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PRELIMINARY BETTIS PLANT SAFE PRACTICE GUIDE FOR STORING, HANDLING, AND PROCESSING ZIRCONIUM AND ITS ALLOYS

October 1, 1956

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BETTIS PLANT
PITTSBURGH, PENNSYLVANIA

Operated for the
U.S. ATOMIC ENERGY COMMISSION
by WESTINGHOUSE
ELECTRIC CORPORATION

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NOTE

This document is an interim memorandum prepared primarily for internal reference and does not represent a final expression of the opinion of Westinghouse. As almost all of our machining is a wet process our safe practices are directed to the wet machinings. Machinings produced under a dry process may be safely handled, stored and shipped by other means as recommended by the plant's own safety department.

When this memorandum is distributed externally, it is with the express understanding that Westinghouse makes no representation as to completeness, accuracy, or usability of information contained therein.

BETTIS PLANT PITTSBURGH, PA.
Operated for the U. S. Atomic Energy Commission by
Westinghouse Electric Corporation

PRELIMINARY BETTIS PLANT SAFE PRACTICE GUIDE

FOR

STORING, HANDLING, AND PROCESSING ZIRCONIUM AND ITS ALLOYS

PURPOSE AND SCOPE

The purpose of this guide is to direct attention to the fire and explosion hazards associated with zirconium and the Zircaloys and to emphasize the measures that should be employed to prevent the occurrence of such hazards. The recommendations and requirements presented are based on conclusions drawn from available reports or data as listed in the bibliography and from actual zirconium fire experience.

INTRODUCTION

The storage, handling, and processing of zirconium and the Zircaloys are hazardous if proper precautions and safeguards are not employed. Hereafter in this guide the word zirconium is intended to include the Zircaloys. Like Mg, Ti, Al, and certain Mg-Ti alloys, zirconium under certain circumstances is highly flammable and explosive; both hazards are related to the surface area-mass relationship. The very finely divided powdered form is flammable and under some conditions explosive, whereas such forms as coarse turnings are ignited only at high temperatures. A number of tests have been directed toward determining the quantitative aspects of the hazards associated with the more dangerous powdered form of the metal. The results of these tests and the experience acquired over the years are employed in this guide to outline methods for the safe handling of zirconium.

There have been very violent fires of zirconium scrap in the form of machine cuttings and fines. However, no detonations have been encountered in their machining, handling, or storage as have occasionally occurred in the production, handling, and storage of powders.

In view of the above considerations, the following procedures are provided as a guide for the safe handling of zirconium. The lack of quantitative data on the flammability and explosibility of zirconium forms commonly encountered in fabrication processes requires that all safety rules be conservative and include adequate safety factors.

MACHINING

Machining of zirconium for the purpose of this guide includes all operations that produce cuttings or dust, e.g., turning, milling, grinding, and shaping. Zirconium in the form of bars, plates, and other larger sized pieces can normally be heated to high temperatures without burning. On the other hand, zirconium turnings, filings, borings, and chips can be ignited by hot chips, sparks, or low temperature flames. For this reason, machining operations should, if possible, be conducted with liberal use of coolants, such as air, cutting oil, or a water-oil emulsion; cutting tools should be kept sharp. If for any reason it is impossible to use coolants on machines cutting zirconium, slow feeds and cutting speeds must be used to prevent the generation of enough heat to ignite turnings, filings, borings, or chips. When zirconium is belt-sanded, the fines must be kept wet to prevent flashing of any unoxidized particles. The machine must be thoroughly washed down after each use.

Only small amounts of turnings, filings, borings, chips, or dust should be allowed to collect on a machine before removal. Upon removal, the scraps, exclusive of dust, should be placed in an appropriate glavanized steel container and immediately covered with a metal lid. The container should remain covered at all times and should be placed at a safe distance from the machine and any source of heat, such as sparks or open flames. Material finer than 20 mesh and coarser than 120 mesh should be collected wet (under water) and placed in 1-lb polyethylene screw-cap containers; the amount of water must always be sufficient to cover the zirconium. Materials finer than 120 mesh should be handled wet and collected under water into 2-oz polyethylene screw-cap bottles; the amount of water must always be sufficient to cover the zirconium, and the container must be tightly capped. In each of these two cases, the amount of water should always be more than 25% of the total contents of the container.

For reasons of economy, each type of scrap should be kept separate from the other; 24-gal containers painted yellow and marked zirconium, Zircaloy-2, and Zircaloy-3 will be supplied for materials coarser than 20 mesh.

For reasons of safety, machine operators will visually inspect scrap as it is produced and further separate it into these five size classifications.[1]

1) Solids---solid metal over 1/8 in. wide by 1/8 in. thick.

2) Coarse cuttings---shavings, borings, chips, turnings, etc., the ends of which measure over 0.01 in. thick and over 0.125 in. wide, or roughly 1/64 in. x 1/8 in., regardless of length (smallest dimension 1/32 in. or over).

3) Fine cuttings---shavings, borings, chips, turnings, etc., the ends of which measure 0.01 in. thick x 0.125 in. wide or smaller, or roughly 1/64 in. x 1/8 in. or smaller (smallest dimension under 1/32 in. but coarser than 20 mesh).

4) Coarse powder---fines, grindings, etc., coarser than 120 mesh but finer than 20 mesh.

5) Fine powder---dust, fines, grindings, etc., 120 mesh or finer.

If coarse and fine cuttings or dust cannot be effectively separated in any operation, they should be treated as the more dangerous finer form.

Bettis Plant experience indicates that exclusive of grinding operations very little, if any, zirconium finer than 120 mesh is produced in normal machining operations.

The scrap containers will be tagged with appropriate warning labels by the machine operator. The warning labels available from the Safety Storeroom will be assigned to each of the scrap classifications as follows.

1) Solids: No warning label is required.

2) <u>Coarse cuttings</u>:

<u>ZIRCONIUM CUTTINGS COARSE</u>
(smallest dimension 1/32 in. or over)
CAUTION! FLAMMABLE!
Keep Away From Fire, Welding, Sparks, and Open Flames
Do Not Put Fines in This Can

3) <u>Fine cuttings</u>:

<u>ZIRCONIUM FINES</u>
(smallest dimensions under 1/32 in.
but coarser than 20 mesh)

WARNING - HIGHLY FLAMMABLE
WILL BURN VIOLENTLY

Keep Away From Heat, Sparks, Open Flames,
Grinding, and Machining Operations
Keep Lid on Can at All Times, Keep Fines
Under Water.
Do Not Put Powder or Dust in This Can.

4) <u>Coarse powder</u>:

<u>ZIRCONIUM POWDER</u>
COARSER THAN 120 MESH SIZE
DANGER! EXPLOSIVE!
Do Not Crush or Rupture Container.
Keep Away From Heat, Sparks, Open Flames,
Keep Under Water in Screw-Cap 1-lb
Polyethylene Containers Enclosed in
Wooden Boxes or Fiber Drums.

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5) Fine powder:

ZIRCONIUM POWDER

FINER THAN 120 MESH SIZE

DANGER! HIGHLY EXPLOSIVE!

IGNITES IN AIR!

FRAGILE!

DO NOT JAR, CRUSH, OR RUPTURE CONTAINERS.

Keep Away From Heat, Sparks, Open Flames,

Fire, and Flammable Materials.

Maximum: Box of 20 Polyethylene 2-Oz

Bottles With Screw-Cap, Taped Closed, Packed Wet.

When the 24-gal containers are two-thirds full, they should be carried to the holding area where they will be picked up periodically. The polyethylene containers shall also be carried to the holding area.

STORAGE

Designated personnel will remove scrap zirconium from the holding area to the weighing and tagging station several times a day as necessary and will net weight each scrap-laden container. Any container holding material with a dimension under 1/32 in. will be 3/4 filled with water at the weighing and tagging station. After inspection of each container's contents, a tag recording the contents, weight, and source of the scrap will be fastened to the container. Containers will be checked for the proper warning label.

After being weighed and tagged, the containers will be removed from the weighing and tagging station to the plant zirconium storage area where they will be picked up as required by personnel responsible for reducing the metal to oxide. The maximum number of drums of coarse cuttings that may be stored at any one time in a single storage area is 300; the maximum number of drums of fine cuttings is 20. While the cans remain in the storage area, personnel must insure that the containers always have sufficient water, that they are adequate and leak-proof, and that the storage area is at all times free of other flammable materials. Transfer of materials from container to container shall not be conducted in the storage area or in any area where an appreciable amount of scrap has collected.

In the holding, weighing, and storage areas protective clothing as prescribed and promulgated by the Safety Section will be worn.

All zirconium holding, weighing, and storage areas shall be conspicuously identified as such by signs. Signs should further indicate "No Smoking or Open Flames."

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SHIPPING

The shipping of zirconium is subject to Interstate Commerce Commission Regulations.[2] These regulations as summarized require no special handling or packaging for any form of zirconium metal of particle size exceeding 20 mesh. However, additional Bettis Plant procedures which follow these regulations must also be carried out to insure safe shipment.

Zirconium metal powder, wet or sludge, may be shipped in metal cans or drums packed in wooden containers. If metal cans are used, they must not exceed 10 lb net weight each and must have either screw caps or tightly, securely closed push-in covers held by crimping at least four points; if inside metal drums are used, they must have bodies of not less than 26 gauge, heads with welded side seams, gasketed closure of positive type (not friction), and capacity not over 50 lb net weight. Gross weight of outside containers must not exceed 150 lb. Wooden kegs not to exceed 75 lb net are also permitted.

Dry zirconium powder or sponge must be packed in containers of the following specifications:

1) wooden boxes with inside metal containers tightly and securely closed by push-in covers held by crimping at least four points, or in screw-cap metal cans (inside containers not exceeding 10 lb net each, outside packages not exceeding 75 lb each);

2) fiberboard boxes with inside containers, which must be securely closed glass bottles or metal containers not over 1 lb net weight each, enclosed in a securely closed metal can and sufficiently cushioned with incombustible materials;

3) metal barrels or drums not exceeding 30 gal capacity (authorized only for zirconium sponge, not powder);

4) metal drums (single trip) not exceeding 30 gal capacity (authorized only for zirconium sponge, not powder).

Metallic solutions, suspensions, and emulsions of zirconium must be packed in wooden boxes with inside metal containers. Each inside container shall not contain more than 20 individual glass or porcelain jars not exceeding 2-oz capacity each, securely closed, and completely cushioned in incombustible cushioning material in sufficient quantity to absorb the contents completely.

In order to insure safe shipment of zirconium, Bettis Plant personnel should adhere to the following procedures in addition to the Interstate Commerce Commission Regulations.

1) <u>Solid zirconium</u>:

   No special shipping or handling is required.

2) <u>Coarse cuttings</u>:

   Ship dry in 55-gal or smaller metal drums. Warning label is required.

3) Fine cuttings:

If shipment is to be made by commercial carrier, ship in 30-gal (or smaller) rust-resistant, heavy-duty metal drums equipped with relief valve or vent and filled with water. If shipment is to be made by Bettis or vendor trucks where spillage is not a problem, galvanized garbage cans can be used, provided lids are secured by baling wire to reduce excessive spillage. Water level should be checked preceding loading for shipment. Warning label is required.

4) Coarse powder:

Ship under water in 1-lb polyethylene screw-cap containers enclosed in either wooden boxes or fiber or metal drums cushioned in Vermiculite, outside container not to exceed 24 lb net. Warning label and I.C.C. label are required. I.C.C. permission for shipping should be obtained.

5) Fine powder:

Ship under water in tightly capped 2-oz (maximum) polyethylene screw-cap containers. Polyethylene containers not to exceed twenty in number must be packed in Vermiculite in a wooden box having outside handling cleats and inside separation for holding bottles in place. The same precautions are to be observed as for other explosive powders. Warning label and I.C.C. label are required. I.C.C. permission for shipping should be obtained.

6) Sponge:

Ship only by Railway Express Agency or Bettis truck and not by commercial carrier. Sponge must be carefully handled; it must not be dropped or exposed to open flames. An I.C.C. label is required.

The warning labels referred to above are those cited under the "Machining" section of this guide, except that for fine powder the label will bear the following additional information.

Date Packed ____________	Size Jars ____________
No. Jars ____________	Gross Wt ____________
Net Wt of Powder ____________	Moisture by Wt ____________%
Powder Min. Size ____________	
Packed by ____________	Company ____________
Address ____________	

FIRE CONTROL[3,4]

Fires involving small quantities of zirconium can be effectively controlled by smothering them with liberal quantities of G-1 (graphite-base) or Metal-X (salt-base) powders. These powders should be applied to the fire by scoops or shovels so as to avoid spreading the fire.

Fire-extinguishing agents such as water, carbon dioxide, foams, and bicarbonate-base dry powders are ineffective on zirconium fires, but they should always be available for use on surrounding combustibles. Carbon tetrachloride must never be used.

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Within a closed container, zirconium fires can sometimes be extinguished with helium or argon in sufficient quantity. At the same time the outside of the container can be cooled with water spray. Air must be completely excluded. Before air is again admitted, the burning mass must be allowed to cool to room temperature.

The Fire Department will insure that sufficient quantities of G-1 or Metal-X powders and suitable scoops or shovels are available in all areas where zirconium fines, chips, turnings, borings, filings, and sponge are produced or stored.

MISCELLANEOUS

All waste, rags, and containers that have been in contact with finer forms (powder) of zirconium should be put in separate appropriately labelled waste cans, immersed in water containing a good wetting agent, and placed in the holding areas. (Labels can be obtained from the Safety Storeroom.) These items will be delivered to the incinerator at regular intervals. The fireman should be instructed to fire these into a hot fire immediately. To avoid the possibility of a flare-back, they should be fired in small quantities.

Burning and welding must never be permitted in an area where there is a possibility that a flame or spark will ignite zirconium. Before such operations are performed, the welder must obtain a permit from the department foreman whose duty it will be to inspect the surrounding area for possible hazards. If such hazards do exist, they must be removed. Welding department supervisors will instruct welders that permits must be obtained and inform them of the flammable and explosive nature of zirconium.

Because of the explosive nature of zirconium powder, all chance of dust cloud or layer formation and all possible sources of ignition should be eliminated in dust-susceptible areas.[5] Dust-producing equipment should be dust-tight; dust accumulations on ledges, beams, floors, and other exposed surfaces should be removed periodically; electrical equipment and wiring should conform to the requirements of the National Electrical Code for hazardous and dusty locations; all open flames and smoking should be prohibited in affected areas; repair work requiring the use of torches and welding equipment should be performed only during shutdowns after removal of all dust; bearings and other moving parts of mechines should be dust-tight and in good working order to prevent overheating; all dust-processing equipment should be properly grounded to prevent accumulation of static charges; where possible, only nonsparking tools should be used; where possible, equipment and rooms in which a potential explosion hazard exists should be provided with relief vents through which the pressure of an incipient dust explosion can be released quickly.

Since it is more difficult to ignite, finely powdered zirconium with a sufficient amount of water is much safer to handle than dry zirconium powder.[3,6] It has been recommended that the water content be 25% or higher. Zirconium powder containing up to 5% water burns in about the same manner as dry powder. When the water content is between 5 and 10%, the powder burns much more violently than the dry powder and is apt to explode.

When zirconium is in contact with water, there exists the possibility of an explosion hazard from hydrogen, particularly at elevated temperatures, such as

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when zirconium is burning. At room temperature the reaction is slight and of little concern unless the hydrogen can accumulate for a long time.

The explosion hazard of zirconium is of particular concern where water can come into contact in a confined volume with large masses of molten zirconium, as it can in a burnthrough in melting furnaces and similar equipment. The resultant reactions can cause a very violent and destructive explosion.

The eutectic properties of zirconium with other metals were discribed recently.[8] Several explosions have occurred because these properties were not fully appreciated. For example, the rolling of steel-clad zirconium must never be done at temperatures over 1650°F since the eutectic between iron and zirconium occurs at 1710°F and there is danger that steel-clad will rupture.

Extremely thin pieces of zirconium, such as foil,[1] must not be etched in carbon brick or steel tanks because of the possible explosion from galvanic action. Plastic tanks should be used to prevent such hazards.

ZIRCONIUM-URANIUM ALLOY

Several laboratories have reported explosions during the pickling and etching of zirconium-uranium alloys. An investigation into the cause of this phenomenon was carried out at Argonne National Laboratory.[7] Their findings revealed that zirconium-uranium alloys containing from 1 to 50 w/o zirconium do not dissolve cleanly in nitric acid but leave a zirconium-uranium epsilon phase residue insoluble in nitric acid. Depending on the composition, homogeneity, and previous thermal history, such alloys contain lesser or greater fractions of finely divided epsilon phase in a matrix of alpha uranium. On treatment with nitric acid the matrix is rapidly dissolved, and the epsilon phase is slowly oxidized. In the course of, or subsequent to, such acid treatment the unoxidized particles of the epsilon phase may undergo a rapid oxidization with explosive violence.

The addition of fluoride ion increases the rate of solution of the residue and prevents the formation of an explosive surface coating. Alloys containing 2, 4, 10, and 20% zirconium have been satisfactorily pickled in a solution of 12M nitric acid and 1.0M hydrofluoric acid at 50° and 75°C. Additions of fluoride should be made to replenish that lost during the pickling process.

Goggles, face shields, and protective clothing should always be used when zirconium-uranium alloys are being pickled or etched. Any new process involving new alloys or methods of pickling should always be tested on a small scale to determine whether the explosive coating might form. A careful visual inspection should be made, and the specimen should be tested by rubbing or striking it after careful drying. This test cannot be considered as conclusive proof that the surface is free of explosive material, since there have been instances in which samples failed to burn when tested but exploded violently when placed in a nitric acid bath. Such samples should be handled carefully. If any coating is present, the sample should be immersed in water to which a small amount of hydrofluoric acid has been added to remove the coating.

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APPENDIX

EXPERIMENTAL DATA

Any combustible solid material in finely divided form can produce a dust explosion if dispersed into the air and ignited.[9] Some combustibles are more readily susceptible to explosion than others; zirconium powder is highly ignitible and explosive. For the sake of comparison, Table I presents dust cloud ignition temperatures and minimum spark requirements for several common, highly explosive materials.

TABLE I

DUST EXPLOSION CHARACTERISTICS OF VARIOUS POWDERS[9]

Type of Powder	Ignition Temp of Dust Cloud °C	Minimum Spark Energy Required to Ignite Dust Cloud, Millijoules
Zirconium	20	15
Magnesium	520	80
Aluminum	545	50
Titanium	480	--
Phenolic Resin	500	10
Polyethylene	450	80

Zirconium is the most easily ignitible dust. This is true not only for dust clouds but also for settled dust layers. It can be ignited by weaker electric sparks than any other powder tested and, when dispersed as a dust cloud in air at ordinary temperatures, can ignite from its own static charge. It is classified as a powder of high explosibility along with Mg, Al, Ti, and certain Mg-Ti alloys.

The results of tests conducted on seven different samples of zirconium powder are presented in Table II. According to the ignition temperatures listed, dust clouds and dust layers constitute severe explosion hazards. The minimum energies required for ignition indicate that dry handling can cause a serious hazard since under some conditions, electrostatic spark energies of the order of 10 millijoules can be built up and discharged from a human body. The data in Table II also indicate that CO_2 and N_2 markedly increase the ignition temperatures but do not definitely inhibit ignition.

Hartmann, Nagy, and Jacobson[10] found further that ignition of dust clouds by electric sparks could be effected with as low as 5% oxygen-helium mixture, 4% oxygen-argon mixture, and 3.3% oxygen-nitrogen mixture. Ignition was produced by electric sparks in pure CO_2, indicating that pure CO_2 does not prevent ignition.

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TABLE II

EXPLOSION CHARACTERISTICS OF SEVERAL SAMPLES OF ZIRCONIUM POWDER[10]

Sample	Ignition Temperature, °C						Minimum Ignition Energy (Millijoules)		Lower Explosive Limit (Oz/ft^3)	Mean Particle Size (Microns)
	Dust Cloud			Dust Layer						
	Air	CO_2	N_2	Air	CO_2	N_2	Dust Cloud	Dust Layer		
1	20	--	--	210	560	530	40	--	0.190	44
2	20	--	--	260	--	--	15	0.4	0.040	44
3	20	--	--	290	--	--	25	0.8	0.070	44
4	20	--	--	220	--	--	5	1	0.045	0 to 10
5	20	650	n.i.	190	620	790	12	6.4	0.045	3.3
6	350	n.i.	n.i.	300	710	n.i.	12	240	0.045	17.9

n.i.--Not ignitible.

Of five samples tested, a value of 90+% inert dust (fuller's earth) was required to prevent ignition and suppress flame propagation when a mixture of zirconium and dust was blown through a cylindrical furnace at 700°C in which a high voltage, low energy, continuous induction spark was used as an ignition source.

Of two samples tested for maximum pressure developed by explosions within a dust concentration range of 0 to 4 g/ft^3, the maximum pressure was 90 lb/in.^{2}

Ignition energy data indicate that even a 0.01 joule energy static spark, which human bodies commonly give, is enough to readily ignite powders under 10 microns in size.

No explosions have been encountered as a result of handling scrap from machining operations. It has been suggested[1] that the reason for this, is that the extreme ease of ignition of very finely divided powders results in their ignition and oxidation at the point of operations in machining. Consequently, the almost insignificant amount of fine powders that may normally be produced in machining operations may never become airborne, except as oxides.

In order to determine the flammability hazard associated with the handling of cuttings produced by Bettis Plant machining operations, about 100 random samples were selected, measured, and brought into contact with flame.[1] The variation in results as summarized below may be ascribed to the difficulty in measuring the cuttings.

1. Pieces 0.003 in. thick x 0.0312 in. wide were readily ignited with a paper match and continued to burn after flame was removed. CSA* = 0.00009 sq in.

2. Pieces 0.005 in. thick x 0.0312 in. wide would burn when held in a match flame, but would not continue after flame was removed. CSA = 0.00016 sq in.

3. Pieces 1/32 in. thick by 1/8 in. wide would glow but would not continue after the flame was removed. CSA = 0.0039 sq in.

4. Pieces 1/64 in. thick x 1/8 in. wide would not continue to glow after the flame was removed. CSA = 0.00195 sq in.

5. Pieces 0.005 in. thick (foil) would not continue to glow after flame was removed if they were over 1/8 in. CSA = 0.00063 sq in.

6. Pieces 0.003 in. thick would not continue to glow after flame was removed if they were over 1/8 in. wide. CSA = 0.00038 sq in.

7. Pieces 0.003 in. thick would burn if under 1/8 in. wide. CSA = 0.00038 sq in.

8. Pieces 0.021 in. thick would not burn when over 1/64 in. wide. CSA = 0.00019 sq in.

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*CSA is used here as an abbreviation for cross-sectional area of the end of a cutting, chip, turning, or piece of foil.

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9. Pieces 0.010 in. thick would not burn when over 1/64 in. wide.
CSA = 0.00016 sq in.

10. Pieces of 0.001 in. thick would not burn when over 1/64 in. wide.
CSA = 0.00014 sq in.

11. Pieces 0.0105 in. thick would burn when under 1/64 in. (0.0156) wide.
CSA = 0.00016 sq in.

12. Pieces 0.006 in. thick would not burn when over 1/32 in. wide.
CSA = 0.00019 sq in.

13. Pieces 0.002 in. thick x 1/4 in. wide would not burn. CSA = 0.0005 sq in.

14. Pieces 0.002 in. thick x 3/16 in. wide would not burn. CSA = 0.0004 sq in.

15. Pieces 0.002 in. thick x 5/32 in. wide would not burn. CSA = 0.0003 sq in.

16. Pieces 0.002 in. thick x 3/32 in. wide would not burn. CSA = 0.0002 sq in.

17. Pieces 0.001 in. thick x 1/4 in. wide would burn. CSA = 0.0002 sq in.

18. Pieces 0.001 in. thick x 1/2 in. wide would burn. CSA = 0.0005 sq in.

19. Pieces 0.001 in. thick x 3/4 in. wide would not burn. CSA = 0.0008 sq in.

20. Wire 0.050 in. diam would not burn. CSA = 0.0020 sq in.

21. Wire 0.045 in. diam would not burn. CSA = 0.0016 sq in.

22. Wire 0.031 in. diam would not burn. CSA = 0.0008 sq in.

23. Wire 0.026 in. diam would not burn. CSA = 0.0005 sq in.

Two separate samples of mixed turnings (0.001 in. to 0.004 in. thick, averaging about 0.0003 sq in. CSA) in 1-qt cans three-quarters full of turnings were almost covered with oil and then ignited with a half cup of gasoline. Each sample burned mildly with a typical oil vapor flame on top. The zirconium stayed cool beneath the oil, and 80% of it oxidized on the surface without ever burning. The fire burned for 18 minutes. The blue colored metal could not subsequently be ignited. (This was almost entirely an oil fire.)

An identical fire was lit with two fresh cans of turnings almost completely covered with water instead of oil. The gasoline ignited the zirconium chips exposed above the water, but when the gasoline was completely consumed and the zirconium had burned to the water level the fire went out. The fire burned for about 4 minutes. (This was mainly a gasoline fire.)

Two cans of similar chips that were moist with water-base coolants were ignited with a quarter cup of gasoline and a torch. This fire started quietly but suddenly burned very violently for 1 minute, then continued to burn more quietly for about 10 minutes (total time). There appeared to be some hydrogen flame during the first 1-1/2 minutes.

The following conclusions may be drawn from the above results.

A. Zirconium turnings, chips, or shavings, with ends having a CSA of 0.0001 sq in. or less would always burn and continue to burn after a source of ignition was removed. They readily ignited with a safety match.

B. Zirconium turnings, chips, shavings or foil, with ends having a CSA of over 0.0005 sq in. would glow, but would not burn nor continue to glow after the flame of a match was removed from them.

C. Zirconium metal with ends having a CSA of over 0.0078 sq in. (1/8 in. x 1/16 in.) would glow and melt under a 2500°F flame but would not glow nor burn after the flame was removed.

D. Zirconium cuttings and fines under water in leak-proof containers are generally very safe. Cuttings and fines under oil are safer than those that are dry; the oil is flammable but apparently presents a simpler fire extinguishing problem.

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