. Blades were replaced during equipment upgrade campaigns, after compressor failure, or as a result of routine maintenance evaluations.

**Table 1.2. Cascades and stages in process buildings at the three GDP sites**

| | | *Converter Equipment Size* | | | | | |
|---|---|---|---|---|---|---|---|
| GDP | Item | 25 | 27 | 0 | 00 | 000 | Total |
| Oak Ridge | Stages | 3,018 | 540 | 300 | 600 | 640 | 5,098 |
| | Cells | 507 | 90 | 30 | 60 | 80 | 767 |
| | Units | 54 | 9 | 3 | 6 | 8 | 80 |
| | Buildings | 1 | 1 | 1 | 1 | 1 | 5 |
| Portsmouth | Stages | 1,620 | 720 | 600 | 500 | 640 | 4,080 |
| | Cells | 140 | 60 | 60 | 50 | 80 | 390 |
| | Units | 7 | 3 | 6 | 5 | 8 | 29 |
| | Buildings | 0.7 | 0.3 | 0.5 | 0.5 | 1 | 3 |
| Paducah | Stages | 0 | 60 | 0 | 800 | 960 | 1,820 |
| | Cells | 0 | 10 | 0 | 80 | 120 | 210 |
| | Units | 0 | 1 | 0 | 8 | 12 | 21 |
| | Buildings | 0 | 1 | 0 | 2 | 2 | 5 |
| Total | Stages | 4,638 | 1,320 | 900 | 1,900 | 2,240 | 10,998 |
| | Cells | 647 | 160 | 90 | 190 | 280 | 1,367 |
| | Units | 61 | 13 | 9 | 19 | 28 | 130 |
| | Buildings | 1.7 | 2.3 | 1.5 | 3.5 | 4 | 13 |

Source: National Research Council 1996a.

Compressor blades were contaminated with uranium both internally and externally

Table 1.3. Uranium content of used aluminum 218 alloy compressor blades[a]

| Blade | U, mg/g blades, compressor AC 6D-11K-48[b] | U, mg/g blades, compressor AC 6D-11K-405[c] |
|---|---|---|
| **Stator A** | | |
| Inlet guide | 3.4 | 1.5 |
| C-1 | 4.4 | 2.4 |
| C-2 | 5.1 | 1.0 |
| C-3 | 5.0 | 0.1 |
| C-4 | 6.5 | 2.6 |
| C-5 | 2.2 | 0.1 |
| C-6 | 5.7 | 2.1 |
| **Stator B** | | |
| Stator vane | 10.0 | 5.2 |
| Inlet guide | 3.3 | 0.1 |
| C-7 | 5.6 | 2.2 |
| C-8 | 2.0 | 0.4 |
| C-9 | 2.9 | 5.8 |
| C-10 | 6.1 | 5.8 |
| **Rotor** | | |
| R-1 | 3.9 | 1.6 |
| R-2 | 4.4 | 0.2 |
| R-3 | 2.7 | 4.5 |
| R-4 | 6.5 | 3.5 |
| R-5 | 5.8 | 0.1 |
| R-6 | 6.9 | 5.1 |
| R-7 | 9.5 | 1.3 |
| R-8 | 6.6 | 0.8 |
| R-9 | 6.7 | 5.2 |
| R-10 | 8.8 | 2.3 |

[a]Source: Kwasnoski 1954. [b]Highest uranium content of group evaluated. [c]Lowest uranium content of group tested.

during operation. A number of metallographic and physical property studies were performed in order to understand the causes of blade failure during operation, to evaluate the quality of incoming blades, to optimize blade alloy composition with respect to one or more physical properties, or to evaluate uranium retention. Die casting, the method normally used to form aluminum compressor blades, laid the groundwork for internal contamination because it created internal voids in the aluminum which were connected to the blade surface. This was ascribed to a variety of causes, including low metal melt temperatures, too-rapid separation of the molds from the casting, and too-rapid cooling of the casting.

During operation, $UF_6$ gas entered surface-connected voids, resulting in the accumulation of uranium precipitates within the blades. Results of the evaluation of aluminum alloy 218 blades, as shown in Table 1.3, indicate that the amount of uranium which accumulates in blades can be estimated to be on the order of 0.2-1% by weight. This is well above the 0.05 wt.% concentration limit that results in classification as "source material" for domestic metal production. Internal uranium precipitates have been reported to be difficult to remove from the blades using conventional surface cleaning techniques (Benton 1953, Shussler and Junkins 1953). If a method which removes uranium and its daughter products to permit reuse, can be developed, compressor blades could be recycled. Although several different methods, such as electrostripping, have potential for removing surface contamination, it may be difficult to remove radioactive contaminants through the tortuous, fine passageways connecting inner voids to the blade surface. Gaseous methods, such as cleaning with $ClF_3$, and melt-refining using fluxes which selectively concentrate uranium and its daughters, may be the most satisfactory methods for decontaminating aluminum compressor blades.

The relatively high concentrations of iron and silicon found in compressor blades are also of concern because, without dilution, they limit use of recovered aluminum to cast applications. This would prevent wrought product applications such as extrusion and rolling that are typically used to produce commercial aluminum products, such as siding, pallets, expanded metal fencing, decking, or guardrails.

Although a number of different alloys, whose compositions are shown in Table 1.4, were used throughout the period, aluminum alloy 214-X (now 514) predominated. This alloy,

**Table 1.4. Compositions of aluminum turbine blade alloys[a]**

| Constituent, % | 214-X Specification[b] | 214-X Measured[b] | 514.0[c] | 218[c] | A-254 Specification | A-254 Measured |
|---|---|---|---|---|---|---|
| Magnesium | 2.5 | 3.58-4.5 | | 7.5-8.5 | 6.0 | 5.61 |
| Silicon | 1.0 | 0.74-1.0 | 0.35 max. | 0.3 max. | | 0.74 |
| Iron | 1.3 | 1.02-1.74 | 0.50 max | 1.8 max. | | 0.27 |
| Manganese | 0.6 | 0.20-0.51 | 0.35 max. | 0.3 max. | 1.5 | 1.41 |
| Copper | 0.12 | 0.05-0.10 | 0.15 max. | 0.2 max. | | |
| Beryllium | | 0.0003-0.003 | | | | |
| Chromium | 0.10 | 0.05 | | | | |
| Titanium | | 0.01 | 0.25 max. | | | |
| Nickel | | | | 0.1 max. | 1.5 | 0.79 |
| Zinc | | | 0.15 max. | 0.1 max. | | |
| Tin | | | | 0.1 max. | | |
| Other | | | | 0.2 max. | | |
| Aluminum | Balance | Balance | | | Balance | Balance |

[a]Source: Ziehlke 1953a. [b]Alloy currently designated 514. [c]ASM 1994.

although classified as a casting alloy, is highly machinable. However, the high concentration of iron tends to restrict it to cast applications.

This report is concerned with recycle of aluminum from axial compressor blades because they are a major component of GDP radioactively contaminated aluminum scrap. In the following sections, relative merits of potential methods for decontaminating used compressor blades to levels low enough to potentially permit public use of the material are evaluated. Since standards for release have not yet been developed, potential in-house uses for recovered aluminum are also considered. These include purification and reuse as compressor blades, as well as recycle for other uses.

# 2. Literature Review

Compressor blades were a major diffusion plant purchase. The compressors, which operated at high speed, contained a large number of blades. Quality evaluations were performed on individual lots of purchased blades. The blades were evaluated for surface finish, porosity, cracks, voids, and constancy of alloy chemistry. Post-uranium production evaluations of the blades were also performed for the determination of uranium uptake, both on the surface of the aluminum and within surface-connected porosities. These studies, which involved a variety of different aluminum alloys used in various types of diffusion plant equipment, provided rough estimates of uranium content and pointed to possible mechanisms for uranium retention. These preliminary studies provide a basis for evaluating technologies for the recycle of blades.

**Uranium deposition.** Hughes and Nolan (1984) estimated deposition of uranium from $UF_6$ onto the surface of aluminum 3003 process piping by evaluating the accumulation of uranium surface films of $AlF_3$ and $UO_2F_2$ onto test coupons. Deposition of $UO_2F_2$ was increased substantially with increasing exposure to oxygen, water, or organics. Their data, shown in Fig. 2.1, demonstrate increasing deposition with increasing time.

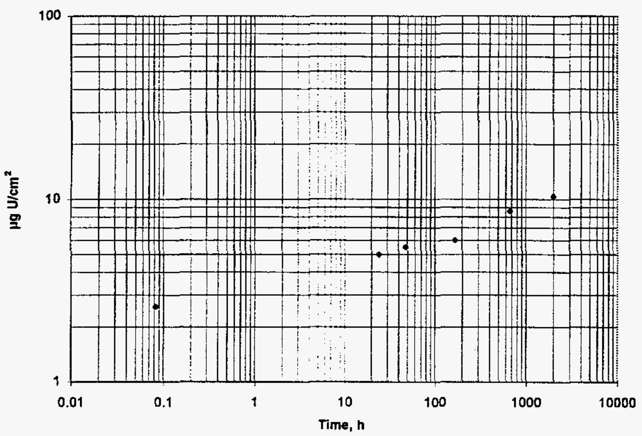


**Fig. 2.1. Uranium deposition from $UF_6$ onto aluminum 3003 coupons at 100 torr. Adapted from Hughes and Nolan 1984.**

In addition to direct deposition on stationary surfaces like pipes, uranium can also be deposited from $UF_6$ gas onto and into compressor blades. Benton (1953) evaluated uranium retention in the blades of a single compressor. This was accomplished by removing sample plugs from blades, dissolving them, and analyzing the uranium content of the resultant solution. Schussler and Junkins evaluated a number of different in-plant studies and determined that uranium deposition onto and into blades accounted for significant uranium consumption (1953). The significant loading of uranium on and into the blades was as a result of certain features of the blade forming process. Die casting increased the accessible surface area to more than 200 X the geometric area. The roughness of die cast blades and other features, such as shrinkage cavities, laps, and cold shuts, were major contributors to the increased accessible surface area.

Kwasnoski (1954), using techniques similar to those of Benton, found a significant variation in the amounts of uranium within blades taken from four compressors which had been operated for varying lengths of time. His results are shown in Table 1.2. Variation in uranium content did not appear strongly correlated with length of service. Kwasnowski reported uranium to average roughly 500 g per compressor, most of which was retained in blades (0.3% w/w) rather than in the more massive sections, such as rotors or stators (0.01% w/w). These values are approximately those expected by extrapolating Hughes and Nolan's short-term data to reflect the extended operating times, and 200-fold increase in internal and external surface areas found with compressor blades.

**Surface-connected porosity.** Enfoliation, or surface connected porosity, was an artifact of the die casting process used to form compressor blades. Typically, a small surface defect, such as a narrow crack, provided access to an internal void in the blade. Resonant frequency testing and metallographic sectioning and etching were used to evaluate the porosity of blades (Ziehlke 1961a). The most common defects found during this type of inspection were shrink porosity and oxide inclusions in the shank region of the blade (Ziehlke 1961b). Typical examples of defective blades are shown in Figs. 2.2, and 2.3.

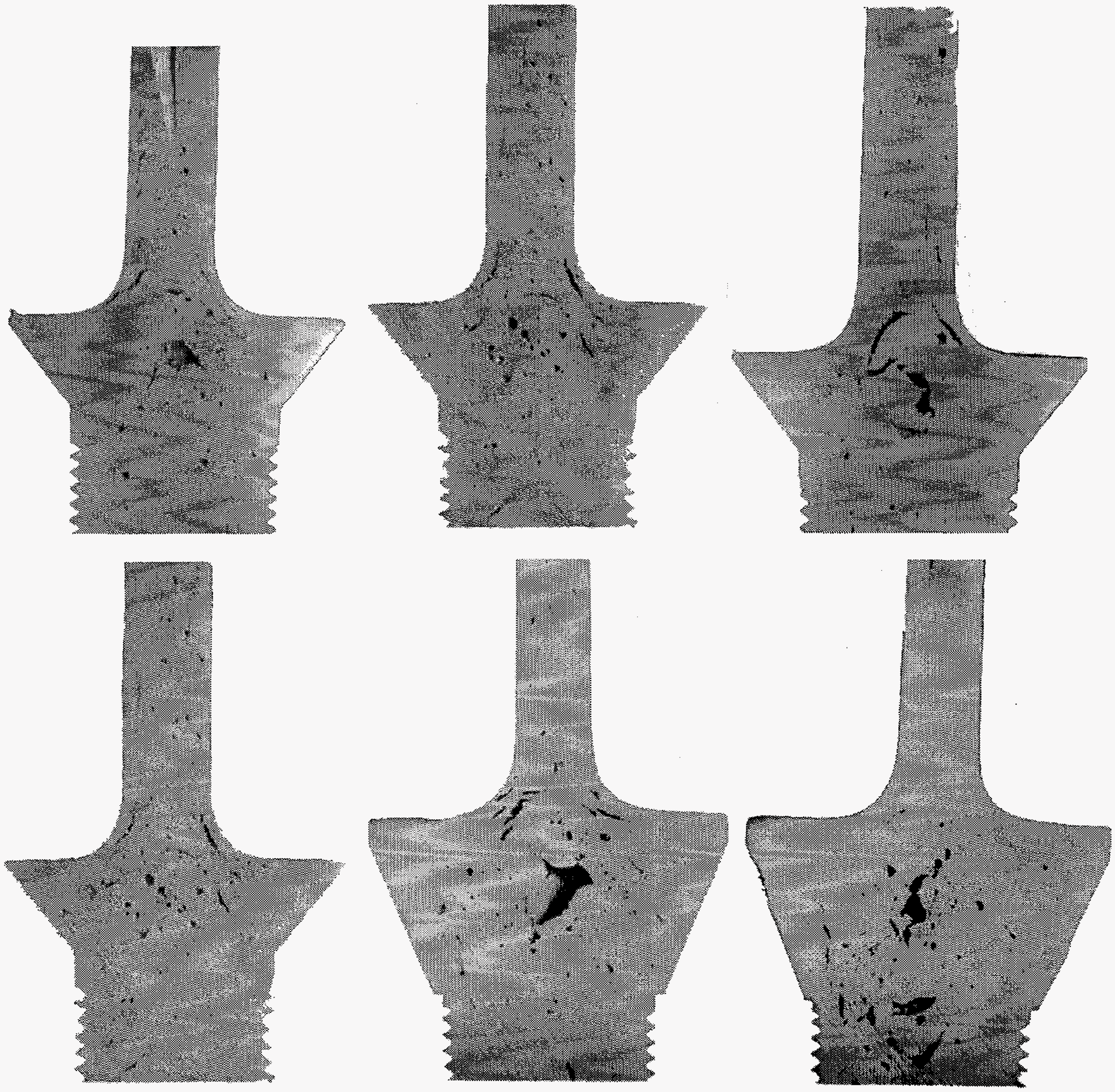

**Fig. 2.2. Voids were produced in many types of blades. Source: Ziehlke 1961a and b.**

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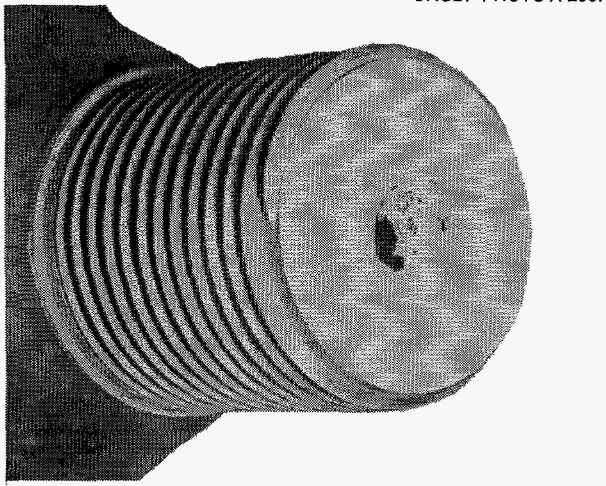

Fig. 2.3. Shrinkage pipe defect in blade shank. Source: Ziehlke 1968.

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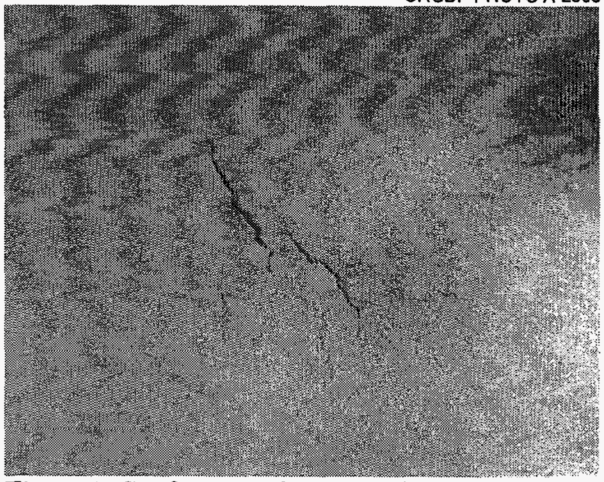

Fig. 2.4. Surface cracks on blade fillet. Source: Ziehlke 1968.

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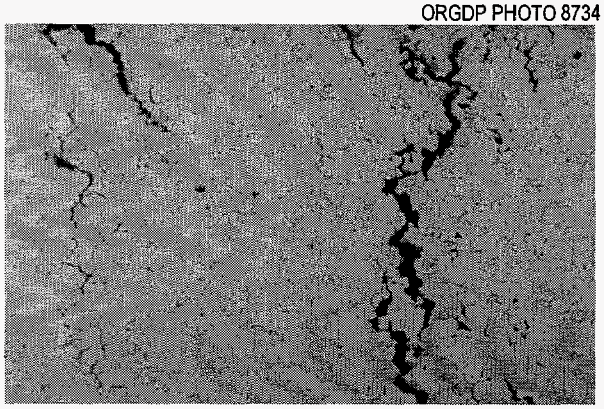

Fig. 2.5. Micrographic section through fillet crack. Source: Ziehlke 1968.

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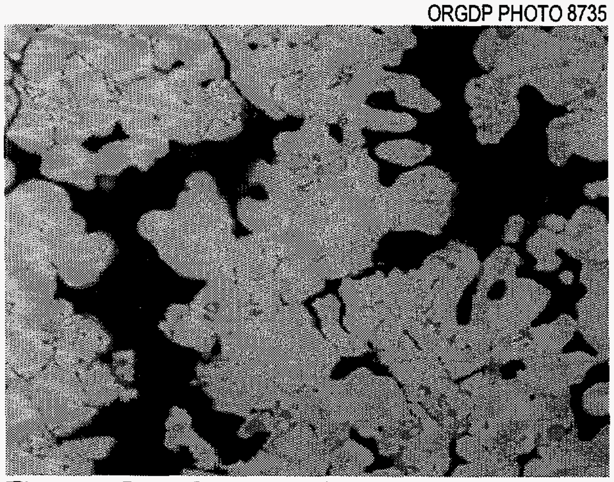


Fig. 2.6. Interdendritic shrinkage pattern underlying surface cracks. Source: Ziehlke 1968.

Microscopic examination of the blades indicated that small surface cracks could lead to a web of connected internal as illustrated in photomicrographs of the fillet region of a compressor blade shown in Figs 2.4, 2.5, and 2.6 (Ziehlke 1965a and 1968). Defects were typically attributed to poor management of the casting process itself.

The figures presented earlier in Table 1.2 indicated that a substantial amount of uranium was retained in compressor blades. The majority of this material is likely to have been deposited within the blade. While uranium on the surface of the blade is likely to be readily removed by ambient pressure washing, electrostripping, or other liquid decontamination techniques, it is likely that a refining technique, such as melt refining, which removes uranium held within the body of blades will be required.

Compressor blades have been satisfactorily recycled as compressor blades using melt refining and casting (Johnston and Penry 1959). These investigators report pilot investigations of melt recycling discarded aluminum 214-X and 218 blades. The aluminum blades were washed to remove surface contamination, dried, and melted in a lime-coated steel vessel with 3% of a proprietary flux (NaCl, NaF, KF). The aluminum was melted at 1350° F and poured into 50 lb ingot molds through a 1 inch spigot in the lower section of the melting pot. The ingots were then sent to Doehler-Jarvis for casting into blades. Table 2.1. shows the aluminum, and Table 2.2, the uranium, mass balances for the pilot operation.

Process losses of uranium were very low. As previously reported by Lay and Taylor (1958) the fatigue strength of recycled blades with small quantities of uranium was acceptable.

As shown in Table 2.3, measurements taken during processing operations indicated that radiation levels were within production plant requirements. Alpha and beta radiation levels in materials, shown in Table 2.4, indicated that melt processing sharply reduced the levels of these materials, predominantly uranium and its daughter products, in aluminum. However, the study did not consider downstream treatment of dross, slag, casting wastes, and other process wastes into which radioactive species are concentrated.

**Table 2.1. Aluminum mass balance for pilot casting[a]**

| Process step | Weight, lb |
|---|---|
| Scrap compressor blades to melting | 900 |
| Aluminum alloy in dross and metal "heel" | 241 |
| Ingots to Doehler-Jarvis | 659 |
| Alloying materials added by Doehler-Jarvis | 35 |
| Doehler-Jarvis melt | 694 |
| Aluminum alloy returned to Paducah: | |
| Compressor blades | 245.7 |
| Doehler-Jarvis quantometer sample | 1.5 |
| Shavings | 0.7 |
| Ingots of excess material | 230 |
| 700 lb furnace bottom cleaning | 68.2 |
| Sprues and cleanup from die casting machine | 74.8 |
| Holding pot cleanup | 22.0 |
| Aluminum alloy content of dross[b] | 35.5 |
| Total accounted for | 678.4 |
| Aluminum alloy unaccounted for | 15.6 |

[a]Adapted from Johnston and Penry 1959. [b]66 pounds of dross.

**Table 2.2. Uranium mass balance for pilot casting[a]**

| Step | U, lb |
|---|---|
| **Ingot Preparation** | |
| Scrap blades, 900 lb@ 930 ppm U | 0.837 |
| Aluminum ingots, 659 lb @ 645 ppm U | 0.425 |
| Balance in dross and metal "heel" | 0.412 |
| **Remelting and Casting** | |
| Aluminum alloy ingots | 0.425 |
| Nonrecoverable alloy scrap, 15 lb @ 250 ppm | 0.004 |
| Balance in returned materials | 0.421 |

[a]Adapted from Johnston and Penry 1959.

The payback period for the process was reported to be less than six months. Recycle appears to have been used to supply some of the replacement Paducah compressor blades made from 214-X. Recycle blades made in 1963 appeared to have suffered from most of the same casting problems that plagued blades made from fresh alloy (Ziehlke 1963). Based on Johnson and Penry's study, production of enough castings to reblade the compressors of a single gaseous diffusion plant, Paducah, required roughly 200–300 tons of aluminum alloy. Heshmatpour and Copeland (1981b) evaluated the use of melt refining for removal of transuranic metals from aluminum, nickel, copper, and lead, and tin scrap. A partition coefficent of 800 for $UO_2$ from an aluminum system into $CaF_2$ flux after heating at 1300 C was found. Heshmatpour, Copeland, and Heestand subsequently reported near complete partitioning of plutonium from aluminum into slags (1983). A recent communication from Heshmatpour indicates that melt refining, with selection of an appropriate flux, is a consistent and effective method for removing uranium and thorium from ferrocolumbium alloys on an industrial scale (Heshmatpour 1996). After processing, the ferrocolumbium alloys are salable in the U.S. The levels of radiological contaminants are roughly equal to those in used aluminum compressor blades.

Although the amounts of flux used in a melting process is small, perhaps 3% relative to the amount of aluminum, the total amount of radiologically contaminated slag and dross is of concern. Heshmatpour and coworkers evaluated methods for reducing the size of slags so that they could be mixed with concrete for disposal (Heshmatpour and Copeland, 1981a; Heshmatpour, Copeland, and Heestand 1981). However, it would be preferable to recover radiological species from slag to minimize waste volume. The slag and dross from aluminum blades could be 20 to 50 times the volume of radiological contaminants. This represents a significant difference in waste disposal cost and volume.

**Table 2.3 . Radiation levels during alloy processing[a,b]**

| Operation | Sampling time, min | $\alpha$ Radiation, dpm/m³ |
|---|---|---|
| Loading 900 lb blades into crucible | 8.5 | 107 |
| Furnace door during temperature rise from 1100 to 1280 F | 18 | 1 |
| Open furnace door, 1380 F | 3 | 6 |
| Open furnace door for inspection, at temperature | 2 | 0 |
| Pouring first 6 castings | 4 | 1 |
| Furnace reopened after reheat and pour 8 castings | 14 | 1 |

[a]Adapted from Johnston and Penry 1959. [b]In 1959, air-borne uranium exposure was limited to 110 dpm/m³

**Table 2.4. Radiation levels in process materials[a]**

| | *$\alpha$ , cpm/100 cm2* | | *$\beta$ , mrad/h* | |
|---|---|---|---|---|
| **Material** | **Surface** | **Wipe** | **Surface** | **Wipe** |
| "Clean" used blades | 700-1500 | 0-200 | 0-0.1 | 0-0.04 |
| "Caked" used blades | 10,000 | 1,300-5,000 | 1.0-3.5 | 0-0.04 |
| Ingots | 150-250 | 0 | 0.08-0.12 | 0 |
| Molds | 0 | 0 | 0 | 0 |
| Melting pot residue | 200-1000 | | 0.6-1.4 | |

[a]Adapted from Johnson and Penry 1959.

# 3. Internal Reuse of Aluminum

There are several possible avenues for recycle of aluminum blade scrap. First, it may be possible to recover essentially uncontaminated material for outside sale or reuse. Second, recycle of aluminum blades *per se* may be possible because the diffusion plants are restocking them. Third, using modern melt-refining techniques, it may be possible to decontaminate the current stock of blades sufficiently to permit their reuse either within DOE nuclear facilities or under industrial *de minimus* standards, externally. These alternatives are discussed in detail below.

Uncontaminated blades may come from three potential sources: quality control samples, rejected blades, and unused stores stock. Based on available information, it appears that a substantial portion of each lot of blades, sometimes on the order of 10%, was removed from incoming stock for quality control tests. Occasionally, whole purchase lots of blades were rejected because of poor production quality. It is unclear whether these materials were stored separately, sent back to the manufacturer for reprocessing, or mixed with other lots of discarded blades. Any unused material, such as unsold stores stock, which was not contaminated should be evaluated for direct sale. Slightly contaminated material could be directly used for casting new compressor blades for the diffusion plants and should be evaluated to determine whether current blade production requirements can be modified to permit its use.

The predominant aluminum alloy, 214-X, now 514, in used blade scrap is high in iron and silicon. The other blade alloys, principally 218 and A-254, were also high in these alloying constituents. This limits reuse predominantly to cast shapes unless composition is modified. Based on earlier experience, several avenues for reusing this material within the Lockheed-Martin facilities are apparent. A high-volume use, is recycle into new compressor blades for the diffusion plants at Paducah and Portsmouth. These plants are purchasing new compressor blades and may be willing to modify current purchasing contracts to permit use of recycled material. Since blade scrap was successfully melt-refined, cast as ingots, and provided to blade manufacturers in the 1950s and 1960s, this option should be evaluated first.

It may be possible to decrease the radiological content and improve the quality of the aluminum alloy and minimize waste by using the novel fluxes and slag disposal methods developed by Heshmatpour and Copeland (1981a, b, 1983) and coworkers (1981). Results obtained by this group in partitioning radiological contaminants from aluminum into slag in a single step are shown in Table 3.1. As indicated in a recent communication (Heshmatpour 1996), firms experienced in related melt refining and decontamination processes may be interested in cooperating in this endeavor.

Based on the technologies used in melt refining ferrocolumbium and aluminum, a process flow diagram for the type of installation that might be used to treat contaminated compressor blade scrap was developed. The series of operations shown in Fig. 3.1 is typical of that required to process two thousand tons of aluminum scrap per year. Parallel multiple facilities would typically be used for higher production levels.

**Table 3.1. Removal of 500 ppm U from Al by fluxing at 1300° C[a,b]**

| Flux | Al:Flux, wt/wt | U in Al, ppm | U in slag, ppm | Fraction U in Al |
|---|---|---|---|---|
| $CaF_2$ | 10 | 1.2 | 9610 | 0.002 |
| NaF | 10 | 111.0 | 1360 | 0.222 |
| $CaF_2$-NaF | 10 | 1.8 | 488 | 0.004 |
| No flux | | 450.0 | | 0.900 |
| NaF-$AlF_3$-$Al_2O_3$ (cryolite) | 20 | 31.4 | 1760 | 0.063 |
| NaF-$AlF_3$-$Al_2O_3$ (cryolite) | 20 | 81.1 | 4190 | 0.162 |
| NaOH-NaCl-$Fe_2O_3$ | 60 | 83.2 | | |
| Borosilicate glass | 10 | 50.6 | | 0.101 |
| CaO-$SiO_2$-$Al_2O_3$-$Fe_2O_3$-$CaF_2$ | 10 | 308.0 | 255 | 0.616 |
| No flux | | 447.0 | | 0.894 |

[a]Added as $UO_2$. Source: Heshmatpour and Copeland 1981b.

Minimization of waste volume is also a major concern. The melt refining techniques described previously create a substantial volume of slag and dross during melt refining and decontamination of ferrocolumbium alloys Mass balances for aluminum 214-X should be evaluated because mixed waste disposal is expensive and difficult. The amount of slag produced during industrial melt-refining operations can be substantial, perhaps as high as 10 to 15% of overall scrap weight. The weight of

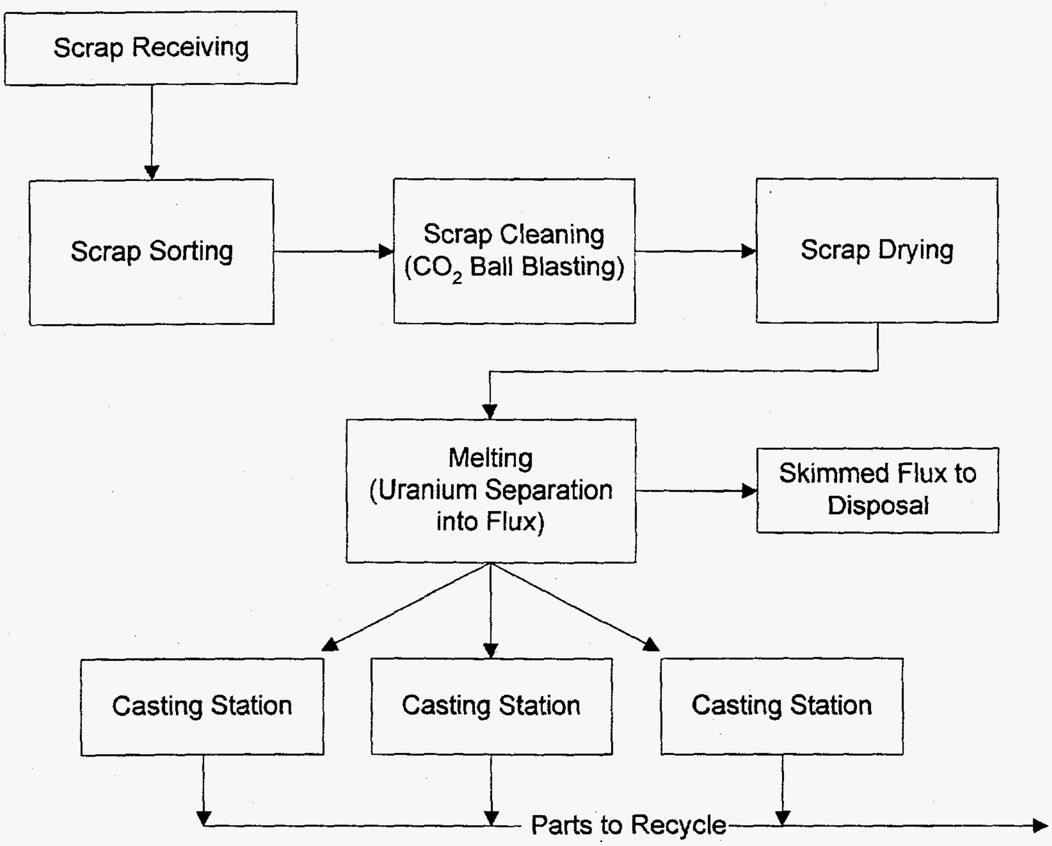
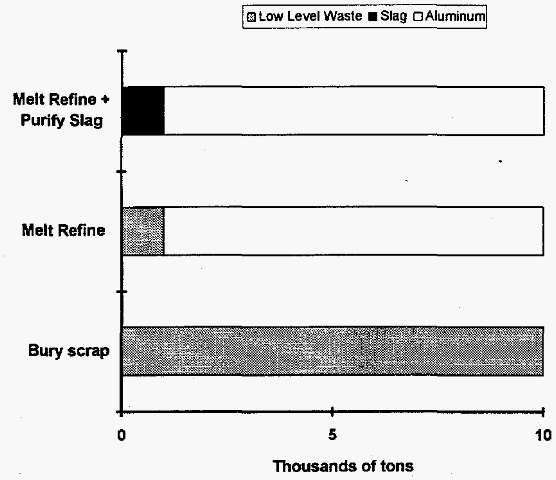



**Fig. 3.1. Production of aluminum from compressor blade scrap**




uranium and other radiological species in compressor blades is on the order of 0.3%. A schematic which illustrates the amounts of wastes produced under different processing assumptions is given in Fig. 3.2. Under present regulations, it might be advantageous to process slag and dross to concentrate uranium and to recycle aluminum and fluoride values. Process technology for meeting these goals could be developed, based on bench tests.

Depending on the degree of decontamination and on internal needs, there are a variety of internal and external applications for which uncontaminated or melt refined blade scrap could be used. The high iron and silicon levels in compressor blade alloys are suitable for making cast parts, rather than the more common rolled, stamped, and machined parts. This limits both internal and external uses of recycled aluminum.

Table 3.2. Uses for recycled aluminum

| Use | Alloy type | Inventory, tons | Processing, ton/yr | Remarks |
|---|---|---|---|---|
| Pallets | Roll | 10 | 2-3 | Stores shelves |
| Guardrails and posts | Roll | 50–250 | 10 | Might also use fence |
| Siding, grid, for buildings | Roll | | | Contamination is a concern |
| Beams and supports for buildings | Extrudable | | | Contamination is a concern |
| Compressor blades | Cast | 200-500 | 5-10 | Used in 1960s. |

Table 3.2 lists some uses for aluminum with the DOE and private nuclear sector and provides an estimate of the amount of aluminum which might be used in these applications. Both cast and rolled alloys were included because blades represent only a fraction of available aluminum. The largest potential use that has been identified is reuse of the material as compressor blades for use at Paducah or Portsmouth. The advantages of this strategy are: 1) minimization of the creation of additional waste, 2) reuse within a controlled environment to minimize the risk of public exposure, and 3) decreased need to purchase additional aluminum alloy. This technique was employed in the 1960s and blades made from recycled material were successfully used. However, present transportation laws may make it difficult to transport radiologically contaminated aluminum between sites in different states.

# 4. Evaluation of Alternatives

Aluminum compressor blades available for recycle were made primarily from aluminum 214-X, an alloy optimized for die casting. During operation, the blades were contaminated by $UF_6$ which entered into the body of the blade through fine cracks leading into internal voids. Although these voids are connected to the surface of the blade, it is difficult to remove uranium by surface cleaning with liquids. The blades can be recycled either into a partially-decontaminated form which is used in a controlled environment or into a well-decontaminated form which has the potential for wider use.

As indicated by Table 3.2, internal options for reusing die cast or machined aluminum are limited and, in the absence of a planned Paducah or Portsmouth compressor upgrade, might account for 10 to 20 tons per year. This would not substantially reduce the volume of stored contaminated blades in the near term.

Neither the DOE nor the NRC has published *de minimus* standards for metal reuse. If the standards currently being applied for foreign shipment of recycled Paducah nickel are used, uranium content of the blades would need to be reduced to levels between 0.1 and 1 ppm, a 3000:1 or better reduction. The unoptimized bench experiments reported by Heshmatpour and Copeland (1981b) indicated that a reduction of 250:1 of U dissolved in Al could be achieved during a single melt-refining step using $CaF_2$ as a flux. This technique has promise and, coupled with thorough surface cleaning, may meet a goal of 0.1 to 1 ppm U in Al.

Several different aspects need to be evaluated at bench scale to ensure that processing is effective. The melt refining process reported by Heshmatpour and Copeland was only evaluated for pure aluminum containing 500 ppm U at 1300° C. Removal of daughter products was not evaluated. Aluminum compressor blades are made of 214-X alloy and contain 3000 ppm U and the daughter products accumulated during decades of storage. The partition may be different for U and its daughter products in the alloy. An evaluation of the lowest possible level of residual U should also be made, together with a quick assessment of the effects of removal of solid U particles by filtration.

Copeland and Heshmatpour's research indicated that $CaF_2$ was effective either alone or in combination with other alkali metal fluorides. It would be attractive to use stores of U-contaminated $CaF_2$ or $MgF_2$ recycled from Y-12 or ORGDP uranium processing. A method for using these materials has the potential to use a waste to treat a waste, especially if methods for removing U from the slag are also developed. This would both decrease process cost and avoid creation of additional waste.

# 5. Conclusions and Recommendations

Compressor stator and rotor blades could become a major source of recyclable aluminum from the gaseous diffusion plants. Blades at ORGDP are primarily used blades which have been contaminated with uranium during use, surface cleaned with nitric acid, and stored in large fiber drums. Reports indicate that there may also be unused stores stock or uncontaminated blades which failed quality inspection.

Several different actions could be taken to reduce scrap compressor blades stored at ORGDP. First, any unused or uncontaminated blades should be located and either sold or recycled by use at Paducah or Portsmouth. Then, research to determine whether simple processing methods can decontaminate blades to an extent permitting reuse. These studies are necessary because: 1) earlier studies were performed on pure aluminum, not on alloys; 2) removal of uranium daughter products was not evaluated; 3) the effect of heating method and temperature was not evaluated; and 4) the process was not optimized to maximize yield and purity of the aluminum and to minimize waste production. During the melt refining process, it may also be possible to use a stored Y-12 Plant waste, alkali metal fluorides from uranium reduction, as the flux. This would minimize both Y-12 and K-25 waste storage.

After an understanding of the conditions for blade decontamination is developed, the melt refining process can either be used in-house or transferred to an industrial partner. Recovery of aluminum alloy through melt refining is expected to be a straightforward industrial process with limited requirements for space and personnel. However, except for use in reblading compressors, uses for cast aluminum products in-house are limited.

The best use of aluminum 214-X is, thus, likely to be found in release for external use. Establishment of *de minimus* standards would provide a basis for development of methods for decontamination of stored metals.

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