ORNL/TM--11503

DE91 001007

Chemical Technology Division

RADIOLUMINESCENT (RL) AIRFIELD LIGHTING SYSTEM PROGRAM

Annual Report: October 1, 1986 - September 30, 1987

J. A. Tompkins*
K. W. Haff
F. J. Schultz

Date Published - September 1990

*Westinghouse Electric Corporation, Las Vegas, Nevada.

Prepared for
U.S. Department of Energy
Office of Nuclear Energy
Washington, D.C. 20545

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.,
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

In 1980, the U.S. Air Force Engineering and Services Center (AFESC) at Tyndall Air Force Base, Florida, requested that the Radioisotope Technology Group of Oak Ridge National Laboratory (ORNL) develop large-scale, tritium-powered, radioluminescent (RL) airfield lighting systems. The RL lighting systems possess the advantages of being portable, requiring no electrical power source, having a long shelf life, and being unaffected by environmental extremes. These characteristics make the RL system well-suited for harsh environments where the cost of electrical power production is high and traditional incandescent airfield lighting systems are difficult to maintain. RL lighting is typically a large-surface-area, low-intensity light source that operates 100% of the time. The RL light sources gradually decrease in brightness over time, so periodic replacement (every 6 to 8 years) is necessary. RL lighting functions best in low ambient light, which provides the high contrast ratios necessary for successful use of these devices.

Previous work has been devoted to research and development aimed at the large-scale light sources (>50 Ci) necessary for RL airfield lighting.[1,2,3] Development work has included the deployment of several large light sets (>100 units) fabricated at ORNL. Many of these deployments have suffered from low-contrast environment, incomplete pilot briefing, inadequate light sets, and unofficial status of the testing group. One successful test was conducted for the Federal Aviation Administration Technical Center near Benton City, Washington, in August 1984. This test, which simulated a typical Alaskan bush airfield in a remote environment, met the minimum requirements for safe use under the prevailing weather conditions.[1]

The goal of this program for fiscal year 1987 was to specify, commercially procure, evaluate, and demonstrate a state-of-the-art airfield lighting system for a Test Wing of the United States Air Force (USAF). The RL system was intended to meet the requirements generated by the Alaskan Air Commands Statement of Need (SON 01-84). These requirements included airfield acquisition at distances greater than 4 miles in a remote environment.

A specification was written by ORNL, based on development of the standard ORNL RL airfield light panel. Procurement was conducted as a competitive bid to encourage the commercial vendors to provide their best design at the lowest price. A demonstration of the lighting system was held at Eglin Air Force Base (AFB), Florida, and was conducted by the Test Wing of the USAF's Armament Development Laboratory.

2. PROCUREMENT PROCESS

2.1 TECHNICAL SPECIFICATIONS FOR RL LIGHTS

Technical specifications for this first large, commercial procurement of RL lights were crucial to successful program completion. The specifications (Appendix A) included the criteria developed for ORNL panels and yet generalized to enable the vendors to improve the design. Specifications included brightness, luminous intensity, light distribution, package integrity, activity level maximums (curies), and quality control testing. The minimally acceptable unit was required to be 25% greater in luminous intensity (0.19 cd) than the original ORNL panel. Package integrity was to meet ANSI-N540 (1975)[4] Class 4 requirements, except for the impact test, which was upgraded to 22 drops from 2 m. Activity level maximums were required to be less than 1000 Ci to ensure the use of Type A[5] packaging. The alternative to Type A packaging is Type B[5] packaging, the weight and bulk of which are sufficient to preclude any simple deployment or transportation mode. At the vendor's facility, quality control (QC) testing was to include well documented 100% testing for tritium leakage and photometric output.

Items not specified were weight, volume, source geometry, directionality (uni-, bi-, and omni-), and packaging materials. These unspecified items were intended to give the RL light vendors maximum latitude to improve the existing design and reduce manufacturing costs.

2.2 COMPETITIVE PROCUREMENT

This procurement was conducted as a competitive bid with purchase and evaluation of prototypes performed by ORNL prior to vendor selection. The U.S. Department of Energy (DOE) provided 300,000 Ci of tritium gas for the light units, but tritium use was still considered a cost in the weighted vendor selection formula. A schedule was developed for the activities necessary to complete delivery of the light units by March 31, 1987. A rigid schedule was necessary since the test date had been set by the USAF prior to the initiation of the procurement cycle. The schedule is shown in Table 1.

Table 1. Procurement schedule

Mailing of solicitation	Sept. 19, 1986
Prebid conference	Oct. 7-8, 1986
Submission of proposals	Oct. 21, 1986
Proposal selection	Oct. 29, 1986
Submission of prototypes	Dec. 1, 1986
Evaluation of prototypes	Dec. 16, 1986
Vendor selection	Dec. 30, 1986
Delivery of units	Mar. 31, 1987

At the prebid conference held in Oak Ridge on October 7-8, 1986, eight interested vendors were briefed on the schedule and the technical specifications required for manufacturing the light source. This discussion was particularly important for eliminating some ambiguity and clarifying all points in the technical specifications package. The manufacturers had met the previous evening and developed their list of questions for the meeting. Some noncritical specifications were changed to match industry standards (e.g., maximum light decay curve). Some questions were answered by telephone calls during the proposal development period (October 9-21), but this practice was held to a minimum.

2.3 PROPOSAL SUBMISSION AND EVALUATION

Proposals for purchase of prototypes for the competitive bid arrived in a timely manner. Eight proposals were received from five firms. Offers ranged from $300,000 to $1,700,000, with two offers between $300,000 and $400,000, four offers between $600,000 and $800,000, and two offers exceeding $1,300,000. The original intent of the prototype selection was to procure all of the submitted prototypes so that ORNL would have a complete picture of the quality of commercial work available. However, since the cost of two systems exceeded the total money available for the bid, the prototypes for these units were not procured. Five of the remaining six offers from three firms were accepted.

2.4 PROTOTYPE SUBMISSION AND SELECTION

Prototypes were submitted by the December 1 deadline. As can be seen in Fig. 1, there was a wide range of prototype unit size, shape, curie content, and light output. Uniform evaluation of the prototypes was essential to determine parameters for the total bid evaluation. Panel unit parameters are shown in Table 2.

After the units had been evaluated, ANSI-N540 (1975) classification of the units was conducted. These classification tests are intended to provide performance guidelines for all types of radioactive light sources. One problem inherent in this edition of the test is that large-scale tritium light sources are not addressed. Most large-scale sources contain more than 50 Ci of tritium gas. Another problem is that the impact test limits are not stringent enough for these large light sources, which is the reason that different impact test criteria were specified by ORNL for these units. The test limits used are shown in Table 3.

ORNL PHOTO-- 8463-86

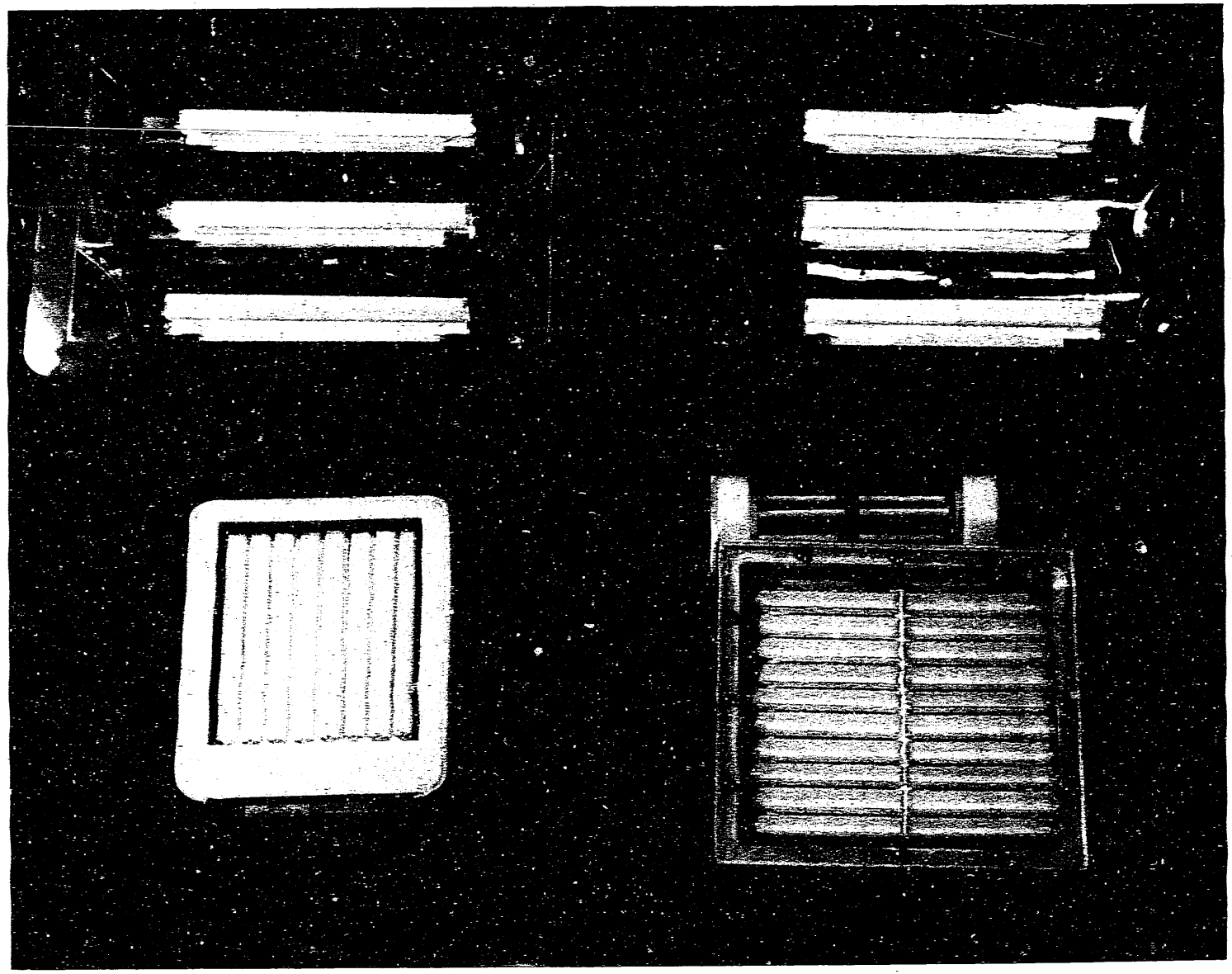


Fig. 1. Four prebid panel units.

Table 2. Prototype evaluation

	Unit Designation				
	A-1	A-2	B-1	C-1	C-2
Luminous intensity, cd	0.119	0.082	0.233	0.235	0.377
Bright., cd/m^2	0.97	0.76	1.0	0.74	1.05
Activity, Ci	700	415	400	500	996
Mode	BI[a]	BI	UNI[b]	BI	BI
Efficiency, mCd/Ci	0.340	0.395	0.582	0.940	0.754
Volume, L	3.7	3.7	7.63	6.83	6.8
Weight, kg	3.0	3.0	2.9	4.5	4.5

[a]BI = bidirectional.
[b]UNI = unidirectional.

Table 3. Test conditions

Thermal	-55°C and 80°C
Thermal shock	-55°C to 80°C
Reduced pressure	<87 mm Hg
Impact	22 x 2 m
Vibration	0 to 50 to 0 Hz in a cycle; 1 cycle/min, for 1 h
Immersion	0 and 80°C; 15 min at temperature; 5 cycles

These tests (with the exception of impact testing) represent Class 4 testing of ANSI-N540, which is the most stringent level of classification. Results of classification work at ORNL demonstrated that four of five units failed some aspect of the testing. The specific failures are identified in Table 4.

Table 4. Failure analysis of prototypes

	Unit Designation				
	A-1	A-2	B-1	C-1	C-2
Thermal	T(-55)				
Thermal shock					
Reduced pressure					
Impact			T(x2)	C(x2)	C(x5)
Vibration					
Immersion					
Total	T[a]	P[a]	T[a]	C[a]	C[a]

[a]T = tube failure; C = case failure; P = passed.

The failure of a unit during thermal testing was unique, since a failure of this type had not previously been observed. Failure of three other units during the rigors of twenty-two 2-m free drops was expected because of high levels of mechanical stress on the units. The failure of the units during testing indicated the time allotted by the vendors for in-house testing. The amount of time available was very small due to the tight schedule imposed by the program sponsor. Another problem confronting the vendor was the inability to drop-test actual light source prototype units. Few vendor facilities can tolerate the large releases of tritium that could occur.

A decision was made by ORNL that package integrity performance could be improved prior to production of the chosen unit. Some manufacturers expressed surprise that the prototypes had been drop-tested since they thought testing would be applied only to the production unit.

2.5 VENDOR SELECTION

Selection of the production model was determined by employing a weighted formula method with the weighing factors shown in Table 5.

Table 5. Selection formula

System price	50%
Luminous intensity	30%
Weight-volume	10%
Production capability	10%

The values of the unit parameters (price, luminous intensity, and weight-volume) were used to determine the number of points awarded in each of the four categories. A total of 100 points was possible. Point factors were calculated as the fractional part of the desirable trait. For example, lowest system cost was given the highest number of weighted points (50), and the remainder of the units were evaluated in terms of the lowest cost [(lowest cost/cost) x 50]. The luminous intensity (LI) and weight-volume (WV) point factors were evaluated in a similar manner, with the highest LI and lowest WV receiving the maximum number of points. All vendors were awarded the ten points for production capability after on-site inspection by ORNL determined that all had sufficient facilities to produce the light units within the required time. The final point evaluations are shown in Table 6.

Table 6. Final point evaluations

Parameter	Unit Designation				
	A-1	A-2	B-1	C-1	C-2
Price	---	---	25.5	50.0	30.8
Luminous intensity	a	a	18.5	18.7	30.0
Weight-volume	10.0	10.0	5.1	0.7	0.7
Production capability	10.0	10.0	10.0	10.0	10.0
Totals	---	---	59.4	79.4	71.5

[a]Units A-1 and A-2 were not evaluated because they did not meet the minimum luminous intensity (0.19 cd) specification.

Vendor selection was simplified in that one vendor had the two highest point totals for the prototypes C-1 and C-2, respectively. Unit C-2 was selected for procurement because it had the highest LI and most closely met the needs of the end user. Safety Light Corporation (SLC), Bloomsburg, Pennsylvania, was the selected vendor. Discussions were held immediately with SLC to determine their willingness to modify the packaging to reduce overall package size and to guarantee that the production model would meet package integrity test criteria. ORNL believed, and SLC agreed, that the package surface area could be decreased by 40% with a 5% loss in LI. Once agreements were reached in these areas, SLC was awarded the contract. Production of light source tubes began on December 22, 1987.

3. MANUFACTURE OF RL LIGHT UNITS

3.1 MANUFACTURING METHODS AND QUALITY CONTROL

Part of the bid award package included the criteria that ORNL quality control methods would be used and documented for these light units. The fundamental issue in using these methods was testing of 100% of the units for physical integrity and photometric output. The test methods required inspection and pressure testing of the unfilled light source tubes. Testing of the filled tubes involved thermal shock of the light sources, followed by a 24-h water soak and liquid scintillation counting of the soak solutions. Extensive documentation was provided during the two on-site inspections to ensure ORNL that the quality control program was 100% effective and that the desired methods were used.

Photometric measurements were made on all light source tubes and assembled units. Of the 1635 tubes fabricated for this project, only 3 failed from loss of integrity, a rejection rate of less than 0.2%. Two of the tubes were discovered using the ORNL soak test. Frequency distribution curves for the luminous intensity of light source tubes (Fig. 2) indicate a Gaussian distribution with a standard deviation of 0.050 cd m^5.

3.2 ORNL EVALUATION OF ASSEMBLED LIGHT UNITS

In March 1987, two production units of the modified light package (Fig. 3) were received at ORNL. These two units were subjected to the ANSI-N540 testing previously described, with minimal damage (scuffed paint) to the units. Additionally, a dummy panel (containing no tritium) was submitted for impact testing from a height of 10 m. This unit was tested to the point of destruction, and a tube broke on the eighth drop.

The two live units received additional testing to determine whether they qualified as Type A shipping packages.[5] These tests included a water spray, free drop (1.2 m), compression, penetration (6 kg from 1 m), free drop (9.0 m), and penetration (6 kg from 1.7 m). The testing of the dummy panel was used as the second free drop since it had greatly exceeded the required drop from 9 m. Test conditions for these packages met or exceeded requirements for Type A packaging. All panels were labeled as Type A shipping packages.

Photometric measurements (bidirectional) were obtained for each lighting unit. The medium value for luminous intensity measurements was 0.355 cd (standard deviation of 0.011 cd). The frequency distribution is shown in Fig. 4.

All packages were smeared prior to shipment, and no indication of tritium leakage was found. After the photometric measurements had been completed, the units were mounted on two-panel racks (Fig. 5) for shipment to the preliminary test site. These racks were not optimized for this type of deployment since the base units did not rotate for storage.

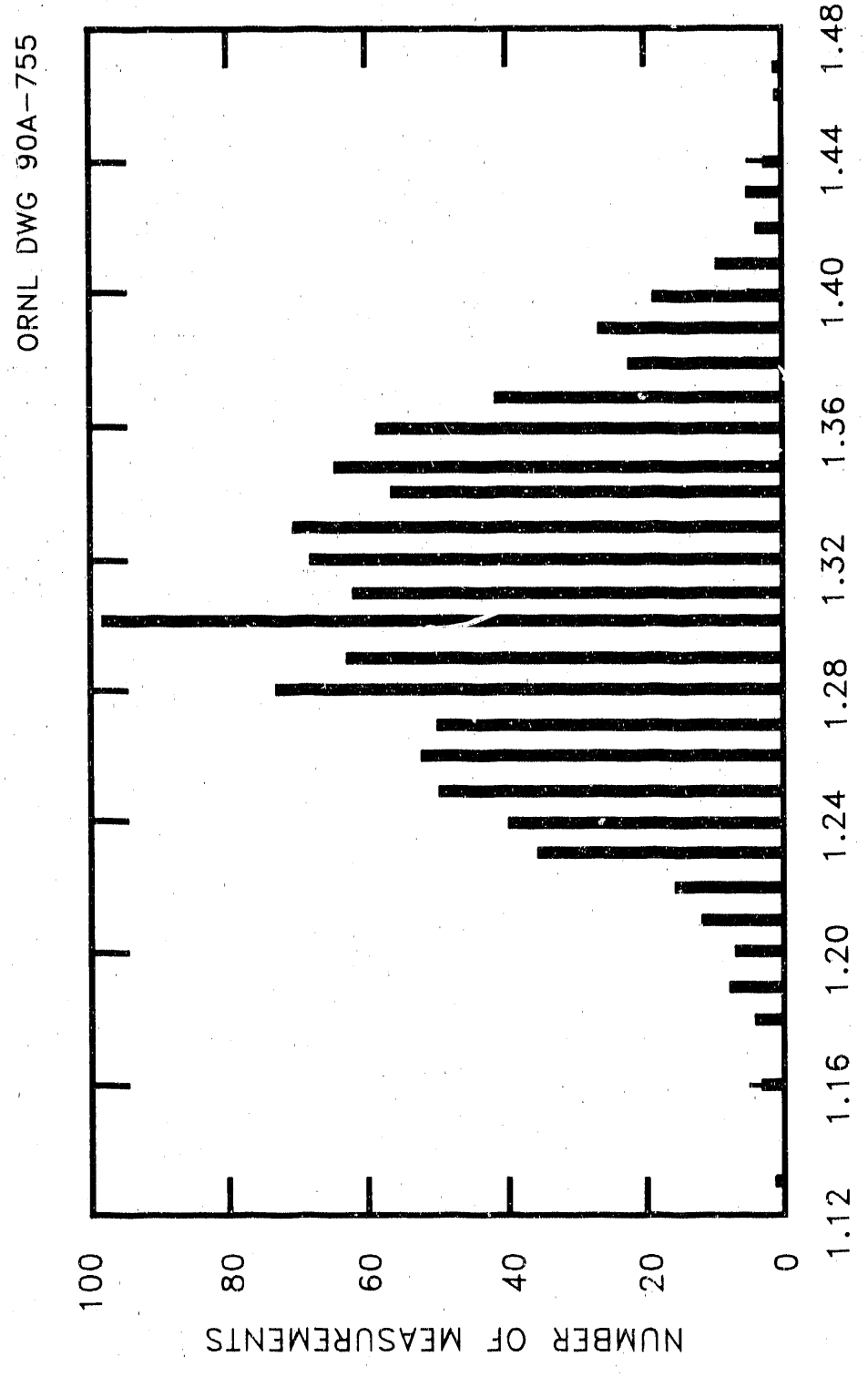


Fig. 2. Frequency distribution of brightness in the light source tubes (1022 out of 1632 tubes).

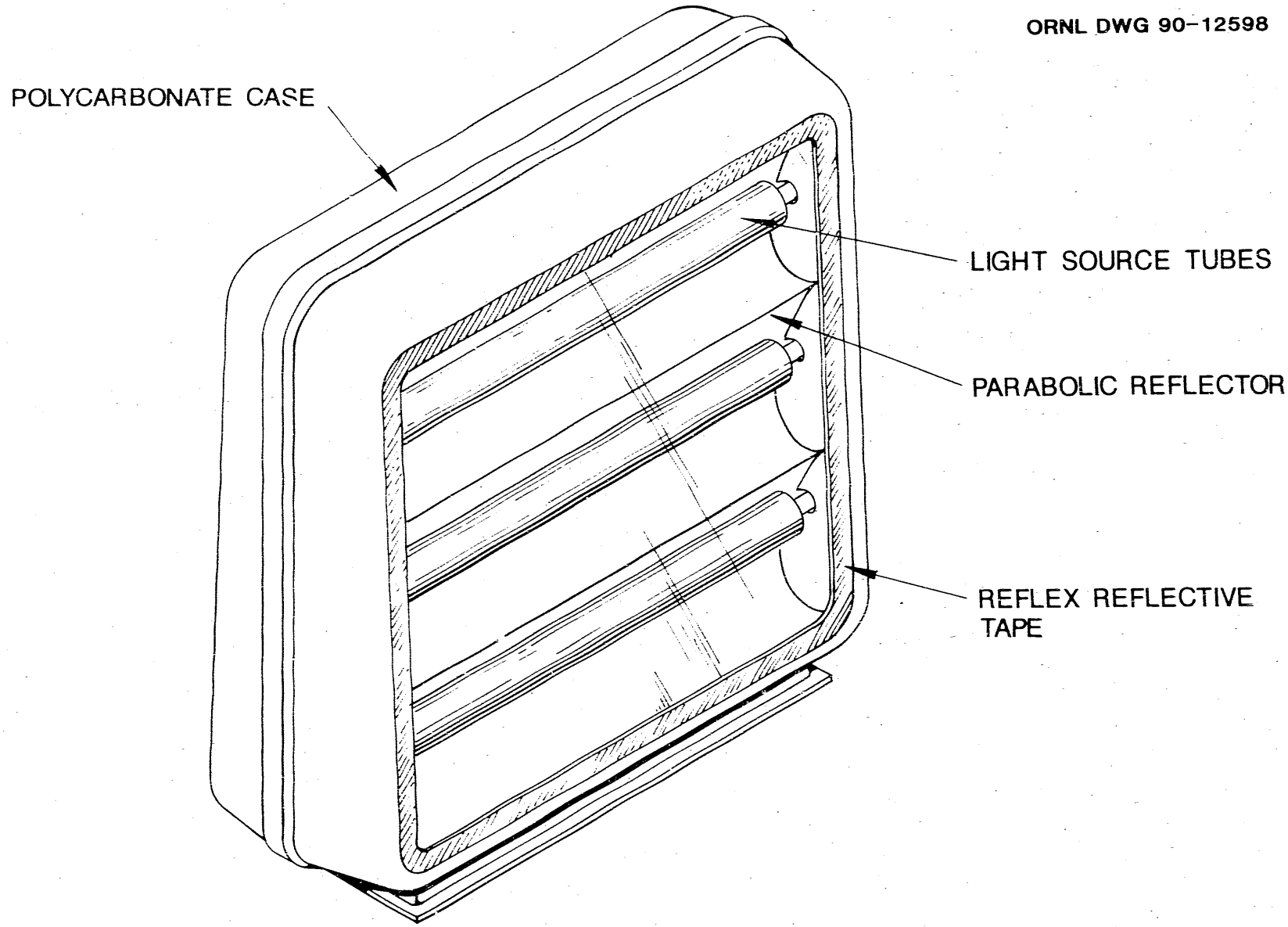


Fig. 3. Schematic of production units.

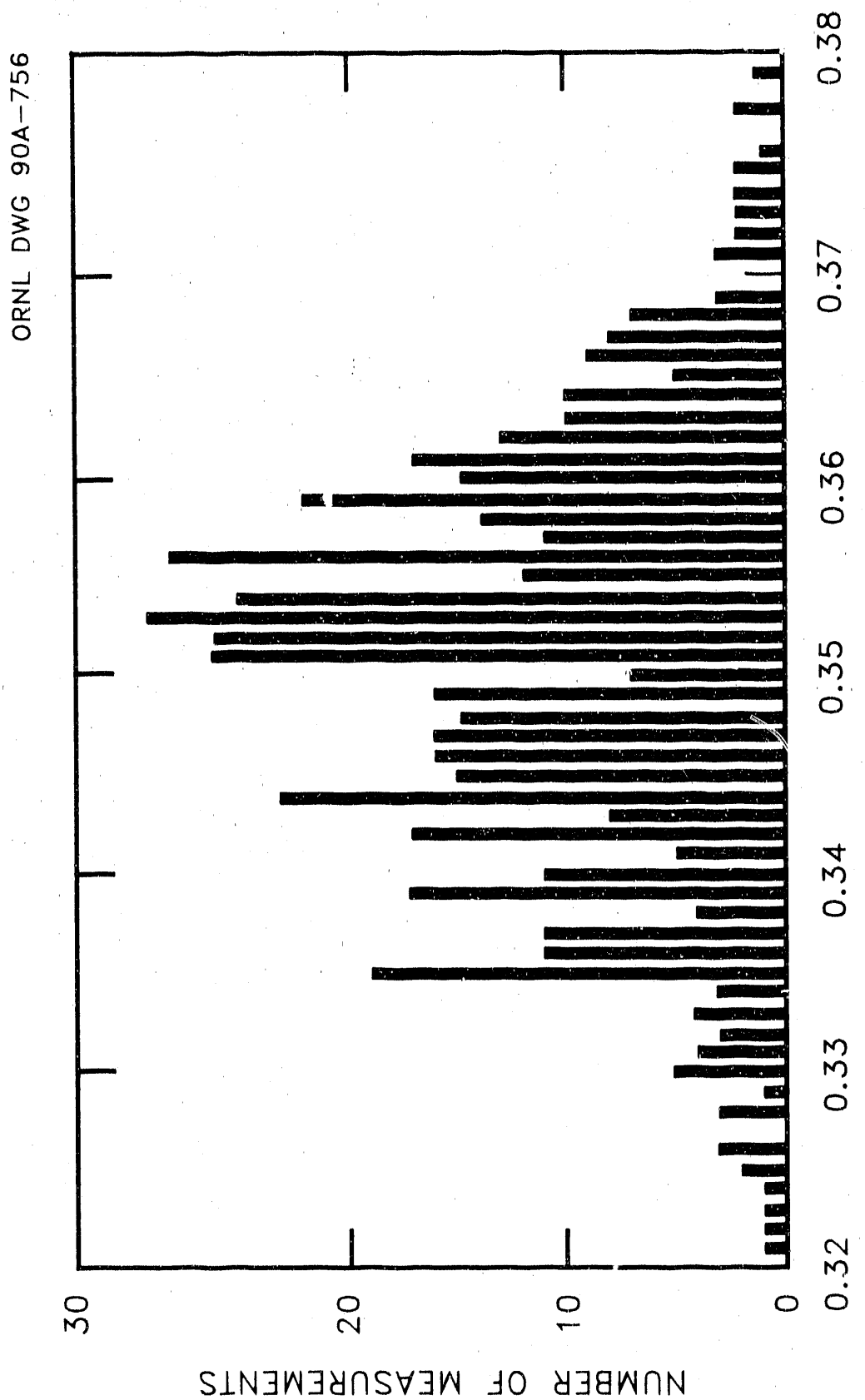


Fig. 4. Frequency distribution (for 272 two-sided panels) of panel luminous density.

ORNL DWG 90-12599

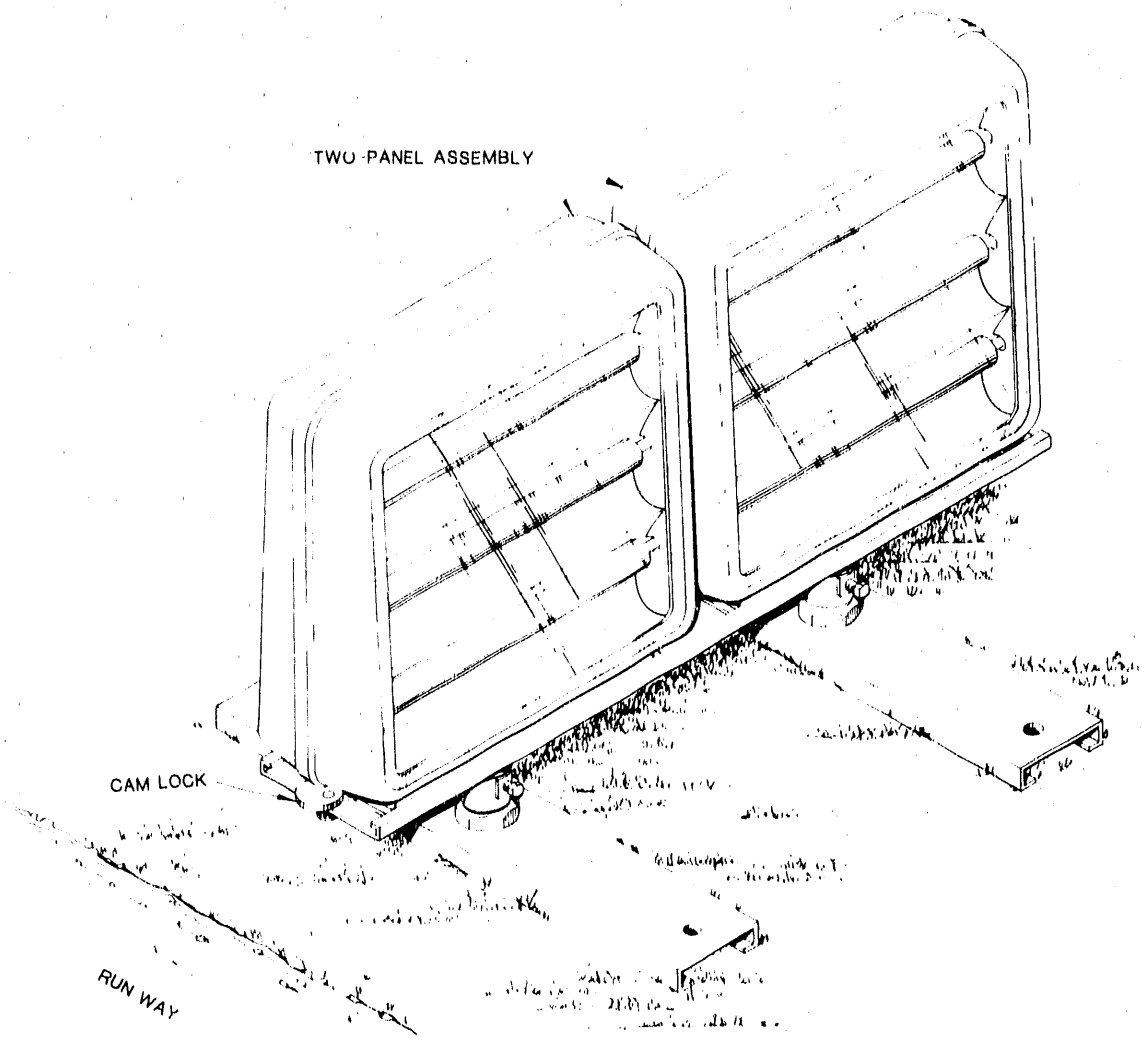
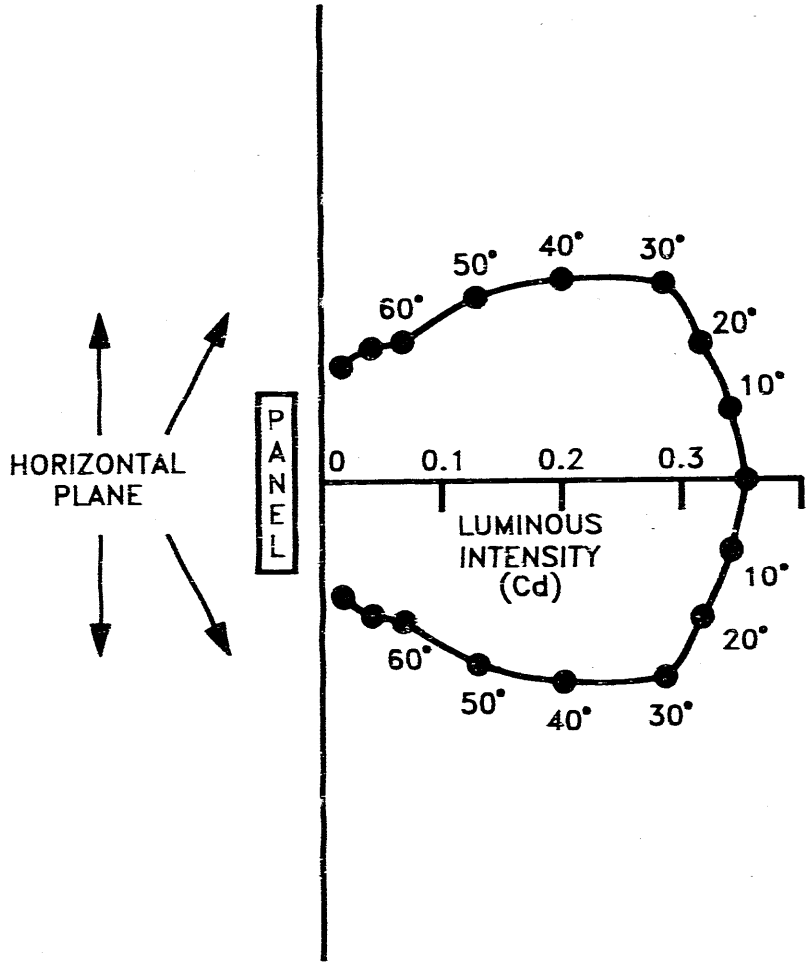


Fig. 5. Schematic of two-panel rack assembly.

Angular distribution of light output (horizontal and vertical, Figs. 6 and 7, respectively) indicated that horizontal distribution was typical of a flat-plate reflector and that vertical distribution was highly influenced by the parabolic reflector and differed significantly (20%) at an angle of 20°. Vertical distribution was adequate since a standard aircraft approach is on a 3° glide slope and the luminous intensity changes very little over a $\pm$ 5° arc.

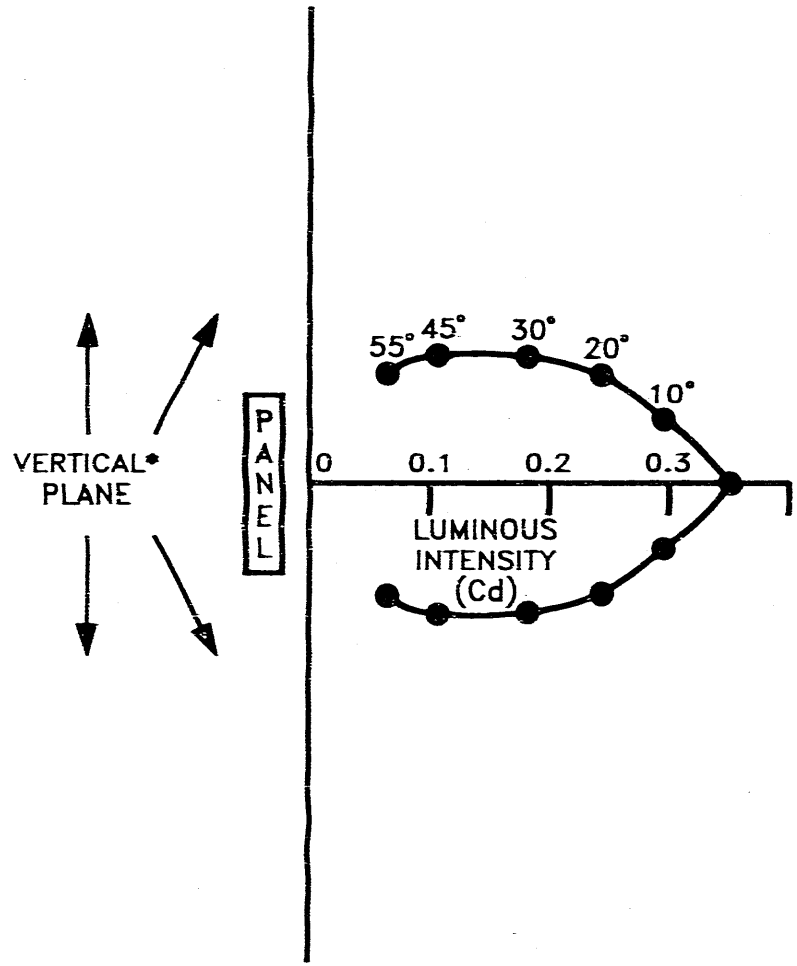
ORNL DWG 90A-758



HORIZONTAL ANGULAR DISTRIBUTION

ANGLE (°)	OUTPUT (%) SLC	(%) IDEAL FLAT PLATE
0	100.0	100.0
10	98.6	99.7
20	95.7	94.0
30	93.5	86.6
40	74.6	76.6
50	57.0	64.3
60	38.9	50.0
70	34.3	34.2

Fig. 6. Horizontal angular light distribution.



VERTICAL ANGULAR DISTRIBUTION

ANGLE (°)	OUTPUT (%) SLC	(%) IDEAL FLAT PLATE
0	100	100.0
10	85	98.5
20	75	94.0
30	60	86.6
45	42	70.7
55	31	57.4

*The actual vertical plane is inclined 3° upward to match aircraft glide slope.

Fig. 7. Vertical angular light distribution.

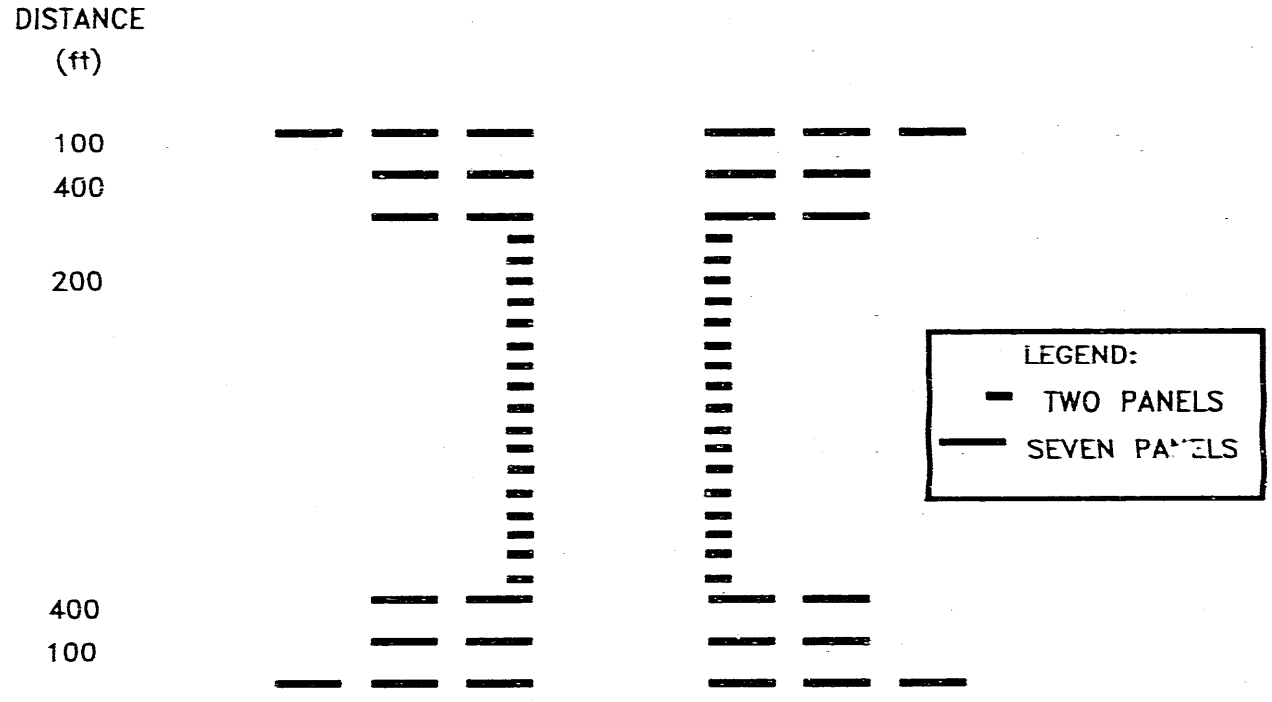
4. FIELD DEMONSTRATIONS

4.1 PRELIMINARY EVALUATION OF THE LIGHTS AT BROOKVILLE, FLORIDA

The 272 light units, mounted on 136 racks, were shipped to Florida on April 21 by an exclusive-use truck, which was retained for the duration of the test. Preliminary testing of the lights occurred at the Hernando County Airport, near Brookville, Florida, on the nights of April 23 and 24. Initial deployment was in the Military Airlift Command (MAC) configuration (Figs. 8 and 9; 264 panels). Deployment of the lights required 1 h 10 min the first night and 1 h the second night using a three-man team (including the driver). The aircraft evaluations were made using a Piper Archer equipped with Loran C navigation instruments, which provided positional accuracy to within 0.1 nautical mile (NM). Flights conducted on April 23 indicated an average usable acquisition distance of 2.1 NM with fog limiting visibility to 2.5 to 3.0 NM. Weather improved on April 24, and the average acquisition distance increased to 3.8 NM with 18 to 20 miles of visibility.

Testing at Brookville included work with the upgraded long-range alignment system (LRAS) originally developed for use at a demonstration in Spangdahlem, Federal Republic of Germany.[2] The LRAS is a group of portable electric (36-W, 2-s interval) strobe lights placed on the centerline of the runway near the threshold. The demonstration at Brookville was used to evaluate the optimum placement of the strobe units for integration with the RL lights. Initial deployment of the LRAS system was in a T-formation with strobe units on each edge and the centerline of the runway displaced 100 ft toward the approaching aircraft. Four additional units were deployed on the centerline at 100 ft from the first unit. This configuration was observed from the aircraft at 4 miles on April 23, and greater than 9 miles on April 24. Pilot observations indicated that the units on the edges of the airfield caused washout of the RL lights as the aircraft moved into short final approach. Removal of the edge strobe units eliminated this problem and ultimately demonstrated the compatibility of the two systems. Pilot observations indicated that the LRAS units could be reduced to three or four in number but needed to be precisely synchronized to produce the optimum effect. The spacing of 100 ft between units was judged to be a minimum, and 200 ft between them was thought to be closer to the optimum.

Airfield Layout for Maximum Deployment of Radioluminescent Light Fixtures - Military Airlift Command Configuration



TOTAL PANELS REQUIRED = 264

TOTAL LENGTH OF RUNWAY = 4600 ft

Fig. 8. Military Airlift Command airfield configuration.

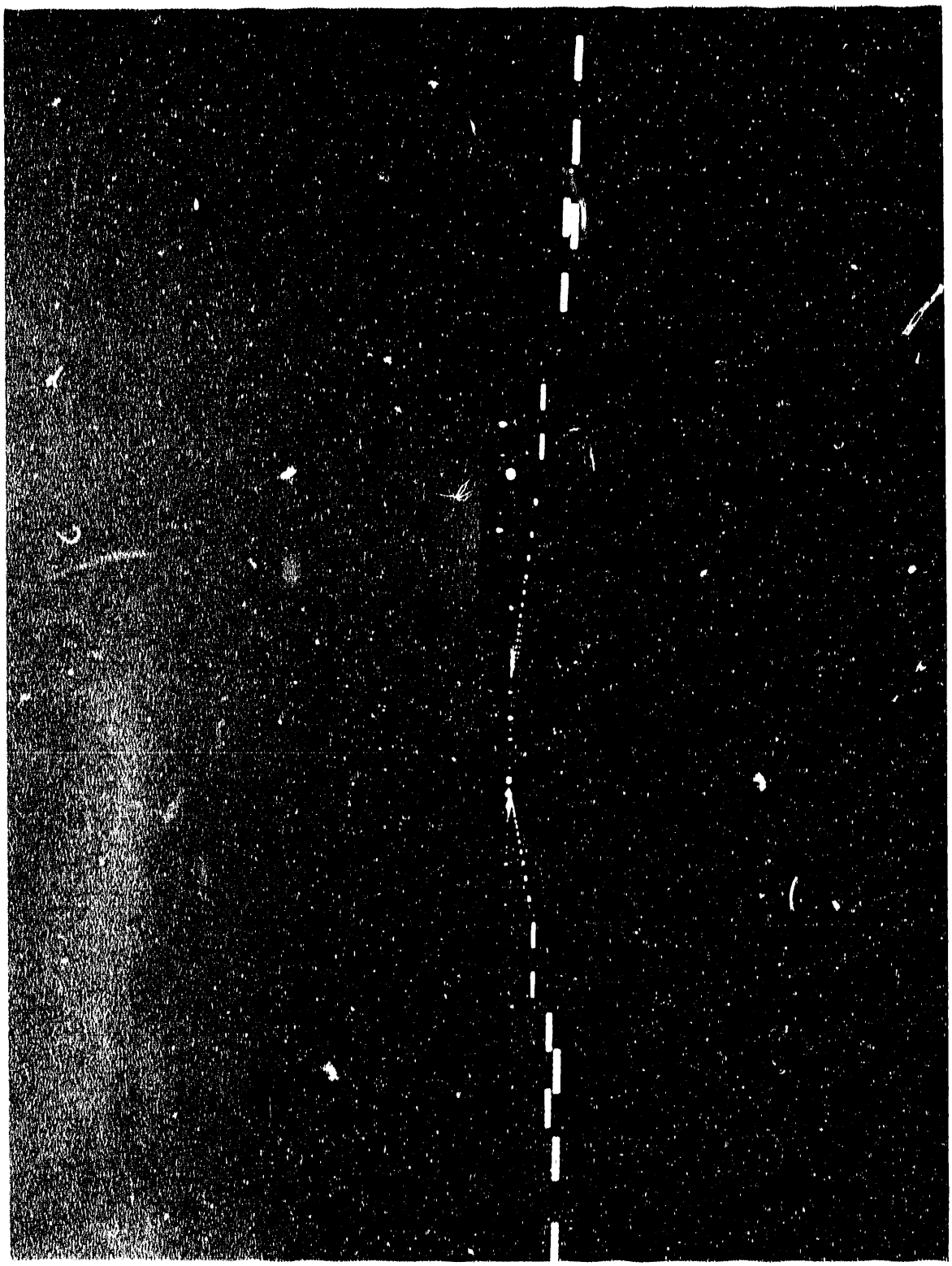


Fig. 9. Military Airlift Command configuration, Brookville, FL.

4.2 DEMONSTRATION AT EGLIN AFB, FLORIDA

The demonstration for the Armament Development Laboratory, Test Wing, at Eglin AFB was started on April 29 and completed on May 22, 1987. A total of 14 deployments was made for the USAF. The MAC configuration was deployed ten times and the alternate configuration (Fig. 10) four times. Deployment time for the MAC configuration varied between 42 and 60 min for a previously marked airfield. Deployment time for the alternate configuration, 27 to 29 min, was of shorter duration because 68 fewer panels were moved and these panels represented those positioned farthest from the edge of the airfield.

Three different types of aircraft were used at Duke Field (Eglin AFB) to test the two configurations. Weather during the test varied from 2 to 3 miles of visibility with fog and rain to greater than 15 miles of visibility. The F-4 and F-15 aircraft made 7 to 11 low passes (Fig. 11) or "touch and go" landings per sortie. The C-130 aircraft made one to two landings (Fig. 12) per sortie. The LRAS system was not tested due to administrative problems. The aircraft and the total sorties for each type are shown in Table 7.

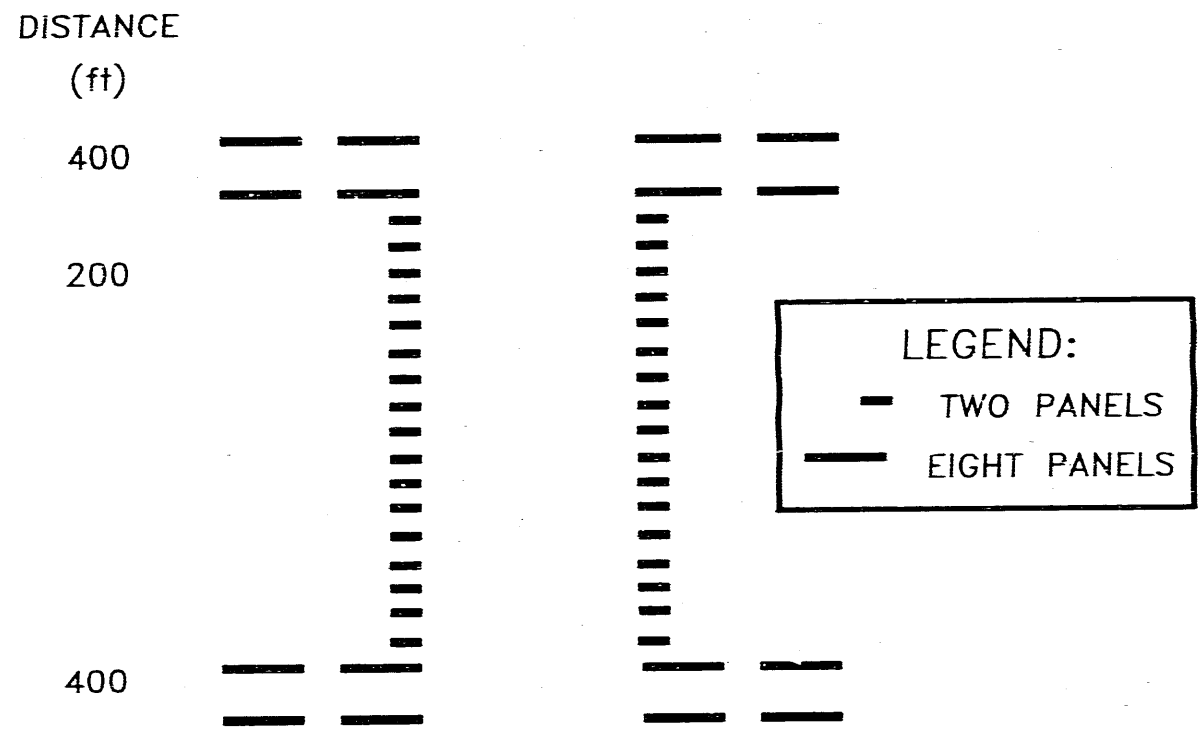
Table 7. Test data from Duke Airfield demonstration

Aircraft Type	Mode	Sorties	Mean range (NM)	Std. dev. (NM)	Samples
F-15	ACQ[a]	1	7.8	1.2	11
F-4	ACQ	5	3.2	0.7	39
	REC[b]	5	2.2	0.6	29
C-130	ACQ	22	3.7	1.2	37
	REC	22	3.1	1.3	40

Source: J. M. Pfieffer and M. Arbona, *Radioluminescent Airfield Lighting System (RAFLIS) Test,* (AD-TR-87-43), Eglin AFB, Florida, August 1987.
[a]ACQ = seeing four corners.
[b]REC = seeing outline.

Comparison of the MAC and alternate configurations yielded approximately equal acquisition distance, which indicates that the alternate configuration is the more cost-effective choice, with its 68 fewer units and lower deployment time. Shorter deployment times for both configurations are possible with a properly developed shipping package (trailer) that allows simplified manual handling operations.

Airfield Layout for Deployment of Radioluminescent Light Fixtures - Alternate Configuration



TOTAL PANELS REQUIRED = 196

TOTAL LENGTH OF RUNWAY = 4400 ft

Fig. 10. Alternate airfield configuration.

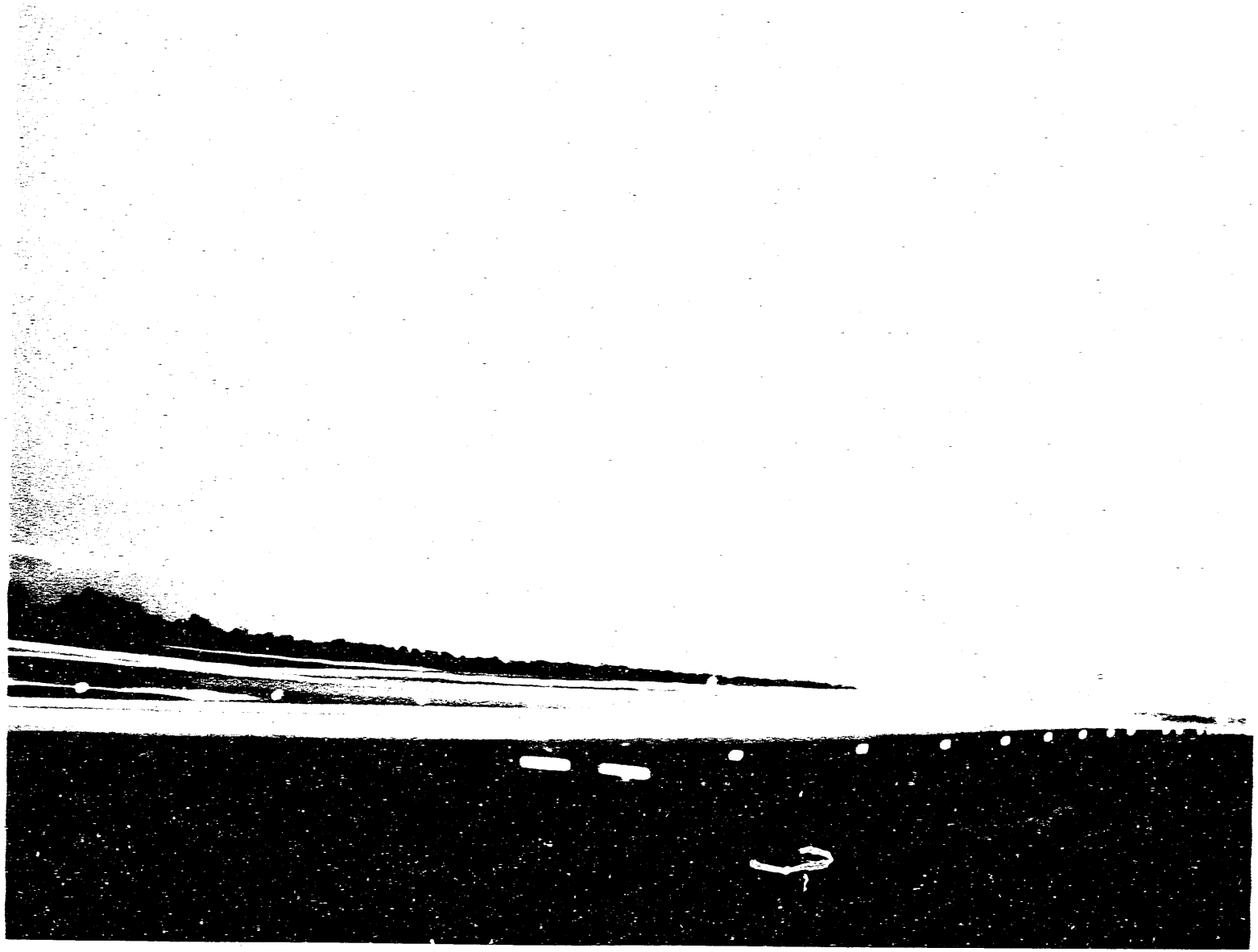


Fig. 11. F-4 aircraft, low pass, Duke Airfield.

The two live units received additional testing to determir
as Type A shipping packages.[5] These tests included a w
(1.2 m), compression, penetration (6 kg from 1 m), free
penetration (6 kg from 1.7 m). The testing of the dumn
second free drop since it had greatly exceeded the requi
conditions for these packages met or exceeded requirem
packaging. All panels were labeled as Type A shipping

Photometric measurements (bidirectio..l) were obtained
The medium value for luminous intensity measurements
deviation of 0.011 cd). The frequency distribution is sho

All packages were smeared prior to shipment, and no in
leakage was found. After the photometric measurement
the units were mounted on two-panel racks (Fig. 5) for
preliminary test site. These racks were not optimized fo
since the base units did not rotate for storage.

ORNL PHOTO- 5423-87

A major limitation on the absolute acquisition and recognition distances achieved during the test was ambient lighting. A prison camp located 3 miles from the airfield directly on the line of approach was very brightly illuminated. Also, the airfield structures generated ambient light (street lights and flood lights) in the immediate vicinity. This made the acquisition and recognition distances conservative with respect to what is possible under remote conditions.

4.3 FIELD TEST CONCLUSIONS

Major conclusions in the Test Wing report (AD-TR-87-43)[3] are shown in Table 8.

Table 8. Major conclusions—Test wing report

1.	The types of aircraft tested can acquire and land on airfields equipped with RL lighting.
2.	The RL system, by itself, does not provide adequate glide slope information.
3.	The RL system requires distance remaining markers.
4.	The RL system requires overrun markers (centerline).
5.	Aircraft landing lights did not wash out the RL system.
6.	The location of the prison may have affected the acquisition and recognition distances.
7.	A learning curve exists for pilot perception of the RL system.

The observable fact that these aircraft landed multiple times on the deployed RL units indicates that the system would serve as minimal lighting for tactical and transport aircraft. C-130 aircraft with slow approach speeds and good low speed maneuverability have little problem using this system. Tactical aircraft with higher approach speeds require greater distances for definite landing alignment. The use of Instrument Landing System (ILS), Microwave Landing System (MLS), or visual aids to provide tactical aircraft with glide slope information appears to be the single greatest limitation of the system as deployed. Use of an RL- or Radioisotope Thermoelectric Generator (RTG) -powered Vertical Angle Slope Indicator (VASI) system will greatly increase the utility of this system.

Distance remaining and overrun markers are a necessity for tactical aircraft. T! se two marking problems can be solved with RL units similar to those used for the edge lighting. Washout problems from landing lights were a concern because of the low intensity of the RL lighting. However, the reflex reflective tape and the clear glazing on the RL units provide sufficient reflected light to give good airfield definition at short distances. Another factor observed in the demonstration was the existence of a learning curve for pilot perception of the RL airfield. The pilots became more comfortable with the lighting system on each successive pass. This would also be reflected in the acquisition distances, which would increase asymptotically to some maximum level as the pilots become accustomed to this type of lighting.

5. SAFETY AND LICENSING ISSUES

5.1 PERSONNEL DOSE

The use of any radioactive material by USAF personnel must be approved by the Air Force's Radioisotope Committee (RIC). The RIC is the permitting authority for all USAF radiation sources. In general, approval by the RIC requires a review of the application, source integrity, training materials, levels of surveillance, and evaluation of the potential danger to USAF personnel.

Prior to the Eglin deployment instruction manuals, a security plan and a safety plan were written for use at Eglin AFB. Realistic accident scenarios involving doses from accidental release of tritium were examined. The scenarios were as follows:

1. warehouse fire,
2. theft and subsequent indoor release,
3. warehouse accident,
4. outdoor or runway accident,
5. release in transit (internal to C-130 aircraft), and
6. release due to diffusion through tubes during storage.

These scenarios were evaluated to determine maximum received dosage (50-year committed dose) to personnel from acute release of activity. Actual dose calculations are included in Appendix B. The worst personnel dose was calculated for a storage facility fire scenario, which involves the release of 250,000 Ci of tritiated water during a major building fire (scenario 2). The 50-year committed dose was 4.33 rem (whole body). The maximum dose to any organ in the body was 8.58 rem to the Res lymph system. The dose to the Res lymph system is equivalent to 1.72 times the annual dose allowed a radiation worker (5.0 rem/year maximum). The dose to the whole body is approximately equivalent to 87% of the accumulated annual dose allowed a radiation worker and approximately equivalent to 87 chest X rays.

This calculation is very conservative in that it assumes that the individual will remain in the exact area of maximum concentration for the entire period of the release (1 h). The conclusion drawn from this scenario is that the stored light-source tubes represent the greatest hazard to personnel during a building fire. Therefore, these fixtures should not be stored in a building containing flammable material. Preferably, they should be stored in a secured area outside any building. Inasmuch as the lights themselves are unaffected by changes in temperature or humidity, this course of action would seem prudent.

5.2 DIFFUSION THROUGH PYREX TUBE

Another exposure scenario studied at ORNL involved chronic exposure to tritium released from stored units by diffusion through the glass and device casing. Work was conducted at ORNL to establish upper limits for these RL light source tubes. Calculation of a diffusion rate based on published data results in a diffusion rate of 17 μCi per year per device[6] (six-tube, 996-Ci RL light). The main source of error in this calculation is that most tritium diffusion rates are measured at about 700°C. Extrapolation of these data back to ambient temperatures generates systematic error. Experimental work at ORNL has established that the upper limit for diffusion out of the tube itself is less than 1.0 μCi of tritium per year per device. This results in an annual rate of 0.3 mCi per year for 272 devices. The lower limit of diffusion is difficult to determine with precision since the solution counting is limited to about 9 counts/min (background) and these samples are only counting between 9 and 10 counts/min (<130 Bq/L). These permeation rates from back diffusion are extremely conservative since the control samples averaged <120 Bq/L and the actual diffusion samples averaged 125 Bq/L. This calculation assumed that all of the activity measured for the diffusion samples (125 Bq/L) resulted from diffusion. In point of fact, at least 120 Bq/L appear to be accounted for by environmental tritium.

Also, these diffusion rates are for the tubes themselves and not for the assembled devices, which represent another barrier between the tritium and the environment. No smears taken of undamaged light units (smeared before and after each shipment) at ORNL have ever indicated anything other than background levels of tritium. These very low diffusion rates are not measurable with tritium air monitors. One method of monitoring changes in the tritium diffusion rate would be to place polystyrene smear pads in air-permeable vials in the storage area. These smear pads could then be counted (liquid scintillation counting) to give an integrated exposure record for the storage. Shipment of these samples to a central counting facility on a biannual basis would offer sufficient monitoring to eliminate chronic exposure to personnel.

6. RECOMMENDATIONS

The following recommendations are made as a result of the testing and evaluation of radioluminescent lights discussed in this report.

1. Research and development on RL VASI, distance-to-go markers, and overrun markers should be continued.

2. Testing of a complete system with the RL VASI, distance remaining markers, and overrun markers be conducted. This testing should be in an area that represents the remote-siting situations in which this system will be used.

3. Testing of the LRAS system with the complete RL package should be tested with the additional components mentioned in item #2.

4. Additional work is needed to transition these units into active service. This work would cover USAF Radioisotope Committee licensing; normal, abnormal, and emergency handling procedures; and packaging for bulk shipment.

7. REFERENCES

1. T.H. Paprocki, *Evaluation of Radioluminescent Lighting System*, DOT/FAA/CT-TN84/89, FAA Tech Center.

2. USAF Airfield Survivability Test (SALTY DEMO), Spangdahlem, Federal Republic of Germany, April-May 1985.

3. J. M. Pfieffer and M. Arbona, *Radioluminescent Airfield Lighting System (RAFLIS) Test*, AD-TR-87-43, Eglin AFB, Fla., August 1987.

4. ANSI-N540, *Classification of Radioactive Self-Luminous Light Sources*, American National Standards Institute, New York, 1975.

5. *Code of Federal Regulations*, 49 CFR Parts 173.465 and 173.466.

6. P. Clark Souers, *Hydrogen Properties for Fusion Energy*, University of California Press, Calif., 1986.

Appendix A

SPECIFICATIONS FOR TRITIUM RADIOLUMINESCENT AIRFIELD LIGHTS

APPENDIX A

SPECIFICATION NO. TRLLIGHT 1.0
SPECIFICATIONS FOR TRITIUM RADIOLUMINESCENT AIRFIELD LIGHTS

Purpose

This specification is written to procure tritium radioluminescent (RL) airfield lights.

Definitions

The following definitions apply for this specification:

a. Tube - a tube is a phosphor-coated, tritium-filled, light source.

b. Fixture - a fixture is an array of tubes. It includes the outer protective covers, mounting brackets, and supports for the tubes.

c. Mounting Device - a mounting device is a breakaway device used to mount and support the light fixture on an airfield.

General Requirements

The fixture and fixture-mounting device will have the following characteristics:

a. It is to be bi-directional or omnidirectional.

b. The fixture mounting device shall be equipped with frangible couplings on the bottom end. The couplings shall meet FAA specifications and be listed in FAA Circular 150/5345-1.

c. All metal parts will be either aluminum or titanium. Neither the fixture nor the mounting device shall contain ferrous metal parts.

d. A single fixture shall contain no more than 1000 Ci.

e. The mounting device containing one or more fixtures shall be a minimum 18 in. high and a maximum of 24 in. above ground level. All fixtures shall be the same height.

f. All licenses, general or site-specific, will be obtained by the manufacturer. He will be solely responsible for the entire package that will be presented to the U.S. Nuclear Regulatory Commission or state equivalent, if required.

g. The light loss through the outer clear cover or shell of the fixture shall be no more than 10% of the initial light output of the tube and grow to no more than 20% in 8 years. The outer cover shall be coated to resist moisture absorption.

h. The fixtures will be serially numbered and labeled in accordance with all U.S. Nuclear Regulatory Commission or state requirements and shall meet all NRC and/or state licensing requirements.

i. The fixtures will be labeled and packaged for shipment in nonreturnable Type A packages in accordance with U.S. Department of Transportation regulations, Code of Federal Regulations, Title 49.

j. The fixtures shall be watertight at 5 psig in water.

k. Six sets of detailed drawings shall be provided to the company.

l. Each fixture shall have white reflective tape around the outline of its shape. The tape shall be 4.4 cm (1.75 in.) wide.

Light Output Requirements

NOTE: Measurements to demonstrate all light output requirements are to be made 80 d after initial loading of tubes with tritium.

a. The brightness of the tube surface shall be measured for each tube. This brightness shall be a minimum of 1.25 cd/m^2 as measured with a recently calibrated Minolta 1° luminescent meter or its equivalent as approved by the company.

b. The luminous intensity of the fixture shall be measured at 0° and 45° angles from the frontal, head-on direction from a distance of at least 10 times the largest dimension of the light source. The minimum luminous intensity will be 0.190 and 0.135 cd, respectively, as measured with a recently calibrated EG&G Model 550 photometer or its equivalent as approved by the company.

Testing Requirements

Documentation of the test results is required to be submitted to the company. Tests 2 through 5 may be performed on dummy (nonradioactive) fixtures.

1. **American National Standard N540.** (Classification of Radioactive Self-Luminous Light Sources).

   - Test level 4 shall be performed to obtain discoloration, temperature, thermal shock, pressure (reduced), vibration, and immersion data.

- The impact test will be a special trial experiment consisting of a free fall to a steel plate 22 times from a height of 2 m.

2. **Rough Handling Test.** (ASTM-D775, Drop Test for Shipping Containers). The purpose of this test is to determine the fixture's capability to withstand rough handling and the ability of the envelope to protect the tritium-filled glass tubes. This test will apply to the fixture itself, not to the shipping package.

3. **Abrasion Test.** (ASTM-D658, Test for Abrasion Resistance of Coatings of Paint, Varnish, Lacquer, and Related Products with the Abrasion Tester). The clear covering of the fixture shall be capable of protecting the fixture against adverse effects on its surface. No light loss through the protective outer surface of the fixture will be allowed as a result of this test.

4. **Temperature and Humidity Cycle Test.** This test shall be conducted in accordance with Military Standard 810C, "Environmental Test Methods," Method 518.1 "Temperature-Humidity-Altitude." The altitude portion of the test will not be conducted, as the fixtures will be used at ground level. The fixtures shall be subjected to the cycle of tests at 70°C (160°F) at 69% humidity to -54°C (-65°F) at 0% humidity.

5. **Leakage Test.** The fixture shall be demonstrated to be leak tight at a pressure of 5 psig in water.

Phosphor Requirements

The phosphor used in the tritium radioluminescent airfield lights will be **GTE Sylvania Type 1260.**

Any substitution of this phosphor will be made only with written approval from the company. Better, more-efficient phosphors are always desirable. If one is to be substituted, the seller shall submit samples and sufficient data to the company to demonstrate the superiority of the phosphor to be substituted at the time of delivery of the prototype.

Construction Materials

Construction materials are limited only in that all materials must meet general structural integrity requirements of the testing program without loss of tritium or breakage of the tubes. No ferrous metals will be allowed in construction of the fixtures. Metal parts will be limited to aluminum and its alloys and titanium.

Quality Assurance During Manufacturing

The following quality assurance (QA) checks will be made during the manufacture of the tritium RL airfield lights. The enclosed Oak Ridge National Laboratory (ORNL) procedures may be used, or the seller may submit his own procedures, with his offer, for approval by the company.

1. **Thermal Shock Test of As-Received Glass Tubes**
   (ORNL Procedure No. IP-204A).
   100% testing requirement

2. **Internal Pressure Test of Glass Tubes**
   (ORNL Procedure No. IP-204D).
   100% testing requirement

3. **Phosphor-Coating Adherence Check**
   (ORNL Procedure No. IP-204F).
   100% testing requirement

4. **Vacuum Drying of Tubes and Storage of Phosphor-Coated Tubes**
   (Steps 2 through 5 of ORNL Procedure No. IP-204G - Tritium Filling Tube Neck-Down).
   100% testing requirement

5. **Water Check on Tritium Gas.** Tritium gas loaded into the RL airfield lights shall not contain more than 0.04% total of water and tritiated water. This shall be determined by mass spectrographic analysis either by the supplier of the gas or tests at the seller's plant. The company must be satisfied that all due precaution is undertaken to prevent water from entering the system at all times.

6. **Oil-Free Tritium.** The seller shall certify that the tritium loaded into the RL airfield lights is oil-free.

7. **Thermal Shock Test of Tritium-Filled Tubes**
   (ORNL Procedure No. IP-204H).
   100% testing requirement

8. **Leak Check of Filled Light Source Tubes by H_2O Leach.** This procedure will be performed in accordance with ANSI N540, Section 8.3.2.

9. **Light Measurement of Completed Tubes.** The surface brightness of the tube and the light output for each fixture must be measured. Since some light decay occurs during the first 80 d after initial manufacture, a light measurement will be made on each tube, before assembly into a light fixture, on the 30th d after manufacture. This light measurement must be equal to, or greater than, that specified in Light Output Requirements above; 100% testing is required. ORNL Procedure No. IP-204J is enclosed. This procedure is for an EG&G Model 550 photometer. An approved equivalent photometer is acceptable.

Performance and Acceptance Tests to Be Performed by Company

The company reserves the right to visit the seller's plant before award of any subcontract, to ensure that the capability exists to manufacture lights in accordance with these specifications. The company also reserves the right to visit the seller's plant during the manufacturing process to observe and to ensure that work quality and testing are being performed as specified herein.

The company also will perform certain acceptance tests. These will include:

1. visual inspection of the quality of workmanship of the completed units,
2. leak tests as necessary,
3. light measurements, and
4. review of all certification documentation.

Warranty

In accordance with the warranty terms and conditions, a light source is defined as "failed" if its light output falls more than 15% below the average of the group of sources purchased at the same time or it loses more than 8% of its luminous intensity over a 1-year period.

Appendix B

PERSONNEL DOSE CALCULATIONS

APPENDIX B

Calculation of Dose from HTO in Tritium Airfield Edge Light in Postulated Storage Facility Fire Accident Scenario

Calculation of Dose from HTO in Tritium Airfield Edge Light in Postulated Indoor Accident Scenario

Calculation of Dose from HTO in Postulated Warehouse Accident Scenario

Calculation of Dose from HTO in Tritium Light Panel in Postulated Outdoor or Runway Accident Scenario

Dose from HTO in Tritium Light Panel in Postulated C-130 Aircraft Release

Dose to an Individual from Tritium Released by Diffusion Through Glass Tubes while Lights are in Storage

Release of Tritium through Glass Tubes from Radioluminescent Lights

Computer Program Used to Calculate Downwind Tritium Concentration after Release of Material from Airfield Edge Lights in a Fire Situation

Computer Program Used to Calculate Downwind Tritium Concentration after Release of Material from Six Airfield Edge Marker Lights at Ground Level

Calculation of Dose from HTO in Tritium Airfield Edge Light in Postulated Storage Facility Fire Accident Scenario

The internal dosimetry of an intake of tritiated water (HTO) associated with a postulated storage facility fire with subsequent release of tritium has been assessed. The assessment is highly speculative and unquestionably represents a worst-case situation. Actual doses are expected to be much less than the calculated value.

The following assumptions apply to this assessment:

1. The total tritium activity per light is 996 Ci. The maximum number of edge lights at any one storage location is 250, and all tubes are broken for a release of 249,000 Ci (total). There are six tubes, each containing 166 Ci in each edge light.

2. The concentration of tritium in the atmosphere is 2.89×10^{-2} $\mu Ci/cm^3$, which occurs at a distance of 500.0 m downwind from the release point and results from diffusion of the tritium upon breakage of all the tubes in the 250 edge lights. The release is assumed to occur over a 1-h period. (The computer program used in making the calculations of this concentration is included in this appendix.) The calculations are made using the Gaussian diffusion plume model presented in "Meteorology and Atomic Energy 1968," edited by David H. Slade of the Air Resources Laboratories.)

3. The plume release height of the fire is assumed to be 50.0 m. (This is consistent with the reported plume height of the storage facility fire in Alaska for the fall of 1987.)

4. The wind velocity is assumed to be 3.0 mph, which results in an atmospheric stability condition "C," moderately unstable.

5. The fraction of the released tritium present as HTO or tritium oxide (TTO) is 100%, which assumes that all the tritium is converted to the oxide form as a result of the fire.

6. The standard man occupational breathing rate of 9.6×10^3 L (3.33×10^2 cm^3/s) in the occupational 8-h day applies (i.e., no heavy breathing occurs).

7. The accuracy of the calculation is probably +0, -100% but cannot be fully assessed without a meaningful experimental study of the situation.

With these assumptions and data, we can calculate the quantity (microcuries) of tritium inhaled as HTO or TTO.

Therefore, we calculate

$$QI = (C_a)(fw)(BR)(t),$$

where

QI = quantity inhaled (μCi),

C_a = log-mean concentration (μCi/cm^3),

fw = fraction of tritium present as HTO or TTO (1.0),

BR = breathing rate (cm^3/s),

t = exposure time (s).

Therefore,

$$QI = (2.89 \times 10^{-2})(1.0)(3.33 \times 10^{2})(3600.0),$$

$$= 3.46 \times 10^{4}\ \mu Ci.$$

The calculation of the 50-year committed dose is made using tabulated values from NUREG/CR-0150 (ORNL/NUREG/TM-190), "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel Facilities," by G. G. Killough, D. E. Dunning, Jr., S. R. Bernard, and J. C. Pleasant, June 1978. The Inhalation Dose Conversion Factor (IDCF) also accounts for absorption of HTO or TTO through the skin. For every microcurie inhaled, 0.5 μCi is absorbed through the skin.

Thus,

$$D(50) = (IDCF)(QI),$$

where

D(50) = 50-year committed dose (rem),

IDCF = inhalation dose conversion factor (rem/μCi),

QI = quantity inhaled (μCi).

The maximum dose to any organ in the body is to the Res lymph*:

$$D(50) = (2.48 \times 10^{-4})(3.46 \times 10^{4}),$$

$$= 8.58 \text{ rem.}$$

The dose to the total body is:

$$D(50) = (1.25 \times 10^{-4})(3.46 \times 10^{4}),$$

$$= 4.33 \text{ rem.}$$

The IDCF values for other areas of the body are presented below:

Organ	IDCF (rem/μCi inhaled)
Lungs	1.25×10^{-4}
Res lymph	2.48×10^{-4}
Total body	1.25×10^{-4}
Liver	1.24×10^{-4}
Bone	5.57×10^{-5}
Red marrow	1.24×10^{-4}
Endosteal cells	9.85×10^{-5}
Thyroid	1.24×10^{-4}
Testes	1.25×10^{-4}

The dose estimates above assume no oxidation of HT or TT to HTO or TTO during the exposure and that internal exposure from HT or TT is negligible. [The ratio of dose rate in a cloud of HT compared with the dose rate of HTO is 1×10^{-4}, as discussed by Pinson and Langham, "Physiology and Toxicology of Tritium in Man," J. Appl. Physiol., **10**, 108, (1957).]

The dose to the lymph system is equivalent to 1.72 times the annual dose allowed a radiation worker. The dose to the total body is approximately equivalent to 87% of the annual allowable dose for a radiation worker, which is roughly comparable to 87 chest X-rays.

This calculation is very conservative in that it assumes the individual will remain in the exact area of maximum concentration for the entire period of the release (1 h).

*reticuloendothial lymph system

Calculation of Dose from HTO in Tritium Airfield Edge Light in Postulated Indoor Accident Scenario

The internal dosimetry of an intake of HTO associated with a postulated indoor accident and subsequent breakage of a tritium airfield edge light has been assessed. The assessment is highly speculative and represents a worst-case scenario. Actual doses are expected to be much less than the calculated value.

The following assumptions apply to this assessment:

1. The total tritium activity is 996 Ci, and all tubes are broken.

2. The instantaneous concentration of tritium in the room is 32.5 $\mu Ci/cm^3$, resulting from diffusion of the tritium upon breakage of all the tubes.

3. The room size is 9 x 15 x 8 ft i.e., large enough to have a party or bar in the room (much smaller than most work areas in which the units are likely to be stored or assembly would take place).

4. The air circulation from all sources is equivalent to one change per hour.

5. The fraction of the released tritium present as HTO or TTO is 0.04%, which is twice the amount as is shown in a typical tritium product analysis. No oxidation of HT or TT takes place. The absorption of HT or TT into water or alcohol present is negligible.

6. The standard man occupational breathing rate of 9.6 x 10^3 L (3.33 x 10^3 cm^2/s) in the occupational 8-h day applies (i.e., no heavy breathing occurs).

7. Once the concentration of tritium in the room has been reduced to 10% of the initial concentration, it is assumed the room has been cleared of people and/or the tritium.

8. No factors are applied to compensate for more than one person being in the room (i.e., the movement and breathing of a large number of people would tend to disperse the material and lower the concentration).

9. The accuracy of the calculation is probably +0, -100% but cannot be fully assessed without a meaningful experimental study of the situation.

Quantity Inhaled

$$QI = (C_a)(fw)(BR)(t),$$

where

QI = quantity inhaled (μCi);

C_a = total tritium concentration (μCi/cm^3), i.e., average room concentration;

fw = fraction of the tritium present as HTO or TTO;

BR = breathing rate during the exposure (cm^3/s);

t = exposure time (s).

The time required to achieve a concentration equal to 10% of the initial concentration is calculated by the following relationship:

$$\ln C_t - \ln C_o = (-F/V_m)(t),$$

where

C_o = initial concentration (μCi/cm^3),

C_t = concentration at time t (μCi/cm^3),

F = flow rate in room (cm^3/s),

V_m = mean volume of room (cm^3),

t = time (s).

Since C_t is 0.1 C_o, the time required for this condition to occur can be calculated as follows:

$$t = (V_m)(\ln 0.1)/(-F),$$

$$C_o = QR/V_m,$$

where

QR = quantity released (μCi),

V_m = room volume (cm^3).

Therefore,

$C_o = 9.96 \times 10^8 / 3.06 \times 10^7$,

$= 32.5$ Ci/cm^3,

and

$C_t = 0.1\ C_o = 3.25\ \mu$Ci/cm^3,

and

$F = 3.06 \times 10^7 / 3.6 \times 10^3 = 8.5 \times 10^3$ cm^3/s,

$t = (3.06 \times 10^7)(\ln 0.1)/(-8.5 \times 10^3)$,

$t = 8.284 \times 10^3$ s (2.3 h).

The log mean concentration is obtained by the following equation:

$C_a = (C_o - C_t)/[\ln (C_o/C_t)]$,

$= (32.5 - 3.25)/\ln 10$,

$= 12.7\ \mu$Ci/cm^3.

Therefore, we calculate

$QI = (C_a)(fw)(BR)(t)$,

where

QI = quantity inhaled (μCi),

C_a = log mean concentration (μCi/cm^3),

fw = fraction of tritium present as HTO or TTO,

B = breathing rate (cm^3/s),

t = exposure time (s).

Therefore,

$QI = (12.7)(4.0 \times 10^{-4})(3.33 \times 10^2)(8.284 \times 10^3)$,

$= 1.401 \times 10^4\ \mu$Ci.

The calculation of 50-year committed dose is made using tabulated values from NUREG/CR-0150, ORNL/NUREG/TM-190, "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel Facilities," by G. G. Killough, D. E. Dunning, Jr., S. R. Bernard, and J. C. Pleasant, June 1978. The Inhalation Dose Conversion Factor (IDCF) also accounts for absorption of HTO or TTO through the skin. For every microcurie inhaled, 0.5 μCi is absorbed through the skin.

Thus,

$$D(50) = (IDCF)(QI),$$

where

$D(50)$ = 50-year committed dose (rem),

$IDCF$ = inhalation dose conversion factor (rem/μCi),

QI = quantity inhaled (μCi).

The maximum dose for any organ in the body is to the Res lymph:

$$D(50) = (2.48 \times 10^{-4})(1.401 \times 10^{4}),$$

$$= 3.47 \text{ rem.}$$

The dose to the total body is:

$$D(50) = (1.25 \times 10^{-4})(1.401 \times 10^{4})$$

$$= 1.75 \text{ rem.}$$

The Inhalation Dose Conversion Factors (IDCFs) for other organs of the body are given below:

Organ	IDCF (rem/μCi inhaled)
Lungs	1.25×10^{-4}
Res lymph	2.48×10^{-4}
Total body	1.25×10^{-4}
Liver	1.24×10^{-4}
Bone	5.57×10^{-5}
Red marrow	1.24×10^{-4}
Endosteal cells	9.85×10^{-5}
Thyroid	1.24×10^{-4}
Testes	1.25×10^{-4}

The dose estimates above assume that there is no oxidation of HT or TT to HTO or TTO during the exposure and that internal exposure from HT or TT is negligible. [The ratio of the dose rate in a cloud of HT compared with the dose rate of HTO is 1×10^{-4} as discussed by Pinson and Langham in "Physiology and Toxicology of Tritium in Man," J. Appl. Physiol., 10, 108, (1957).]

This dose to the lymph system is equivalent to 70% of the annual dose allowed a radiation worker. The dose to the total body is equivalent to approximately 35% of the annual dose allowed a radiation worker and roughly equal to 35 chest X rays.

This calculation is very conservative since it assumes that the individual will remain in the room for 2.3 h after breakage occurs.

Calculation of Dose from HTO in Postulated Warehouse Accident Scenario

The internal dosimetry of an intake of HTO associated with a postulated warehouse accident and subsequent breakage of six tritium airfield lights has been assessed. The assessment is speculative and represents a worst-case scenario. Actual doses are expected to be much less than the calculated value.

The following assumptions apply to this assessment:

1. The total tritium activity in 6 lights is 5976 Ci, and all 6 tubes in each of the 6 lights are broken.

2. The instantaneous concentration of tritium in the warehouse area is 43.9 μCi/cm^3, resulting from diffusion of the tritium upon breakage of all the tubes.

3. The warehouse area size is 20 x 20 x 12 ft (smaller than most work areas in which the units are likely to be stored or assembly would take place).

4. The air circulation from all sources is equivalent to five changes per hour.

5. The fraction of the released tritium present as HTO or TTO is 0.04%, which is twice the amount as is shown in a typical tritium product analysis. No oxidation of HT or TT takes place. The absorption of HT or TT into water present is negligible.

6. The standard man occupational breathing rate of 9.6 x 10^3 L (3.33 x 10^2 cm^3/s) in the occupational 8-h day applies (i.e., no heavy breathing occurs).

7. Once the concentration of tritium in the room has been reduced to 10% of the initial concentration, it is assumed that the area has been cleared of people and/or the tritium.

8. No factors are applied to compensate for more than one person or activity being in the area (i.e., the movement and breathing of several people would tend to disperse the material and lower the concentration).

9. The accuracy of the calculation is probably +0, -100% but cannot be fully assessed without a meaningful experimental study of the situation.

With these assumptions and data, the quantity (microcuries) of tritium inhaled as HTO or TTO can be calculated.

Thus,

$$QI = (C)(fw)(BR)(t),$$

where

QI = quantity inhaled (μCi),

C_a = total tritium concentration (μCi/cm^3); i.e., average room concentration;

fw = fraction of the tritium present as HTO or TTO;

BR = breathing rate during the exposure (cm^3/s);

t = exposure time (s).

The time required to achieve a concentration of 10% of the initial concentration is calculated by the following relationship:

$$\ln C_t - \ln C_o = (-F/V_m)(t),$$

where

C_o = initial concentration (μCi/cm^3),

C_t = concentration at time t (μCi/cm^3),

F = flow rate in room (cm^3/s),

V_m = mean volume of room (cm^3),

t = time (s).

Since C_t is 0.1 C_o, the time required for this condition to occur can be calculated as follows:

$$t = (V_m)(\ln 0.1)/(-F),$$

$$C_o = QR/V_m,$$

where

QR = quantity released (μCi)

V_m = room volume (cm^3).

Therefore,

$C_o = 5.976 \times 10^9 / 1.36 \times 10^8 = 43.9\ \mu Ci/cm^3$.

and,

$C_t = 0.1\ C_o = 4.39\ \mu Ci/cm^3$,

and

$F = 1.36 \times 10^8 / 7.2 \times 10^2 = 1.89 \times 10^5\ cm^3/s$,

$t = (1.36 \times 10^8)(\ln 0.1)/(-1.89 \times 10^5)$,

$= 1.657 \times 10^3$ s (0.46 h).

The log mean concentration is obtained by the following equation:

$C_a = (C_o - C_t)/[\ln (C_o/C_t)]$,

$= (43.9 - 4.39)/\ln 10$,

$= 17.16\ \mu Ci/cm^3$.

Therefore, we calculate

$QI = (Ca)(fw)(BR)(t)$,

where

QI = quantity inhaled (μCi),

C_a = log mean concentration ($\mu Ci/cm^3$),

fw = fraction of tritium present as HTO or TTO,

BR = breathing rate (cm^3/s),

t = exposure time (s).

Thus,

$QI = (17.16)(4.0 \times 10^{-4})(3.33 \times 10^2)(1.657 \times 10^3)$,

$= 3.79 \times 10^3\ \mu Ci$.

The calculation of a 50-year committed dose is made using tabulated values from NUREG/CR-0150, ORNL/NUREG/TM-190, "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel Facilities," by G. G. Killough, D. E. Dunning, Jr., S. R. Bernard, and J. C. Pleasant, June 1978. The Inhalation Dose Conversion Factor (IDCF) also accounts for absorption of HTO or TTO through the skin. For every microcurie inhaled, 0.5 μCi is absorbed through the skin.

$$D(50) = (IDCF)(QI),$$

where

D(50) = 50-year committed dose (rem),

IDCF = inhalation dose conversion factor (rem/μCi),

QI = quantity inhaled (μCi).

The maximum dose any organ in the body is to the Res lymph:

$$D(50) = (2.48 \times 10^{-4})(3.79 \times 10^{3}),$$

$$= 0.94 \text{ rem.}$$

The dose to the total body is:

$$D(50) = (1.25 \times 10^{-4})(3.79 \times 10^{3})$$

$$= 0.47 \text{ rem.}$$

The Inhalation Dose Conversion Factors (ICDFs) for other organs of the body are given below:

Organ	IDCF (rem/μCi inhaled)
Lungs	1.25×10^{-4}
Res lymph	2.48×10^{-4}
Total body	1.25×10^{-4}
Liver	1.24×10^{-4}
Bone	5.57×10^{-5}
Red marrow	1.24×10^{-4}
Endosteal cells	9.85×10^{-5}
Thyroid	1.24×10^{-4}
Testes	1.25×10^{-4}

The dose estimates above assume that there is no oxidation of HT or TT to HTO or TTO during the exposure and that internal exposure from HT or TT is negligible. [The ratio of the dose rate in a cloud of HT compared with the dose rate of HTO is 1 x 10^{-4} as discussed by Pinson and Langham, "Physiology and Toxicology of Tritium in Man," J. Appl. Physiol., **10**, 108, (1957)].

This dose to the lymph system is equivalent to one-fifth the annual dose allowed a radiation worker. The dose to the total body is equivalent to approximately one-tenth the annual dose allowed a radiation worker and approximately equivalent to ten chest X rays.

This calculation is very conservative in that it assumes that the individual will remain in the area for approximately 0.5 h after breakage occurs.

Calculation of Dose from HTO in Tritium Light Panel in Postulated Outdoor or Runway Accident Scenario

The internal dosimetry of an intake of HTO associated with a postulated outdoor accident and subsequent breakage of six tritium runway edge lights has been assessed. The assessment is highly speculative and unquestionably represents a worst-case situation. Actual doses are expected to be much less than the calculated value.

The following assumptions apply to this assessment:

1. The total tritium activity per edge light is 996 Ci. The maximum number of lights broken at any one location on the runway is 6, and all tubes are broken for a total release of 5976 Ci. There are 6 tubes, each containing 166 Ci of tritium in each light.

2. The instantaneous concentration of tritium in the atmosphere is 6.66×10^2 $\mu Ci/cm^3$, which occurs at a distance of 10.0 m downwind from the release point and results from diffusion of the tritium upon breakage of all the tubes in the six signs. (Calculations supporting this concentration are attached. The calculations are made using the diffusion plume model presented in "Meteorology and Atomic Energy 1968," edited by David H. Slade of the Air Resources Laboratories).

3. The release height is assumed to be 1.0 m.

4. The wind velocity is assumed to be 3.0 mph, which results in an atmospheric stability condition "C"— moderately unstable.

5. The fraction of the released tritium present as HTO or TTO is 0.04%, which is twice the amount as is shown in a typical tritium product analysis. No oxidation of HT or TT takes place. The absorption of HT or TT into the atmospheric water present is negligible.

6. The standard man occupational breathing rate of 9.6×10^3 L (3.33×10^2 cm^3/s) in the occupational 8-h day applies (i.e., no heavy breathing occurs).

7. The accuracy of the calculation is probably +0, -100% but cannot be fully assessed without a meaningful experimental study of the situation.

With these assumptions and data, we can calculate the quantity (microcuries) of tritium inhaled as HTO or TTO.

Therefore,

$$QI = (C_a)(fw)(BR)(t),$$

where

QI = quantity inhaled (μCi),

C_a = concentration of tritium in the air (μCi/cm^3),

fw = fraction of tritium present as HTO or TTO,

BR = breathing rate (cm^3/s),

t = exposure time (s).

Therefore,

$$QI = (6.66 \times 10^{2})(4.0 \times 10^{-4})(3.33 \times 10^{2})(60.0),$$

$$= 5.323 \times 10^{3}\ \mu Ci.$$

The calculation of 50-year committed dose is made using tabulated values from NUREG/CR-0150, ORNL/NUREG/TM-190, "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel Facilities," by G. G. Killough, D. E. Dunning, Jr., S. R. Bernard, and J. C. Pleasant, June 1978. The Inhalation Dose Conversion Factor (IDCF) also accounts for absorption of HTO or TTO through the skin. For every μCi inhaled, 0.5 μCi is absorbed through the skin.

Thus,

$$D(50) = (IDCF)(QI),$$

where

D(50) = 50-year committed dose (rem),

IDCF = inhalation dose conversion factor (rem/μCi),

QI = quantity inhaled (μCi).

The maximum dose to any organ in the body is to the Res lymph:

$$D(50) = (2.48 \times 10^{-4})(5.323 \times 10^{3})$$

$$= 1.32 \text{ rem.}$$

The dose to the total body is:

$$D(50) = (1.25 \times 10^{-4})(5.323 \times 10^{3})$$

$$= 0.665 \text{ rem.}$$

The Inhalation Dose Conversion Factors for other areas of the body are presented below:

Organ	IDCF (rem/μCi inhaled)
Lungs	1.25×10^{-4}
Res lymph	2.48×10^{-4}
Total body	1.25×10^{-4}
Liver	1.24×10^{-4}
Bone	5.57×10^{-5}
Red marrow	1.24×10^{-4}
Endosteal cells	9.85×10^{-5}
Thyroid	1.24×10^{-4}
Testes	1.25×10^{-4}

These dose estimates assume no oxidation of HT or TT to HTO or TTO during the exposure and that internal exposure from HT or TT is negligible. [The ratio of dose rate in a cloud of HT compared with the dose rate of HTO is 1×10^{-4} as discussed by Pinson and Langham, "Physiology and Toxicology of Tritium in Man," J. Appl. Physiol., **10**, 108, (1957).]

The dose to the lymph system is equivalent to 26% of the annual dose allowed a radiation worker. The dose to the total body is approximately equivalent to 13% of the annual dose allowed a radiation worker and approximately equivalent to 13 chest X rays.

This calculation is very conservative in that it assumes that the individual will remain in the exact area of maximum concentration for the entire period.

Dose From HTO in Tritium Light Panel in Postulated C-130 Aircraft Release

The internal dosimetry of an intake of HTO associated with a postulated release of tritium from a six-tube tritium light panel in the cargo section of a C-130 aircraft has been assessed. The assessment is speculative and represents a worst-case situation. Actual doses are expected to be less than the calculated value.

The following assumptions apply to this assessment:

1. The total tritium activity is 996 Ci (166 Ci/tube), and all tubes are broken.
2. The instantaneous concentration of tritium in the aircraft is 7.3 μCi/cm^3, resulting from diffusion of the tritium upon breakage of all the tubes.
3. The cargo section of the aircraft is 10 x 12 x 40 ft.
4. The air circulation from all sources is equivalent to ten changes per hour.
5. The fraction of the released tritium present as HTO or TTO is 0.04%. No oxidation of HT or TT takes place. (The 0.04% is actually twice that normally experienced in tritium products distributed by ORNL.)
6. The standard man occupational breathing rate of 9600 L in the occupational 8-h day applies (i.e., no heavy breathing occurs).
7. Once the concentration in the aircraft reaches 10% of the initial concentration, it is assumed that the aircraft has been cleared of people and/or the tritium.
8. No factors are applied to compensate for more than one person being in the aircraft (i.e., the movement and breathing of a large number of people would tend to disperse the material and lower the concentration).
9. The accuracy of the calculation is probably +0%, -100% but cannot be fully assessed without a meaningful experimental study of the situation.

With these assumptions and data, the quantity (μCi) of tritium inhaled as HTO or TTO can be calculated as follows:

$$QI = (C_a)(fw)(BR)(t),$$

where

QI = quantity inhaled (μCi),

C_a = total tritium concentration (μCi/cm^3); i.e., average room concentration,

fw = fraction of the tritium present as HTO or TTO,

BR = breathing rate during the exposure (cm^3/s),

t = exposure time(s).

The time required to achieve a concentration of 10% of the initial concentration is calculated by the following relationship:

$$\ln C_t - \ln C_o = (-F/V_m)(t),$$

where

C_o = initial concentration ($\mu Ci/cm^3$),

C_t = concentration at time ($\mu Ci/cm^3$),

F = flow rate in room (cm^3/s),

V_m = mean volume of room (cm^3),

t = time (s).

Since C_t is 0.1 C_o, the time required for this condition to occur can be calculated as follows:

$$t = (V_m)(\ln 0.1)/(-F),$$

$$C_o = QR/V_m,$$

where

QR = quantity released (μCi),

V_m = room volume (cm^3).

Therefore

$$C_o = 9.96 \times 10^8/1.36 \times 10^8,$$

$$C_o = 7.32\ \mu Ci/cm^3,$$

$$C_t = 0.1\ Co = 0.732\ \mu Ci/cm^3,$$

and

$$F = (10)(1.36 \times 10^{8})/3.6 \times 10^{3} = 3.78 \times 10^{5}\ cm^3/s,$$

$$t = (1.36 \times 10^{8})(\ln 0.1)/(-3.78 \times 10^{5}),$$

$$t = 8.284 \times 10^{2}\ s\ (0.23\ h).$$

The log mean concentration is obtained by the following equation:

$$C_a = (C_o - C_t)/[\ln (C_o/C_t)],$$

$$= (7.32 - 0.732)/\ln 10,$$

$$= 2.86\ \mu Ci/cm^3.$$

Therefore, we calculate

$$QI = (C_a)(fw)(BR)(t),$$

where

QI = quantity inhaled (μCi),

C_a = log mean concentration ($\mu Ci/cm^3$),

fw = fraction of tritium present as HTO or TTO,

BR = breathing rate (cm^3/s),

t = exposure time (s).

Thus,

$$QI = (2.86)(4.0 \times 10^{-4})(3.33 \times 10^{2})(8.284 \times 10^{2}),$$

$$= 3.16 \times 10^{2}\mu Ci.$$

The calculation of 50-year committed dose is made using tabulated values from NUREG/CR-0150 (ORNL/NUREG/TM-190), "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel Facilities," by G. G. Killough, D. E. Dunning, Jr., S. R. Bernard, and J. C. Pleasant, June 1978. The Inhalation Dose Conversion (IDCF) also accounts for absorption of HTO or TTO through the skin. For every microcurie inhaled, 0.5 μCi is absorbed through the skin.

$D(50) = (IDCF)(QI)$,

where

$D(50)$ = 50-year committed dose (rem),

$IDCF$ = inhalation dose conversion factor (rem/μCi),

QI = quantity inhaled (μCi).

The maximum dose to any organ in the body is to the Res lymph:

$D(50) = (2.48 \times 10^{-4})(3.16 \times 10^{2})$,

$= 0.078$ rem (78 mrem).

The dose to the total body is:

$D(50) = (1.25 \times 10^{-4})(3.16 \times 10^{2})$,

$= 0.04$ rem (40 mrem).

The IDCFs for other organs of the body are given below:

Organ	IDCF (rem/μCi inhaled)
Lungs	1.25×10^{-4}
Res lymph	2.48×10^{-4}
Total body	1.25×10^{-4}
Liver	1.24×10^{-4}
Bone	5.57×10^{-5}
Red marrow	1.24×10^{-4}
Endosteal cells	9.85×10^{-5}
Thyroid	1.24×10^{-4}
Testes	1.25×10^{-4}

The dose estimates above assume that there is no oxidation of HT or TT to HTO or TTO during the exposure and that internal exposure from HT or TT is negligible. [The ratio of dose rate in a cloud of HT compared with the dose rate of HTO is 1×10^{-4} as discussed by Pinson and Langham, "Physiology and Toxicology of Tritium in Man," J. Appl. Physiol., **10**, 108, (1957).]

This dose to the lymph system is equivalent to 2% of the annual dose allowed a radiation worker. The dose to the total body is equivalent to approximately 1% of the annual dose allowed a radiation worker and approximately equivalent to one chest X ray.

Dose to an Individual From Tritium Released by Diffusion through Glass Tubes while Lights are in Storage

ASSUMPTIONS:

1. All 272 light panels are stored in one nonventilated storage room.

2. Storage room size is 9 x 15 x 8 ft. (This size is probably smaller than the typical storage area but is assumed for conservatism.)

3. Air circulation and natural ventilation are ignored.

4. The concentration of tritium in the room is assumed to be 4.3×10^{-7} $\mu Ci/cm^3$, resulting from diffusion of the tritium from the lights into the room during a 1-year period during which the lights and room were undisturbed.

5. The fraction of released tritium present as HTO or TTO is assumed to be 100% to allow for the absorption by and conversion to tritiated water over the long storage period.

6. The standard man occupational breathing rate of 9.6×10^3 L in the occupational 8-h day applies. This is equivalent to 3.33×10^2 cm^3/s.

7. No factors are applied to compensate for more than one person being in the room (i.e., the movement and breathing of several people would tend to disperse the material and lower the concentration).

8. The accuracy of the calculation is probably +0, -100% but cannot be fully assessed without a meaningful experimental study of the situation.

9. The total exposure time is assumed to be 1 h (3600 s).

With these assumptions and data, we can calculate the quantity (microcuries) of tritium inhaled as HTO or TTO:

$$QI = (C_a)(fw)(BR)(t),$$

where

QI = quantity inhaled, μCi;

C_a = total tritium concentration, $\mu Ci/cm^3$;

fw = fraction of the tritium present as HTO or TTO;

BR = breathing rate during the exposure, cm^3/s;

t = exposure time, s.

Therefore,

$QI = (4.3 \times 10^{-7})(1.0)(3.33 \times 10^{2})(3600)$

$= 0.52\ \mu Ci.$

The calculation of a 50-year committed dose is made using tabulated values from NUREG/CR-0150, ORNL/NUREG/TM-190, "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel Facilities," by G. G. Killough, D. E. Dunning, Jr., S. R. Bernard, and J. C. Pleasant, June 1978. The Inhalation Dose Conversion Factor (IDCF) also accounts for absorption of HTO or TTO through the skin. For every μCi inhaled, 0.5 μCi is absorbed through the skin.

$D(50) = (IDCF)(QI),$

where

D(50) = 50-year committed dose, rem;

IDCF = inhalation dose conversion factor, rem/μCi;

QI = quantity inhaled, μCi.

The maximum dose to any organ in the body is to the Res lymph:

$D(50) = (2.48 \times 10^{-4})(0.52)$

$= 1.3 \times 10^{-4}$ rem or 0.13 mrem.

The dose to the total body is:

$D(50) = (1.25 \times 10^{-4})(0.52)$

$= 6.5 \times 10^{-5}$ rem or 0.07 mrem.

The Inhalation Dose Conversion Factors (IDCFs) for other organs of the body are given below:

Organ	IDCF (rem/μCi inhaled)
Lungs	1.25×10^{-4}
Res lymph	2.48×10^{-4}
Total body	1.25×10^{-4}
Liver	1.24×10^{-4}
Bone	5.57×10^{-5}
Red marrow	1.24×10^{-4}
Endosteal cells	9.85×10^{-5}
Thyroid	1.24×10^{-4}
Testes	1.25×10^{-4}

This dose to the lymph system is very small and is considered inconsequential. It is very conservative in that it is assumed that no diffusion out of the storage area occurs during a 1-year period and that no dilution of the material occurs during the opening of the area. It also assumes that the individual will work in the area for 1 h with no previous "airing out" of the facility.

Release of Tritium through Glass Tubes from Radioluminescent Lights

ASSUMPTIONS:

1. The average temperature is 300°K (approximately 27°C, slightly warmer than normal room temperature).

2. The back diffusion, or back permeation pressure is 0.1 Pa. Actual pressure in the tube is less than 1 atm. The positive back permeation pressure has been determined by experimentation to be 7.0×10^{-6} Pa. This value is very conservative since the controls used in the experiment were within 5% of the actual samples.

$$P = k \times A \times T \times 1/t \times dP \times f,$$

where

P = permeation rate, mol/s;

k = permeation constant for hydrogen through Pyrex glass

= 3.6×10^{-17} mol/(m)(s)(Pa)(°K);

A = area, m^2;

T = temperature, °K;

t = thickness of glass, m;

dP = pressure differential, Pa;

f = factor to convert from hydrogen to tritium (ratio of molecular weights squared).

Therefore, for a typical RL light tube, we can calculate the diffusion for a period of time, as follows:

$$P = (3.6 \times 10^{-17})(0.021)(300)(1/1.6 \times 10^{-3})(7.0 \times 10^{-6})(4/36)$$

$$= 1.1025 \times 10^{-19} \text{ mol/s.}$$

The curies released per tube in 1 year can be calculated as follows:

$$C = P \times g \times SpA \times t \times f,$$

where

C = curies released per tube, Ci/unit time;

P = permeation rate, mol/s;

g = mol weight (6), g/mol;

SpA = specific activity (9640), Ci/g;

t = time, year;

f = conversion factor, s/year.

Therefore,

$C = (1.1025 \times 10^{-19})(6)(9640)(365)(24)(3600)$

$= 2.011 \times 10^{-7}$ Ci/year = 0.201 μCi/year.

Computer Program Used to Calculate Downwind Tritium Concentration after Release of Material From Airfield Edge Lights in a Fire Situation

```
C  DECEMBER 01, 1987
C  DOWNWIND TRITIUM CONCENTRATION AFTER RELEASE OF
MATERIAL
C  FROM 250 AIRFIELD EDGE LIGHTS EACH CONTAINING 996 CI
   IN A FIRE
C  SITUATION.
C  CALCULATION FOR ATMOSPHERIC STABILITY CONDITION "C",
C  SLIGHTLY UNSTABLE
C
C  Q = RELEASE RATE OF RADIONUCLIDE IN CURIES PER
SECOND
C
C  U = WIND VELOCITY IN METERS/SEC (3 MILES/HOUR=1.341 M/S)
C
C  H = PLUME HEIGHT IN METERS
C
      DIMENSION D(22),SIGZ(22),SIGY(22)
      DATA D/2.0,5.0,10.0,30.0,50.0,70.0,100.0,200.0,300.0,
C  400.0,500.0,600.0,800.0,1000.0,1200.0,1500.0,1750.0,
C  2000.0,2500.0,3000.0,4000.0,5000.0/
      DATA SIGZ/0.16,0.40,0.78,2.30,3.85,5.35,7.60,15.00,
C  22.00,30.00,36.50,42.00,53.50,66.00,74.50,94.50,105.00,
C  125.00,148.00,172.00,206.00,258.00/
      DATA SIGY/0.23,0.59,1.20,3.70,6.30,8.90,13.00,26.00,37.00,
C  48.00,61.0070.50,89.00,113.00,133.00,160.00,180.00,205.00,
C  250.00,295.00,378.00,463.00/
C
      DATA Q/69.2/,U/1.341/,H/50.0/
C
C
      WRITE(3,100)
C
C
100 FORMAT(1X,5X,'DISTANCE',6X,'DIFF.COEF.',
8X,'CONCENTRATION',/,
C  6X,'(METERS)',5X,'SIGZ  -  SIGY',8X,'MICROCI/CM3')
      DO 210 I=1,22
CHI=(Q/(3.14159*U*SIGZ(I)*SIGY(I)))*EXP(-(H**2/(2*(SIGZ(I)**2))))
C
      WRITE(3,205) D(I),SIGZ(I),SIGY(I),CHI
205 FORMAT(6X,F6.1,6X,F6.2,2X,F6.2,7X,E12.7)
C
210 CONTINUE
C
```

Computer Program Used to Calculate Downwind Tritium Concentration after Release of Material from Six Airfield Edge Marker Lights at Ground Level

```
  C  DECEMBER 01, 1987
  C  DOWNWIND TRITIUM CONCENTRATION AFTER RELEASE OF
MATERIAL
  C  FROM SIX AIRFIELD EDGE MARKER LIGHTS AT GROUND
LEVEL.
  C  CALCULATION IS FOR AN ATMOSPHERIC STABILITY
CONDITION "C",
  C  SLIGHTLY UNSTABLE
  C
  C  Q = RELEASE RATE OF RADIONUCLIDE IN CURIES PER
SECOND
  C
  C  U = WIND VELOCITY IN METERS/SEC (3 MILES/HOUR=1.341 M/S)
  C
  C  H = HEIGHT OF RELEASE IN METERS
  C
      DIMENSION D(22),SIGZ(22),SIGY(22)
      DATA D/2.0,5.0,10.0,30.0,50.0,70.0,100.0,200.0,300.0,
  C  400.0,500.0,600.0,800.0,1000.0,1200.0,1500.0,1750.0,
  C  2000.0,2500.0,3000.0,4000.0,5000.0/
      DATA SIGZ/0.16,0.40,0.78,2.30,3.85,5.35,7.60,15.00,
  C  22.00,30.00,36.50,42.00,53.50,66.00,74.50,94.50,105.00,
  C  125.00,148.00,172.00,206.00,258.00/
      DATA SIGY/0.23,0.59,1.20,3.70,6.30,8.90,13.00,26.00,37.00,
  C  48.00,61.00,70.50,89.00,113.00,133.00,160.00,180.00,205.00,
  C  250.00,295.00,378.00,463.00/
  C
      DATA Q/5976.0/,U/1.341/,H/1.0/
  C
  C
      WRITE(3,100)
  C
  C
  100 FORMAT(1X,5X,'DISTANCE',6X,'DIFF.
COEF.',8X,'CONCENTRATION',/,
  C  6X,'(METERS)',5X,'SIGZ      SIGY',8X,'MICROCI/CM3')
      DO 210 I=1,22
  CHI=(Q/(3.14159*U*SIGZ(I)*SIGY(I)))*EXP((H**2/(2*(SIGZ(I)**2))))
  C
      WRITE(3,205) D(I),SIGZ(I),SIGY(I),CHI
  205 FORMAT(6X,F6.1,6X,F6.2,2X,F6.2,7X,E12.7)
  C
  210 CONTINUE
  C
  STOP
  END
```

END

DATE FILMED

11/09/90