The Boeing Company
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BOEING

September 8, 1994
4-1210-94R-0522

P. A. Schofield, Research Associate
Exposure Assessment Group
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge TN 37831-6102

Subject: Boeing Use of Depleted Uranium Counterweights in Aircraft

Dear Mr. Schofield:

In regard to your request of August 10, 1994, the Radiation Health Protection group has collected the enclosed information regarding the use of depleted uranium as a counterweight in aircraft by The Boeing Company. We have not engaged in the production of rockets, missiles or projectiles containing depleted uranium, and are unable to answer questions in these areas.

If you require further information or have any questions regarding the information provided, please call me or Richard Edwards. We can both be reached at (206) 393-8250.

Sincerely,

Tom

Thomas D. Gallacher, Radiation Safety Officer
Senior Manager
Corporate Radiation Health Protection
Mail Stop 6Y-38

TDG:gw

Enclosure

I. 747 Tail Assembly Counterweights

A. Description of Items

Typical depleted counterweights used in the Boeing 747 are triangular prisms manufactured of cast depleted uranium (DU). The counterweights are flash coated and painted with a primer to reduce surface oxidation. See attachment (1) for diagram of a typical (33 pound) counterweight.

Manufacturer:	National Lead
Weight:	Varies from 12 to 83 pounds (5.5 to 37.7 kg)
Amount of Depleted Uranium (DU):	99%+ base metal (unalloyed), varies from 12 to 83 pounds (5.5 to 37.7 kg).
Cladding:	Flash coated with 0.002" nickel, 0.001" cadmium.
Coating:	$Zn(CrO_4)$, $Sr(CrO_4)$, TiO_2 primer paint.

B. Number per aircraft & Number used in U.S.

Number used per aircraft: Depending on model and configuration, 21 to 31 counterweights in each tail assembly. Each aircraft has between 692 and 1059 pounds of DU.

Number in use in the U.S.: Unknown. Sales of 747's containing depleted uranium counterweights were international in scope. Customer airlines may or may not use these aircraft on U.S. routes. Further, starting in 1981, customer airlines were provided tungsten replacement counterweights which may or may not have been installed in place of the original depleted uranium counterweights. At the worst case, the following estimate can be made based on the number of aircraft and spare depleted uranium counterweights sold. There were 550 aircraft produced between 1968 and 1981 utilizing depleted uranium counterweights. With spares, there is a possible world distribution of 15,000 weights (about 300 tons).

C. Information on use and reuse of the item

Depleted uranium was used as a counterweight in the tail assemblies of 747's produced from 1968 to 1981. Since then, tungsten counterweights have been used in new 747's. Tungsten equivalents have been sent as spares since 1981.

From the inception of the program to 1980, Boeing returned counterweights to the manufacturer of the counterweights for salvage. These weights were recycled into other uses. We recommended customer airlines do so as well, but we have no hard data on whether or not they did so. The manufacturer terminated the recycling program in 1980. Until 1983, the manufacturer was receiving counterweights for disposal rather than salvage. After 1983, the weights were disposed of as radioactive waste using alternate disposal sites (predominately Nuclear Metals, Inc. and vendors providing services via the Richland, Washington disposal facility).

D. Dose estimates

1. To workers

Boeing has conducted two dosimetric studies of exposures to workers. For both studies, whole body exposures were measured with film badges which were provided and processed by Landauer, Inc. These badges have a minimum detectable exposure of 10 millirem per issue period (monthly). In the second study, extremity exposures were measured with finger rings, also provided by Landauer, having a minimum detectable exposure of 30 millirem per issue period (also monthly). The periods of the study were December 1968 to February 1970 for the first study and September 1977 to April 1978 for the second.

The first study involved 4 employees responsible for the installation of depleted uranium counterweights. There were 27 separate monthly readings in this evaluation.

The second study involved 37 employees, including personnel responsible for installation, storage and transportation of depleted uranium counterweights. There were 296 monthly exposure reports.

Both of these studies showed all worker whole body exposures were less than 2.6% of the exposure limits for occupationally exposed employees (5000 millirem per year) and less than 26% of the limits for members of the general public in effect at that time (500 millirem per year). Because of limitations in the technology available for monitoring exposure and the monthly issue cycle used, we are unable to prove from these studies that the exposures to workers were less than the current limit for members of the general public (100 millirem per year). As The Boeing Company no longer engages in these activities, we cannot repeat this study.

The second study demonstrated that all worker extremity exposures were less than 1% of the exposure limits for occupationally exposed employees (18750 millirem per quarter). The average worker's exposure was less than 0.5% of the limit. There is no limit established for the general public for exposures of this nature.

a. Handling

Whole body: Maximum - 20 millirem in one month whole body (1 occurrence - due to installation and removal of parts). Average - below detection limits (10 millirem per issue period).

Extremity: All readings below detection limits (30 millirem per issue period).

b. Distribution

Whole body: All readings below detection limits (10 millirem per issue period).

Extremity: All readings below detection limits (30 millirem per issue period).

c. Storage

Whole body: All readings below detection limits (10 millirem per issue period).

Extremity: All readings below detection limits (30 millirem per issue period).

d. Transportation:

Whole body: All readings below detection limits (10 millirem per issue period).

Extremity: Two instances of recordable exposures, one of 100 millirem, one of 50 millirem. Both exposures were found to be a result of preparing a shipment of 11 counterweights for return to the manufacturer. The 100 millirem exposure was incurred by a shipping clerk, the 50 millirem exposure by a stores clerk. The two workers spent a full day and half a day respectively working with the materials. All other readings below detection limits (30 millirem per issue period).

e. Flight operations

Not evaluated by this study as this type of exposure is inapplicable to most Boeing personnel and as indicated below, the anticipated dose rates from depleted uranium counterweights are insignificant compared to natural sources of radiation.

The nearest counterweight is approximately 25 feet from the aft end of the cabin of the 747 and an equivalent distance from the ground. For purposes of calculating exposures, the distance to personnel on the ground is reduced to 20 feet to determine dose to the head.

Based on the data from National Lead, reported in the section on exposures to the general public, dose rates to flight crew will be less than 0.8 microrem per hour. During a 2000 hour working year, this results in a maximum potential exposure of 1.6 millirem, less than 2% of the 100 millirem per year limit for members of the general public. This is only 1/600th of the 500 microrem per hour increase in dose rate from cosmic radiation flight crew experience at 39,000 feet.

Dose rates to ground personnel will be less than 1.3 microrem per hour. During a 2000 hour working year, this results in a maximum potential exposure of 2.6 millirem, less than 3% of the 100 millirem per year limit for members of the general public.

f. Disposal

Not evaluated by this study as exposures to Boeing personnel during disposal operations were not separated in these studies. Disposal operations involve removing, packaging and shipping depleted uranium counterweights. The exposures incurred would be similar to those incurred during handling, distribution, storage and transportation as a result of installation. As such, it is reasonable to assume that the exposures of workers during disposal would generally remain below detectable limits (10 millirem per issue period).

2. To public

The exposure estimates presented here are based on ion chamber and dosimetric studies of counterweights provided by National Lead and position of counterweights in relation to the ground and to the pressure envelope (cabin).

The Boeing Company has conducted two studies of exposure rates of a 33 pound counterweight which resulted in slightly lower readings than the National Lead study. (Note: Direct conversion of weight/activity to photon output extremely unreliable due to a very large self-shielding factor.)

The National Lead study, valid on depleted uranium in the 70 pound to 1000 pound range (range studied by National Lead), used dosimetric results for survey readings, instrumentation for 6" and 12" readings. The dose rates reported by National Lead are as follows:

Distance	Beta & Gamma*	Gamma only
Surface	220 mrem/hr	3.0 mrem/hr
6 inches	22 mrem/hr	0.9 mrem/hr
12 inches	7.0 mrem/hr	0.3 mrem/hr

* The Boeing study conducted in 1977 indicated that a 2 millimeter aluminum shield (roughly equivalent to aircraft skin) yields a fourfold reduction in beta-gamma dose rates. This reduction would apply to personnel outside the tail structure in the vicinity of the counterweights.

Application of the inverse square law to these dose rates (and supposing that the range of beta emissions in air is no more than 1 meter) yields the following:

Distance	Beta & Gamma	Gamma only
12 inches	7.0 mrem/hr	0.5 mrem/hr
1 meter	50 microrem/hr	50 microrem/hr
20 feet	1.3 microrem/hr	1.3 microrem/hr
25 feet	0.8 microrem/hr	0.8 microrem/hr

As reported in National Council on Radiation Protection and Measurement (NCRP) Report No. 93, the average exposure from all sources for people living in the United States is 360 millirem per year, which is equivalent to 42 microrem per hour. The increase in exposure rate to cosmic radiation during air travel at 39,000 feet, also as reported in NCRP Report No. 93, is roughly 500 microrem per hour, or some 600 times the maximum possible exposure rate from the counterweights (0.8 microrem per hour for a passenger located at least 25 feet from the tail).

a. Handling

Not evaluated. Depleted uranium counterweights are installed in an area of the aircraft inaccessible to passengers and crew

b. Distribution

Not evaluated. Depleted uranium counterweights are no longer being sold as spares.

c. **Storage**

Not evaluated. Depleted uranium counterweights are no longer being sold as spares.

d. **Transportation:**

Not evaluated. Transportation of depleted uranium counterweights is performed in accordance with applicable Department of Transportation regulations, or in the case of air shipments, International Air Transport Association regulations. These shipments have typically resulted in dose rates at the surface of the package between 0.2 and 7 millirem per hour and at 1 meter from the package of background to 0.5 millirem per hour. Nominal values for spare parts shipments were 3 millirem per hour at the package surface and 0.3 millirem per hour at 1 meter. Note, in air shipments, depleted uranium counterweights are shipped as "Cargo Aircraft Only" shipments.

e. **Flight operations**

As the nearest counterweight is approximately 25 feet from the aft end of the cabin of the 747, the maximum dose rates to passengers will be less than 0.8 microrem per hour. This is less than 1/600th of the 500 microrem per hour increase in dose rate from cosmic radiation experienced while flying at 39,000 feet. During a 6 hour transcontinental flight, this results in a maximum potential exposure of 0.0048 millirem, less than 1/200th of 1% of the 100 millirem per year limit for members of the general public.

f. **Disposal**

Not evaluated. Operations involving removing, packaging and shipping depleted uranium counterweights for disposal are similar to those incurred during handling, distribution, storage and transportation as a result of installation.

E. **Potential misuse and accidents**

Four primary misuse or accident scenarios have been considered with regards to depleted uranium counterweights

- Aircraft accident involving fire
- Storage facility fire
- Loss of material
- Contamination from surface corrosion

1. **Aircraft accident involving fire**

We regard an accident involving a 747 with fire damage to the tail structure to be an extremely low probability occurrence (less than 1.6×10^{-7}). As of December 1988, the 747 fleet had engaged in 6,323,589 departures. During this period, there were 18 hull loss accidents. Only one accident involved significant fire damage of the empennage (tail). A second accident showed evidence of fire damage to the skin of the tail, but investigation showed that the structure and counterweights were relatively free of fire damage.

In the event of a fire involving the tail, we calculate the airborne respirable uranium oxide concentration to be 3×10^{-12} microcuries per milliliter at 100 meters from the aircraft. (See Attachment 2)

2. **Storage facility accident involving fire**

We regard an accident involving a fire in a storage facility containing spare depleted uranium counterweights to be another extremely low probability occurrence. As of this date, we have been informed of one structural fire of this type in the 26 years since depleted uranium has been in use. The fire duration and probable maximum temperatures were similar to those used in the aircraft fire calculations. Further, since tungsten weights are now being used as spares, the likelihood of depleted uranium being present is greatly reduced.

3. **Loss of depleted uranium counterweight**

As the depleted uranium counterweights are installed parts, we view this as an extremely unlikely occurrence. We have no reports of an installed counterweight having been lost. Since the inception of the program in 1968, we have reports of two incidents in which depleted uranium counterweights were lost. In the first, a counterweight was removed from a storeroom. The counterweight was recovered and corrective action taken to further reduce the number of people with access to the area. In the second incident, three counterweights were lost. These counterweights had been removed from aircraft as part of a replacement program prior to their loss. Corrective action was taken at the time of each event to improve access control and accountability with the result that no repetitions have been reported.

4. **Contamination from surface corrosion**

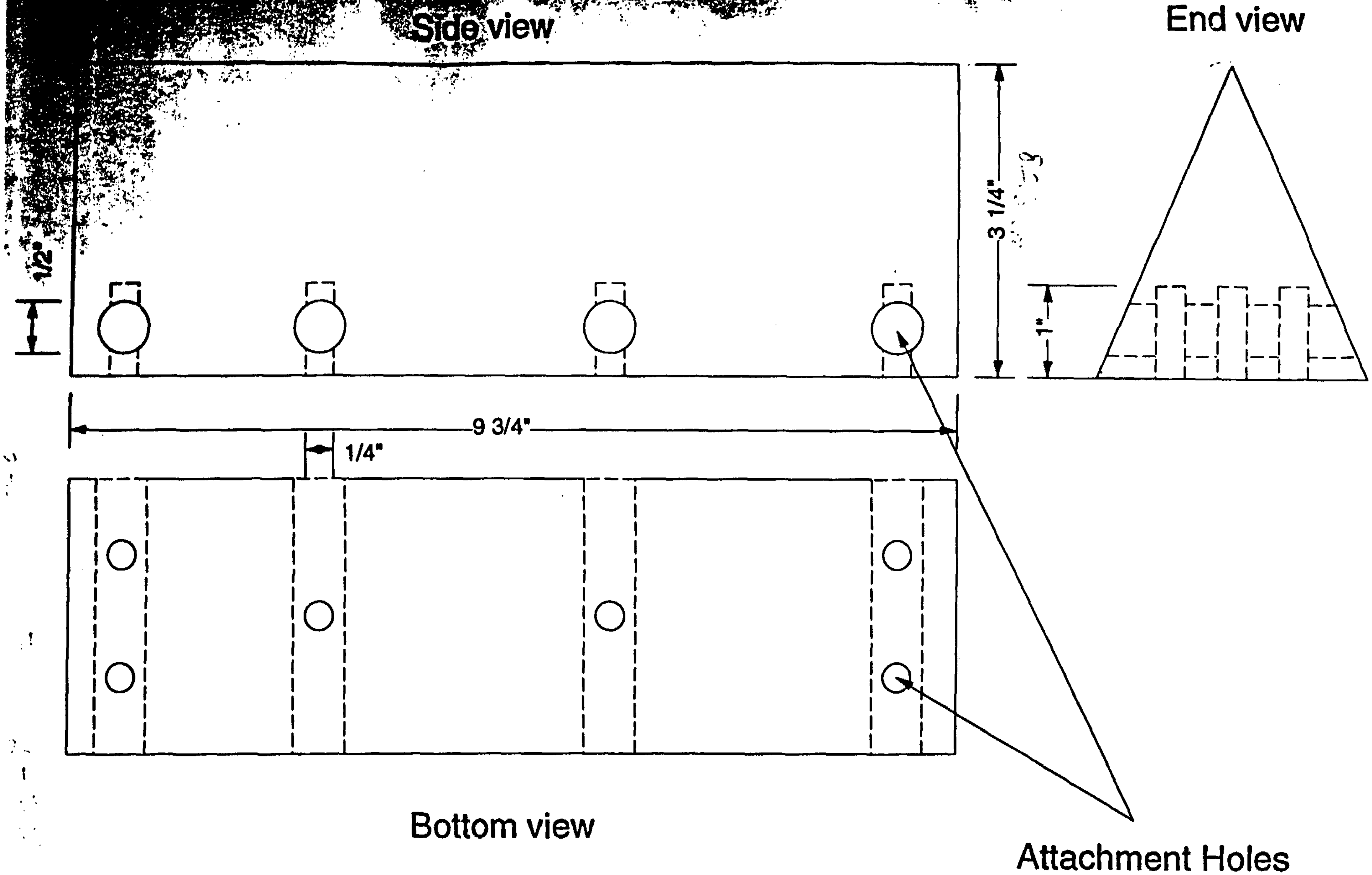
Based on our experience from modification work conducted on 747's, we expect that 10% of existing aircraft with depleted uranium counterweights still installed may exhibit surface corrosion. Our survey of this phenomenon in 1976 indicated that the typical damage area ranged from 1% to 50% of the exposed surface, with removable contamination ranging from 100 to 1500 disintegrations per minute per 100 square centimeters. Based on an exposed area of 200 square centimeters, the approximate exposed area of a 33 pound counterweight, this would yield a total removable activity of 7×10^{-4} microcuries per weight. This is on the order of 1 ten-thousandth of an Annual Limit of Intake, assuming nearly 100% ingestion.

Due to the structure of the aircraft, this would only become an issue during maintenance work requiring direct contact with the counterweight. The possibility of contamination is readily identified by the change in the appearance of the weight. Further, personnel protection against such precautions is readily achieved. Boeing workers wear gloves when handling counterweights and seal potentially corroded weights in plastic. These steps effectively preclude contamination from spreading. The Boeing Service Manual contains similar instructions to airline personnel regarding identifying and handling potentially corroded counterweights.

II. Helicopter Rotor Counterweights

The Boeing Company produced helicopters utilizing depleted uranium as a rotor tip weight prior to 1979. These weights consisted of small (one-half pound) triangular weights. From one to three weights were installed per blade. Virtually all the helicopters manufactured prior to 1979 have had their blades replaced with the composite blades which do not contain the depleted uranium weights. As such, the likelihood of a given helicopter produced by The Boeing Company currently contains depleted uranium is becoming vanishingly small. However, should a given helicopter still have depleted uranium tip weights, we believe any analysis based on the 747 weights will be ultraconservative. This belief is based on the small size and number of these weights compared to the size and number of weights installed in 747 tail assemblies.

We are unable to produce a more rigorous analysis of the use of these weights with respect to the questions you have asked within the time frame you have requested, as we have a limited amount of information on this particular use at this office.



Typical (33 pound counterweight)

Attachment 1

Calculation of airborne activity due to a fire

The U.S. Army[1] tested the dispersal of depleted uranium from a four hour fire at 800 degrees Celsius. The study concluded a respirable fraction of 0.0008% over a four hour period. Considering a 1200 pound maximum for the amount of depleted uranium on a given aircraft, this would yield less than 0.01 pounds of respirable uranium oxides (about 2 microcuries). Using the Pasquille-Gifford Equation[2] for a ground release event, and assuming very stable atmospheric conditions to limit dispersion to a minimum, we obtain a maximum concentration at 100 meters of 3×10^{-12} microcuries per milliliter.

$$X(x,y) = Q * (\pi * \sigma_y * \sigma_z * u)^{-1}$$

Where: Q = 2 microcuries / 4 hours = 1.4×10^{-4} microcuries per second (µCi/sec)

σ_y = horizontal diffusion factor at 100 meters = 4 meters

σ_z = vertical diffusion factor at 100 meters = 1.5 meters

u = 2 meters per second (< 5 mph)

$$X(x,y) = 1.4 \times 10^{-4}\ \mu Ci/sec * (\pi * 4\ m * 1.5\ m * 2\ m/sec)^{-1}$$

$$X(x,y) = 3 \times 10^{-6}\ \mu Ci/m^3 = 3 \times 10^{-12}\ \mu Ci/ml$$

1 Tank burn test "Operation Hot Box", U.S. Army Armament Research and Development Command, DU Task Force; Dover, NJ; 30 November 1979

2 Metrology and Atomic Energy; D.H. Slade, ed.; USAEC: Washington, D.C.; 1955

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