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Environmental Hardening of Equipment Operating in an Automated Test Bed Enclosure

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December 1990

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**Special Isotope Separation
Program (SIS)**

**Environmental Hardening of Equipment
Operating in an Automated Test Bed Enclosure**

M.L. Hayward

December 1990

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Special Isotope Separation Program (SIS)

Environmental Hardening of Equipment Operating in Automated Glove Box Test Bed

1.0 Introduction

Lawrence Livermore National Laboratory's Plutonium Systems Engineering plans to demonstrate a materials handling system in an automated test bed located in the cold test facility, in FY91.

The equipment operating in the automated glove box test bed consists of a modified, bridge mounted robot that is electrically driven, robot tooling, a tilt-pour furnace, mechanisms for loading and unloading the furnace, mechanisms for loading and unloading the crucible, and mechanisms for button breakout and can opening. Each of the pieces of equipment mentioned have components such as motors (with or without brushes), bearings, resolvers, encoders, sliding surfaces, cabling, and electrical connectors that must function in the harsh environment of the test bed enclosure, and each of the components described must be hardened to the enclosure environment.

The automated test bed is to provide a representation of a weapons-grade plutonium enclosure. Although the decision to operate the enclosure in a nitrogen or argon atmosphere has not been made, this report considers the dry argon atmosphere as the more difficult case. Other environmental requirements on the equipment operating in the test bed enclosure are: low moisture and low oxygen atmosphere, and some abrasive dust resulting from the process. A surrogate material will provide flow and dusting characteristics of weapons-grade plutonium oxide. Weapons-grade plutonium will not be introduced into the test bed enclosure. However, for future reference, radiation effects on materials will be addressed in Section 4.

1.1 Purpose

The purpose of this document is to provide vendors information and guidance for environmentally hardening automated equipment that will be operated in LLNL's automated test bed enclosure.

1.2 Scope

The scope of this document is to provide environmental hardening information to vendors that are supplying equipment which will be operating in LLNL's automated test bed enclosure. The information supplied in this document was assembled from

experiences that were reported from research and development of similar activities. The information was selected from technical areas such as vacuum, space, and inert-atmosphere hot cells. All information in this document was extracted from the references listed in Section 6.

2.0 Enclosure Environment

The automated test bed environment will consist of the following:

- Dry argon or dry nitrogen (selectable)
- Operates with a slight positive or slight negative pressure inside the enclosure (selectable)
- Abrasive dust (surrogate material such as Al_2O_3)
- Low moisture (<50 ppm)
- Low oxygen (<50 ppm)
- Alpha radiation dose is approximately 1.2×10^5 Rad/h (Not present in LLNL's automate test bed enclosure) see Appendix I.

A reduction of moisture and oxygen, compared to normal air atmosphere and the increase of dust and argon (argon being the inert element) can cause severe problems with equipment designed for normal air atmosphere. Due to the dusty environment, motors must be protected to prevent accumulation of dust inside the motor housings. Most off-the-shelf motorized equipment is designed to operate in air. Therefore, the thermal conductivity and electrical characteristics may not be suitable for a dry argon environment. The thermal conductivity of argon is 2/3 that of nitrogen or air (Table I), therefore, careful consideration must be given to motors operating in the argon atmosphere.

Argon has 1/3 the dielectric strength of air. Care must be taken to procure electrical equipment, or modify electrical equipment to operate in an argon environment. Attention must be given to connector pin spacings and ionization to prevent flashover. Table II provides specifications for procuring connectors with suitable pin spacings to voltage in an argon atmosphere. Table III provides electrical pin spacings in air for comparison.

Motor brushes designed for air operation wear at a very high rate in a low moisture, low oxygen environment (Graph I)⁵. The conventional brushes must be replaced with special brushes. Appendix II, Brush Materials Tests Data, compares the various brushes selected for tests and the results of those tests. The special brushes recommended in Section 4.2 was from the results of the brush test.

Table I. Thermal Conductivity of Gases at Various Temperatures*

The values in this table are given as cal/sec cm C x 10⁶. For W/m K multiply by 0.0004184. For Btu/hr-ft-deg F multiply by 0.0002419.

Gas	40°F	60°F	80°F	100°F	120°F
Air	58.31	60.34	62.20	64.22	66.04
Argon	40.09	41.33	42.57	44.22	45.46
Helium	343.42	352.10	360.36	368.63	376.07
Nitrogen	58.27	60.34	62.40	64.06	65.71
Oxygen	59.43	61.58	63.64	65.91	68.19

* From "CRC Handbook of Chemistry and Physics," 53rd ed., R.C. Weast, Ed., The Chemical Rubber Co., 1972.

Table II. Minimum Electrical Pin Spacing in Argon**

Voltage Range	Minimum Spacing (in)
<100	1/16
100-200	1/8
200-300	2/16

** The performance of electrical equipment in a dry argon atmosphere⁴.

Table III. Electrical Pin Spacing in Air***

		Operating Voltages Suggested*			
MS Service Rating	Test Voltage (RMS) 60 cps	DC	AC (rms)	Air Spacing nom. in.	Creepage Distance nom. in.
Inst	1000	250	200	—	1/16
A	2000	700	500	1/16	1/8
D	2800	1250	900	1/8	3/16
E	3500	1750	1250	3/16	1/4
B	4500	2450	1750	1/4	5/16
C	7000	4200	3000	5/16	1

*** Cannon Connectors⁸.

A comparison between Tables II and III indicate the voltage must be reduced approximately 60% of that in air to prevent flashover from pin to pin in an argon atmosphere.

Graph I. DC Motor Brush Wear (Brush grade: Special Stackpole 660 Brush, Motor: 1/4 hp EEMCO-C-743-C, Speed: 6,000 rpm)***

*** Test of commutating brushes for use in DC motors operating in a dry argon atmosphere (Reference 5, Section 6.0.)

3.0 Equipment Description

The automated glove box test bed is to evaluate commercially available automation equipment and demonstrate the feasibility of automating a pyrochemical furnace operation. The equipment will consist of, but not be limited to the following:

- Modified IBM electrically operated cantilevered robot and process tooling
- One-quarter ton hoist (motorized)
- Tilt-pour furnace (including motors, encoders, gearboxes, bearings, electrical switches and connectors)
- Crucible load/unload fixture (motorized)
- Calcination boat load/unload fixture (motorized)
- Button breakout fixture (motorized)
- Can opener (motorized)
- Tilt-pour upper-assembly lift

The above equipment must be environmentally hardened to operate in the automated test bed enclosure.

To operate in the automated test bed enclosure, the IBM ECR must be removed from the conventional stanchions and cast frame and mounted on a pair of linear bearings supported from the enclosure frame.

The IBM ECR is a Cartesian-coordinated robot mounted on linear bearings. Attached to the z-axis are the roll, pitch, and yaw axis with gripper assembly. All axis and gripper assemblies are electric motor driven, have absolute encoders for positioning, tach generators for speed control, and a sensor control card on the gripper assembly for gripping sensitivity and position. All of these components must be environmentally hardened per Section 4.0 of this report. Ball Aerospace Systems Group provides a motor and encoder rework service per BASG procedure 166047⁶. This procedure provides instruction for lubricating bearings, installing shaft seals, applying a sealer coat to all exterior surfaces in preparation for using motors and encoders in an inert gas or vacuum atmosphere.

The quarter-ton hoist consists of a motor, bearings, and switches. The motor brushes and bearings must be hardened and the motor must be fully enclosed to be protected from the dusty atmosphere.

The tilt-pour furnace has been environmentally hardened and tested and is ready for transfer into the automated test bed enclosure. The crucible load/unload is a mechanical fixture that receives the crucible from the robot and positions the crucible to receive the charge without spillage or dusting. The crucible load/unload is motorized with two motors. Motor one positions the crucible in the fixture, motor two lifts the fixture to assist in

loading. The crucible load/unload fixture has position feed back using encoders. Electrical switches function to prevent over-travel and also become part of the safety interlocks.

The calcining boat load/unload fixture transfers the PuO_2 powder from a storage can into the boat and, after calcining, returns the powder from the boat into a can. The calcining boat load/unload fixture has a motor, encoder, bearings, and switches that must be environmentally hardened.

The button-breakout device is a fixture requiring motors, encoders, slides or linear bearings, and switches that must be environmentally hardened.

The can opener is an off-the-shelf item that must be environmentally hardened for the automated test bed enclosure.

The tilt-pour upper assembly lift mechanism is designed such that all motors and encoders are located outside of the automated test bed enclosure. Therefore, no hardening will be required for the lift.

4.0 Identifiable Problems and Solutions

Identifiable problems resulting from the environment described in Section 2.0 of this document are as follows:

- Motor overheating
- Brush wear
- Bearing overheating and seizing
- Slide seizure
- Electrical flashover
- Lubricant degradation
- Dust
- Effects of radiation
- Dry atmosphere

Each of the above problems will be addressed and solutions recommended according to availability, cost, and preference. If options are available they will be noted. The solutions to these problems have been tested and proven. This section relates the remedial action, provided from the references in Section 6.0 of this document, to the appropriate problems described above.

4.1 Motor Overheating

Due to enclosure of the motors, and low thermal conductivity of argon (two-thirds that of air) motors tend to overheat when operated continuously at near-full load. The overheating of the motor may be resolved in several ways: first, by circulating a cooling medium through the motor housing; second, by operating the motor in the 15 to 20% of the normal duty cycle; or third, size of motors to handle same load at reduced current. Introducing a cooling medium is usually difficult to accomplish. Either the second or third option would be recommended for the automated test bed.

4.2 Brush Wear

Operation of dc motor in a dry, low oxygen atmosphere can cause rapid wear of the commutating brushes. Use of dc motors in argon cells have presented commutation problems required extensive tests of brush materials see Appendix II for test data.

Brush wear may be eliminated in the following ways:

- Select brushless motors
- Remove conventional brushes and install special brushes (grade 660) manufactured by Stackpole Carbon Co. or equivalent⁷. These are resin-bonded, carbon-graphite brushes containing 5% molybdenum disulfide.

- Increase the moisture content of the glove box atmosphere to 90 ppm (**Graph I**).. (The selection of the moisture content must be approved by the customer.)
- Rework motor per Ball BASG Procedure 166047.

4.3 Bearing Overheating and Seizing

Several solutions are available to prevent bearing overheating or seizing. Bearings may be operated dry (without lubrication) under certain conditions, such as a very light load and at a very slow speeds (approximately ten percent of manufacturers ratings). However, due to dusting this is not recommended for the automated test bed robot. The following methods may be considered:

- MoS₂ impingement to the ball surfaces. Two sources for the above application of MoS₂ are Ball Aerospace, Boulder, Co. and E/M Lubricants, West Lafayette, Indiana
- Chevron NRRG-159 grease (light film hand applied)¹
- Ion-plated lead film

Chevron NRRG-159 grease is recommended for lubricating the linear bearings that provides the robot's "Y" travel.

4.4 Slide Seizure

To prevent microwelding or cold welding in a dry, dusty environment, precautions must be provided. For this precaution, Bostik Nuclear Grade NEVER SEEZ ® lightly applied will prevent any galling in a dry, inert atmosphere⁹. Another prevention to galling is to use two dissimilar hardened metals for the rubbing surfaces. A light film of NEVER SEEZ is recommended.

4.5 Electrical Flashover

Flashover may occur at the connector pins due to low dielectric strength, ionization resulting from the inert gas (argon) atmosphere, and incomplete insulation⁴. To minimize the flashover problems in the inert atmosphere pin spacings must be as per Table II. Precautions must be taken during the assembly of connectors to cover the conductor fully with potting and the insulation is to totally cover the conductor.

4.6 Lubricant Degradation

Lubricant degradation should not be a problem in the inert atmosphere as long as the recommended lubricants are used in the areas specified^{1,2,3,8,12}.

4.7 Dust

Most of the dust will be contained and controlled through the process. However, there will be some residual dust that could create problems.

Recommendation is to totally enclose and seal the motors and use bellows to cover the x,y, and z axis of the robot. Cable harnesses and equipment located inside the test bed must be designed such that good housekeeping practices may be implemented. The harnesses and equipment must be designed to eliminate sharp edges, crevices, and hard-to-reach cavities. The design should produce smooth, polished surfaces for easy wiping.

4.8 Effects of Radiation

The predominant radioactive decay of plutonium is by alpha particle emission. Calculations were performed to correlate alpha particle emission to an equivalent radiation dose rate (Appendix I). The numbers that were calculated were to be used as a factor in determining the amount and rapidity of degradation of materials utilized in the construction of a weapons-grade plutonium processing enclosure. The calculation assumes approximately 200 grams of plutonium oxide is distributed over a surface area of 20 square meters (200000 cm^2) and that amount of plutonium would result in a radiation dose of approximately $1.2 \times 10^5 \text{ Rad/hr}$. The majority of materials are adversely affected when exposed to accumulated radiation doses of approximately 10^7 or 10^8 Rad/hr . The calculations would indicate that the materials of construction in a glove box would start to deteriorate after approximately 1 year of service.

However, alpha particles are not a penetrating radiation and the calculated dose is a surface phenomena that reacts with surrounding materials differently than the highly penetrating neutron and gamma radiations. Alpha particles from plutonium have a very high energy level and they dissipate this energy by conversion to heat that is transferred into the interacting materials. The heat that is generated by the high energy alpha particles may become more damaging to the materials of construction and equipment components than the radiation exposure. Weapon-grade plutonium processing enclosures should be carefully evaluated and properly designed to assure the generated heat is rapidly and efficiently dissipated to minimize adverse impacts on the equipment within the enclosure.

Good housekeeping is also a good method to maintain low radiation in an enclosure. If electrical cables are covered with a material such as heat shrink, the cable can easily be wiped periodically.

5.0 Special Treatment–Linear Motion Bearings

Bearing Engineering Inc. was contacted regarding the application of the THK linear motion bearing (LMB) in a dry argon box. The question of operating the LMB in the dry environment under light load and slow speed without lubrication was addressed, and is permissible, (though it is expected the life of the bearing would shorten somewhat) and could expect a 10 year life. However, the Pu dusting is a problem, not from the Pu, but from the dust. Bearing Engineering suggested the bearing be covered with a bellows, and if not protected from the dust by a bellows, add a light film of lubricant to the bearings (Section 4.3). Bellows can be custom fabricated by any bellows manufacturing company in the US.

Due to the mounting arrangement, Bearing Engineering suggested using THK linear bearings, HSR type. The HSR type bearing provides equal load capacity in four directions allowing a better distribution of load to the bearing track way.

Due to the length (approximately 18 ft) of the enclosure and the length of the bearing rail (approximately 5 1/2 ft), three joints are required to join the bearing for a continuous length of 18 feet of travel. The joints must be of a precision fit and maintain the fit to prevent damage to the bearings.

Appendix I. Alpha Dose Calculations for Typical Glove Box

The calculation of the alpha dose in a glove box was performed as part of the materials research and radiation hardening effort of this project. The numbers calculated are, and will be used as a factor in determining the amount and rapidity of degradation of materials in the glove box.

A box loss of 200 g of plutonium oxide is assumed in a glove box with internal surface area of approximately 20 square meters (200,000 cm²). This gives a film (assuming uniform distribution) of approximately 10^{-3} g/cm² = 1 mg/cm². The 5.2 MeV alpha particles have a range of about 4 mg/cm², so this 1 mg/cm² film reduces the average energy to approximately 4.6 MeV through self shielding.

The range of these 4.6 MeV alpha particles is calculated using the reasonable assumption that the range in water is a good estimate for the range in most materials of interest to us. The calculations follow:

Range in air is 4.5 mg/cm²

for water

11% is H

89% is O (by weight)

$$R_H = 4.5 (.306) = 1.38 \text{ mg/cm}^2$$

where the multipliers .306 and 1.0

are functions of the energy of the

$$R_O = 4.5 (1) = 4.5 \text{ mg/cm}^2$$

alpha particle and the element of
interest.

$$\frac{1}{R_{H_2O}} = \frac{.89}{4.5} + \frac{.11}{1.38}$$

$$R_{H_2O} = 3.6 \text{ mg/cm}^2$$

so the range of these alpha particles is approximately 3.6 mg/cm². The alpha activity of the plutonium is calculated by:

		Specific Activity Ci/g	Actual Activity Ci/g
Pu	238	1.74×10^1	1.7×10^2
Pu	239	6.15×10^{-2}	5.7×10^{-2}
Pu	240	2.3×10^{-1}	1.4×10^{-2}
Pu	241	4.56×10^{-3}	—0—
			8.8×10^{-2} Ci/g

For a film of PuO₂ dust, we have approximately 4.4×10^{-2} Ci/g in each direction. To determine the energy density deposited per second, these calculations were performed:

$$4.4 \times 10^{-2} \text{ Ci/g} = 1.7 \times 10^9 \text{ g}^{-1} \times \text{S}^{-1}$$

$$1.7 \times 10^9 \text{ g}^{-1} \times \text{S}^{-1} \times 4.6 \times 10^6 \text{ eV} \times 1.6 \times 10^{-12} \frac{\text{erg}}{\text{eV}} \approx 1.3 \times 10^4 \text{ erg} \times \text{S}^{-1} \times \text{g}^{-1}$$

$$1.3 \times 10^4 \text{ erg} \times \text{S}^{-1} \times \text{g}^{-1} \times 10^{-3} \text{ g} \times \text{cm}^{-2} \text{ (film size)} = 13 \text{ ergs} \times \text{S}^{-1} \times \text{cm}^{-2}$$

The energy is deposited onto the top 3.6 mg/cm² layer (top 36μm) so the dose is

$$\frac{13 \text{ erg} \times \text{S}^{-1} \times \text{cm}^{-2}}{3.6 \times 10^{-3} \text{ g} \times \text{cm}^{-2}}$$

If the layer is twice as thick (i.e., 2 mg/cm²), the dose is approximately 1.5×10^5 rad/h. Self shielding will limit the maximum dose to less than 2.5×10^5 rad/h.

Appendix II. Brush Materials Tested

The brush materials tested were recommended by various brush manufacturers for possible use in the dry argon atmosphere. Table I lists the composition and manufacturer of each brush tested.

Table I. Brush materials

Grade	Manufacturer	Composition	Treatment
56	Stackpole Carbon Co.	Electrolytic graphite	BaF ₂
316	Stackpole Carbon Co.	Resin-bonded carbon-graphite	None
505	Stackpole Carbon Co.	Carbon-graphite	MoS ₂
660	Stackpole Carbon Co.	Resin-bonded carbon-graphite	MoS ₂
687	Stackpole Carbon Co.	Graphite	None
25B	Superior Carbon Co.	Electro-graphite	C ₂ compound
82B	Superior Carbon Co.	Graphite	None
35A	Superior Carbon Co.	Carbon-graphite	MoS ₂
B54-27	Superior Carbon Co.	Graphite-20 to 25% silver	Unknown
NAA	Union Carbide-Carbon Prod.	Carbon-graphite	MoS ₂

The tests were divided into three sets. The initial set consisted of tests of brush materials made in an attempt to obtain the best replacement brushes in the shortest possible time. A second set of more extensive tests was made on the best brush material found in the initial tests. The last set of tests was performed on materials received near the end of the testing program. Since the new brush material for the argon cell manipulator motors had already been selected at that time, the last set of tests was performed only to supply information for possible future applications.

There are now a multitude of brush materials manufactured by the companies shown or by other companies that would probably perform as well as those tested. However, because of the nature of the testing program, only those recommended by manufacturers at the time of the tests were tried.

In the initial set of tests, Grades 316, 505, 660, 687, 25B, and 82B were used to determine which of these grades could replace the Grade 56 brush then being used in the argon cell. **Table II** shows the results of these tests.

Table II. Brush wear rates during initial tests

Brush Grade	H₂O Concentration Range, ppm	Average Wear Rate, in/hr	Oxygen Content
56	9.7–11.4	0.296	Less than 50 ppm
316	15.6	0.0325	Less than 50 ppm
505	8.2–10.8	0.124	Less than 50 ppm
660	1.7–21	0.0184	Less than 50 ppm
687	2.8–20	0.0303	Less than 50 ppm
25B	3.0–8.1	0.550	Less than 50 ppm
82B	2.0–9.0	0.102	Less than 50 ppm

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