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Radioluminescent (RL) Lighting System Development Program

Final Report: October 1, 1987–March 31, 1989

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FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/TM-11648

Chemical Technology Division

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1. INTRODUCTION

The Oak Ridge National Laboratory (ORNL) has been actively engaged in the development of radioluminescent (RL) lights for the past 10 years. Primary emphasis of the program at ORNL has been on the development and improvement of gas-tube technology lights that have been manufactured by private industry for over 30 years. The primary use of these lights until this time has been "exit" signs with some small numbers of applications in other areas. The goal of the ORNL program has been to improve the light output and brightness of the lights to an acceptable level for use as airfield marker signs, runway lights, and taxiway lights. This goal has been achieved in that a greater than 100% light output has been obtained in commercial lights purchased for the U.S. Air Force (USAF)[1] and for the State of Florida.[2] Other potential uses for RL lights include emergency lighting in the holds or engine rooms of ships or warehouses, decorative lighting, highway information and street signs, and maritime signage along ship channels. 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 lighting systems are difficult to maintain.

The luminescent phenomenon[3] can be visualized in a usual semiconductor band theory wherein a valence band electron is excited into the conduction band. On subsequent return to the lower energy, or valence state, visible radiation is emitted as required by energy conservation. This implies a band gap on the order of 1 to 4 eV, or in the 400- to 700-nm region. The phosphors most generally used have trapping levels in the forbidden gap that allows persistence of light emission. Generally, it is assumed that these trapping levels capture electrons that have been raised to the conduction band. As a valence-trap transition is forbidden, the electron must be raised to the conduction band (possibly by thermal activity) and subsequently drop to the valence band and emit its characteristic radiation. It is also possible for the conduction-band-to-trapping-level transitions to emit visible radiation as confirmed by the fact that a number of phosphors emit several wavelengths. Thermal effects smear the forbidden gap and trapping levels over an energy region so that the emitted radiation is not monochromatic. The complete analysis of this phenomenon is complex and not well understood. Many compounds exhibit phosphorescence under beta radiation, and the conventionally used compounds are composed of elements shown in the periodic table as group IIB-VIA with closely controlled impurities of the IB and VA groups.

Human eye response to light is critically important when evaluating low-intensity RL lighting. The selection of a phosphor to maximize this response can determine the success or failure of the use situation. Human vision consists of the combined response of two types of sensing elements in the retina of the eye. The two types are rods and cones, which are present in varying ratios over the area of the retina;

however, there is a small high-resolution area near the center of the visual field (the fovea centralis) that contains only cones. The cones are responsible for the sensation of color, but the threshold for stimulation of the cones (photopic vision) is nearly 10 times higher than that required for stimulation of the rods (scotopic vision) by low-intensity blue light. Thus, at low brightness, dark-adapted (full dark acquisition requires approximately 45 min) extra-foveal vision is extremely sensitive in perceiving blue light but without perception of color. The peak of the scotopic luminosity function is at 507 nm, with an absolute conversion factor of 1746 scotopic lumens per watt (lm/W); the peak of the photopic luminosity function is at 555 nm, with an absolute conversion factor of 680 lm/W. The scotopic function is considered representative of eyes under 30 years old and for viewing at angles greater than 5° from the fovea. The human eye response is shown in Fig. 1. Phosphors for tritium RL lights with photon output wavelengths in the 500-600 nm range are usually selected. A more detailed discussion of this theory of light observation is given in Ref. 4 along with calculations on the conversion of energy to light for krypton light fixtures.

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. The work reported here is a summary of the improved gas-tube technology work and the initiation of work on a light source utilizing a solid matrix concept. Metal matrices were examined here because the ORNL Isotope Research Materials Laboratory (IRML) has had many years of experience in producing these materials for other research purposes. Other solid matrices have been and are being examined at other Department of Energy (DOE) laboratories including Pacific Northwest Laboratory (PNL), Sandia National Laboratory (SNL), and Mound Research Laboratories (MRL). A brief history of the ORNL gas-tube technology work is presented in this report as well as the report on work done on the solid matrix lights.

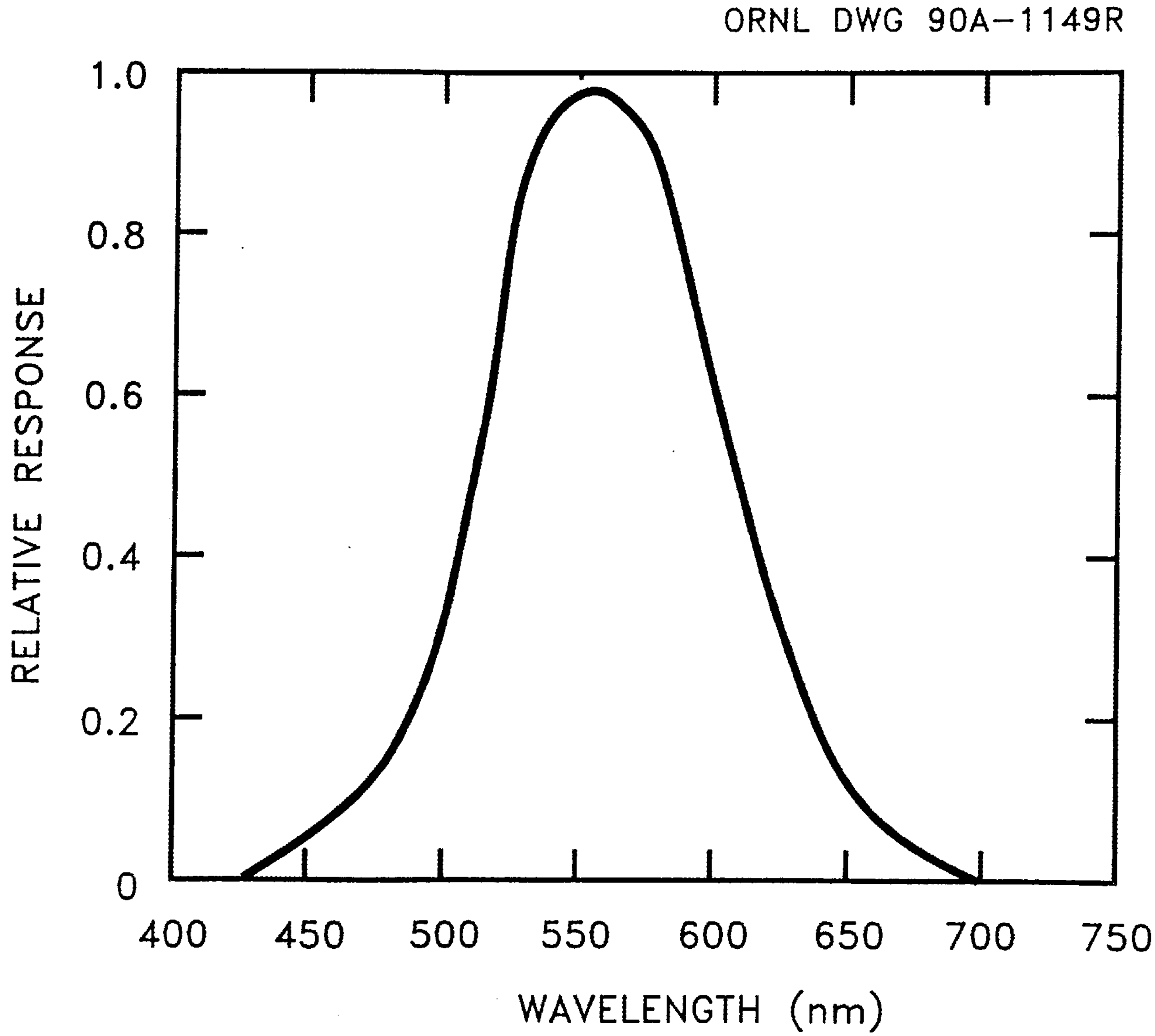

Fig. 1. Photopic response of human eye to light.

2. CHRONOLOGICAL HISTORY OF THE ORNL RL LIGHT PROGRAM

Work was initiated on the ORNL RL light program at the invitation of the DOE program manager in FY 1979. During this year, a liaison was established with the USAF, and a presentation was made to Air Force personnel at Andrews Air Force Base (AFB), Maryland. Initially, work was done on lights utilizing krypton-85 because of its promise of greater light output per unit area and volume. Work during the year concentrated on developing a granular phosphor technique to eliminate binders that held the phosphors in place and the attendant problems associated with binders discovered in work done at Battelle Memorial Institute.[5] U.S. Air Force financial participation in the program began in FY 1980. The work on krypton-85 lights continued in FY 1980 with development of light-pipes and shields designed to optimize light output and cut down on the weight of the units.[6] Shipping containers were designed for use with these lights during this period. These containers were very heavy and difficult to handle in field situations, and it was obvious that lighter systems would be needed. Subsequently, work was proposed for building tritium light systems to overcome the weight problems, and the first tritium light was built at ORNL in FY 1980.

In FY 1981, ORNL was tasked to fabricate krypton-85 taxiway markers and to demonstrate their utility. Work was continued on light-pipe development, especially on ways to increase light output and reduce losses. New designs for shields and reflectors for the krypton lights were made to further reduce weight and increase light output. Improvements of up to 225% increased light output were achieved by a combination of improved phosphors, improved reflectors and light-pipe designs, and source geometry.[4] Demonstrations were held at Bogue Field, North Carolina, for the U.S. Navy and Marines and at Andrews AFB, Maryland, for the USAF. In FY 1982, U.S. Army participation in the program began. Work on the krypton-85 lights was dropped during this year, however, because of weight and volume problems and the desire of the services for a more portable system. It was proposed during this year (FY 1982) that solid matrix systems be developed to increase light output and reduce volume and weight. Instrument lighting for aircraft was demonstrated, and work continued in earnest on improvement of phosphor binding and coating techniques to determine optimum coating conditions and characteristics. In this same time period, runway distance-to-go markers were fabricated and installed for testing at Tyndall AFB, Florida.

During FY 1983, several demonstrations of RL lighting systems were held for the armed forces and the most recent program supporter, the state of Alaska.[7] The demonstrations included one for the U.S. Army in Hawaii, the USAF and the state of Alaska held in Alaska, and the U.S. Army at Ft. Benning, Georgia. Increased attention was paid to making the light fixtures more rugged, and improved shock mounting for the lights were developed. The improved units were successfully air-dropped in the Ft. Benning, Georgia, tests. "Clear face" light tubes were examined and found not to be as effective as fully coated tubes. Rotor tip lights for helicopters were designed, built, and tested during this year. The first commercial light tubes were purchased to compare with those being fabricated at ORNL. The ORNL tubes had 42.5% greater light output. This was attributed to coating thickness, and it was decided that a technology transfer conference was needed to pass on information gathered in this program to the commercial companies. Also during this year, the first RL Vertical Angle Slope Indicator (VASI) was built and demonstrated, and a concerted effort to develop reflectors for use with the lights was begun. Reflectorization, while effective in increasing the frontal light output by a factor of three, was very directional and not totally usable. Panel lights were made that did use reflectors effectively. A crescent-shaped light tube was developed in FY 1983 to take advantage of the strength of the curved surface while lessening the space between surfaces in the tube. An annular tube was also designed and built.

Repeated failures of light tubes indicated a great need for procedure development with attention to manufacturing quality assurance (QA) and quality control. These procedures were developed in FY 1984 with reduction of tube failure to zero and increasing light output by 100%. Blue taxiway lights were built and successfully tested on the Fairbanks, Alaska, airport taxiways. Work continued on ruggedization of the lights and ORNL light panels. The increased emphasis on QA resulted in greater light output with a smaller variation. A second arctic test was held for the USAF and the state of Alaska.[8] Experiments in vapor deposition of phosphor were conducted with only partial success. A solid monolithic phosphor coating offers the advantage of no binder failure. A technology transfer conference was held in Oak Ridge on March 1984 with all free world manufacturers of RL lights in attendance. During this year, the state of Florida became an active participant in the program.[2] The USAF changed the requirement for a simple cover to shut off the lights to a shut off capability. In FY 1985, a lay-down rack with radio controlled and manual release mechanisms was designed and built for the USAF. The system could be shut down in less than 1 min with electrical controls and in less than 3 min manually. A complete runway system was built and tested in the SALTY DEMO 85 exercise in Germany in May 1985.

During FY 1986, no DOE money was allocated to ORNL for this program. Funding was provided by the USAF, the U.S. Army, the state of Florida, and the state of Alaska. During this period, pressurization studies demonstrated that light output of tritium lights could be increased by up to a factor of 2.5. Calculations indicated that even greater light output increases could be obtained. Gas specie identification work on old sources was begun with U. S. Army funding. Preliminary specifications for Florida taxiway markers and airfield signs were written.

During FY 1987, specifications for an airfield lighting system for the USAF were developed and safety calculations were made to demonstrate the safety of the system.[1] A full set of lights were purchased from a commercial vendor using ORNL specified manufacturing techniques, safety requirements, and design considerations. The lights met or exceeded all expectations and were successfully tested at Eglin AFB, Florida.[9] The state of Alaska implemented RL lighting systems at three state-operated airports utilizing lights manufactured at ORNL. Specifications for airfield signage for Albert Whitted Airport in St. Petersburg, Florida, were also written, and this signage was purchased during this year.[2] These signs were installed during FY 1989 and are currently being tested.

3. TECHNICAL DEVELOPMENT EFFORTS

3.1 STORAGE OF USAF LIGHTS

Several concepts were examined to develop storage racks and containers, for use both here at ORNL and at USAF sites. A design for 72-, 100-, and 136-unit storage containers was developed. Compact storage of these units requires that the base assembly rotate 90°. Fig. 2 is a sketch of this panel storage unit. None of these storage units were fabricated, and the units have been shipped to PNL for use in other RL light program projects.

3.2 LITERATURE SEARCH

An extensive literature search of the DOE and Department of Defense (DOD) information data bases for RL light information found a group of reports dealing with tritium and tritide light sources, phosphor evaluations, and fabrication QA. An annotated bibliography containing all of the known citations for this work was prepared.

3.3 FLORIDA AIRPORT SIGNS

The RL light signs for use on the Albert Whitted Airport in St. Petersburg, Florida, were received, tested, and installed during the period of this report. Included in this work were calculations to determine maximum personnel dosages in several accident scenarios and other licensing activities. The calculations include personnel dosages in the event of fires in storage areas, accidents involving RL lights on runways and taxiways, and accidents involving mishaps in transportation. The signage was installed on the airport during the period February 28 - March 1, 1989. The complete effort of this program is described in a separate report.[2]

3.4 PROPOSALS FOR ADDITIONAL USAF RL LIGHT WORK

Three proposals[10] were written and submitted to the USAF Alaskan Air Command (AAC) for completion of the RL light work needed to integrate RL light systems into the AAC operations. These proposals included development of a VASI, an RL Runway Distance Remaining Marker, and Airfield Lighting Transition Implementation. The proposals are included in Appendix A. None of these three proposals were supported due to lack of funds.

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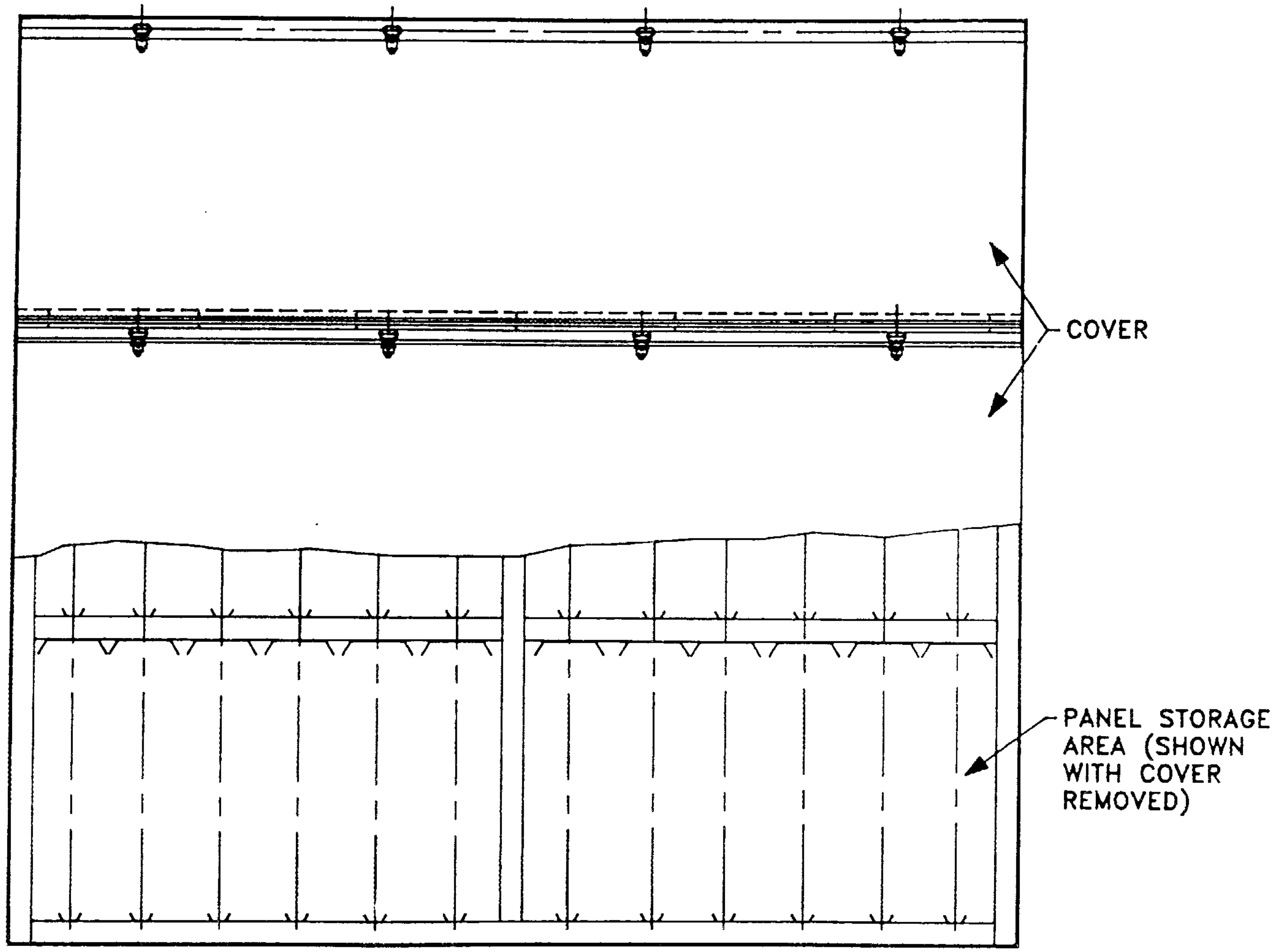

Fig. 2. RL light panel storage unit.

3.5 USAF RL LIGHT LICENSING ACTIVITIES

The ORNL-supplied portions of the license application for use of RL light systems on USAF bases were assembled and transmitted to the USAF in May 1988.[11] The material submitted included the partially completed (items 5, 6, 10, and 11 of the application which were germane to the ORNL scope of work) "Application for Material License," U.S. Nuclear Regulatory Commission Form 313; seven personnel exposure scenarios; a Safety Plan; a Security Plan; and an Instruction Manual for Installing Tritium RL Airfield Lights. Details of these activities can be found in a separate report.[1]

3.6 RL LIGHT EGRESS MARKER UNIT

A conceptual design for an egress marker use in naval vessels was originated. The unit was not built because of budgetary restraints; however, the unit was to be built to maximize durability, effectiveness of utilization of contained tritium, and safety. The outer shell of the device would consist of a metal case with a polycarbonate (coated to resist moisture absorption) cover sealed with a weather resistant caulking. Using reflective tape in pinstripes was suggested for greater illumination by flashlights.

Alignment of the gas- (tritium-) containing tubes under the legend was considered critical to optimum performance. Mounting devices would utilize tamper-proof screws to minimize theft possibilities. The device would have to meet ANSI-N540[12] class 4 standards for RL devices. The proposed unit was 3/4 x 3-1/2 x 6-1/4 in. and weighed approximately 300 g. The legend brightness was expected to be 0.4 to 0.5 ft-L, and the unit would contain 9 Ci of tritium. A sketch of this concept is presented in Fig. 3.

Naval development applications have generated a requirement for small gas-filled RL light sources for aircraft egress marking. Some sources were ordered in late November 1988 and delivered in early January 1989. The sponsor requested a prototype lighting unit that would be used to take the place of what are currently called battle lanterns. This work was canceled due to lack of funding.

3.7 SOLID MATRIX TRITIUM LIGHT SOURCES

Eight copper discs were coated with 0.295- to 1.823-μm layers of titanium by electron beam evaporation by staff members of the ORNL IRML. The discs were 1 in. diam by 0.375-in. thick. The titanium coatings were then tritiated and evaluated as a solid source of tritium that could be used in place of tritium gas. Screens of GTE 1261 phosphor (8, 6, and 4 mg/cm^2) were made, and measurements were made in air and in a vacuum (<200 μm pressure) utilizing these screens and tritiated titanium source discs. The data from these experiments are presented in Table 1. The irregularity in the measurements, which seemed to stem from air trapped between the screen and the source, did not disappear with the removed air.

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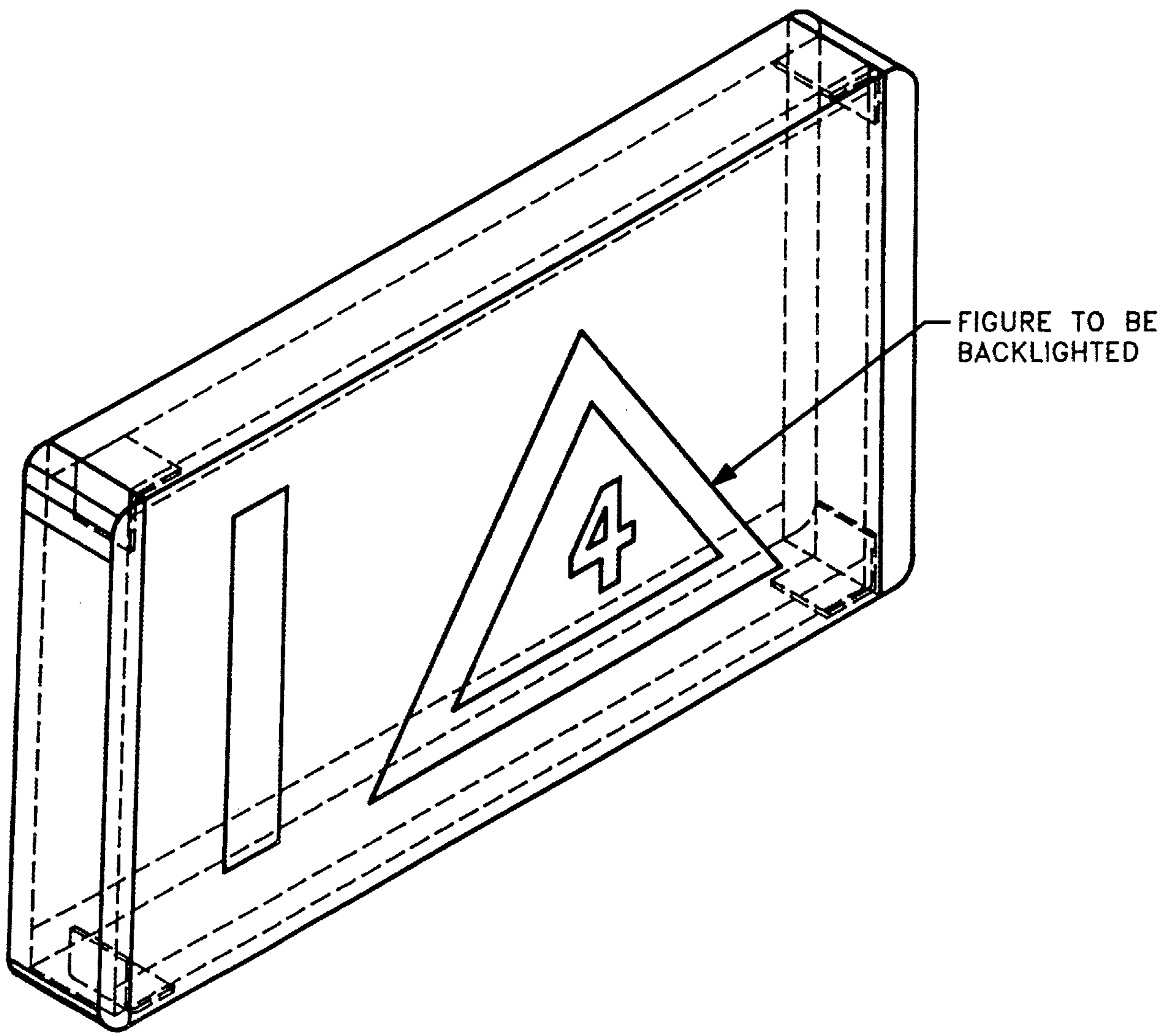


Fig. 3. Conceptual design for naval vessel egress marker.

Table 1. Tritiated titanium light source data

Disc no.	Ti coating thickness (μm)	Light output (cd x 10^{-3})						
		4[a](A)[b]	4(V)[c]	6(A)	6(V)	8(A)	8(V)	12(V)
1	0.295	0.047	0.065	0.037	0.056	0.053	0.066	0.015
2	0.413	0.036	0.045	0.029	0.039	0.055	0.052	0.014
3	0.487	0.083	0.107	0.062	0.091	0.0	0.098	0.038
4	0.726	0.054	0.061	0.043	0.052	0.088	0.084	0.020
5	0.912	0.081	0.109	0.060	0.093	0.108	0.108	0.028
6	1.019	0.107	0.128	0.080	0.111	0.136	0.132	0.040
7	1.158	0.061	0.069	0.050	0.060	0.096	0.092	0.021
8	1.823	0.050	0.064	0.040	0.058	—[d]	—	0.019

[a]The numeral designates the phosphor screen thickness in mg/cm^2.
[b]A = Measurements taken with air between screen and source.
[c]V = Measurements taken with air evacuated from between screen and source.
[d]No measurement was taken.

The results of the experiment indicate a major difference among the tritiated coupons. One set of coupons has a much lower light output response. The difference in response between air and vacuum measurements was consistent for each tritide coupon and screen. Variation in light output was from -0.004 to 0.033 x 10^{-3} cd (-4 to +51%). These results are plotted in Figs. 4 through 7.

Overall response of the tritiated films was not what theory predicted with light output increasing asymptotically to some maximum due to shielding of the beta particles within the film. The samples with greater than 1 μm tritiated titanium coating thickness actually showed decreases in light output. The probable mechanism for these differences is oxidation of the tritide coating. The brightest of these samples was about 0.05 ft-L, which is substantially less than the 1.2 ft-L obtained from the gas-filled lights purchased in 1987 for the USAF program. Six additional tritide sources were fabricated with increased surface area. The surface area of the sources was increased by machining ridges on the surface of each copper coupon. The number of ridges or lines/inch can be used as a relative measure of

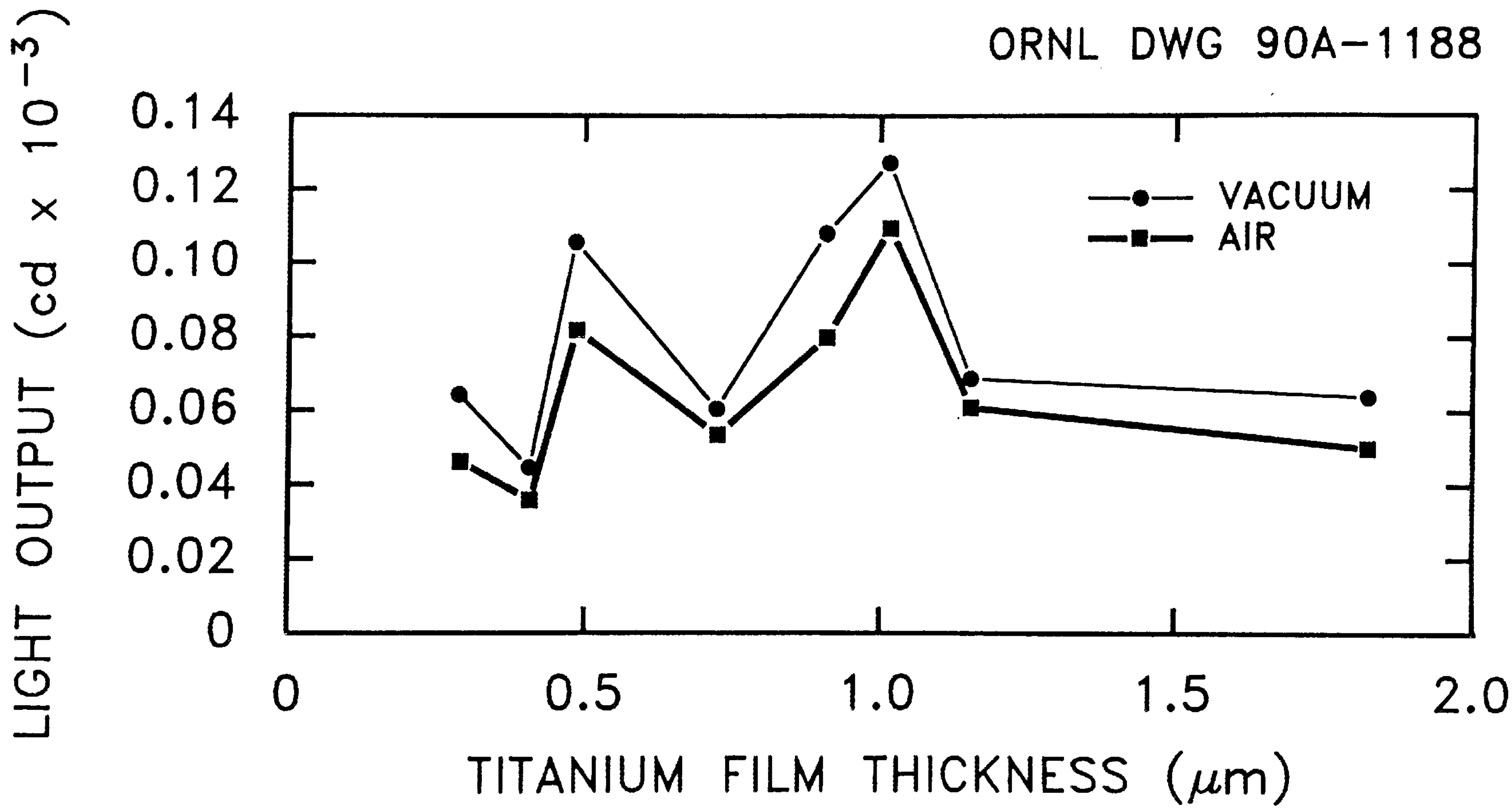


Fig. 4. Tritiated titanium light source for screen thickness of 4 mg/cm^2.

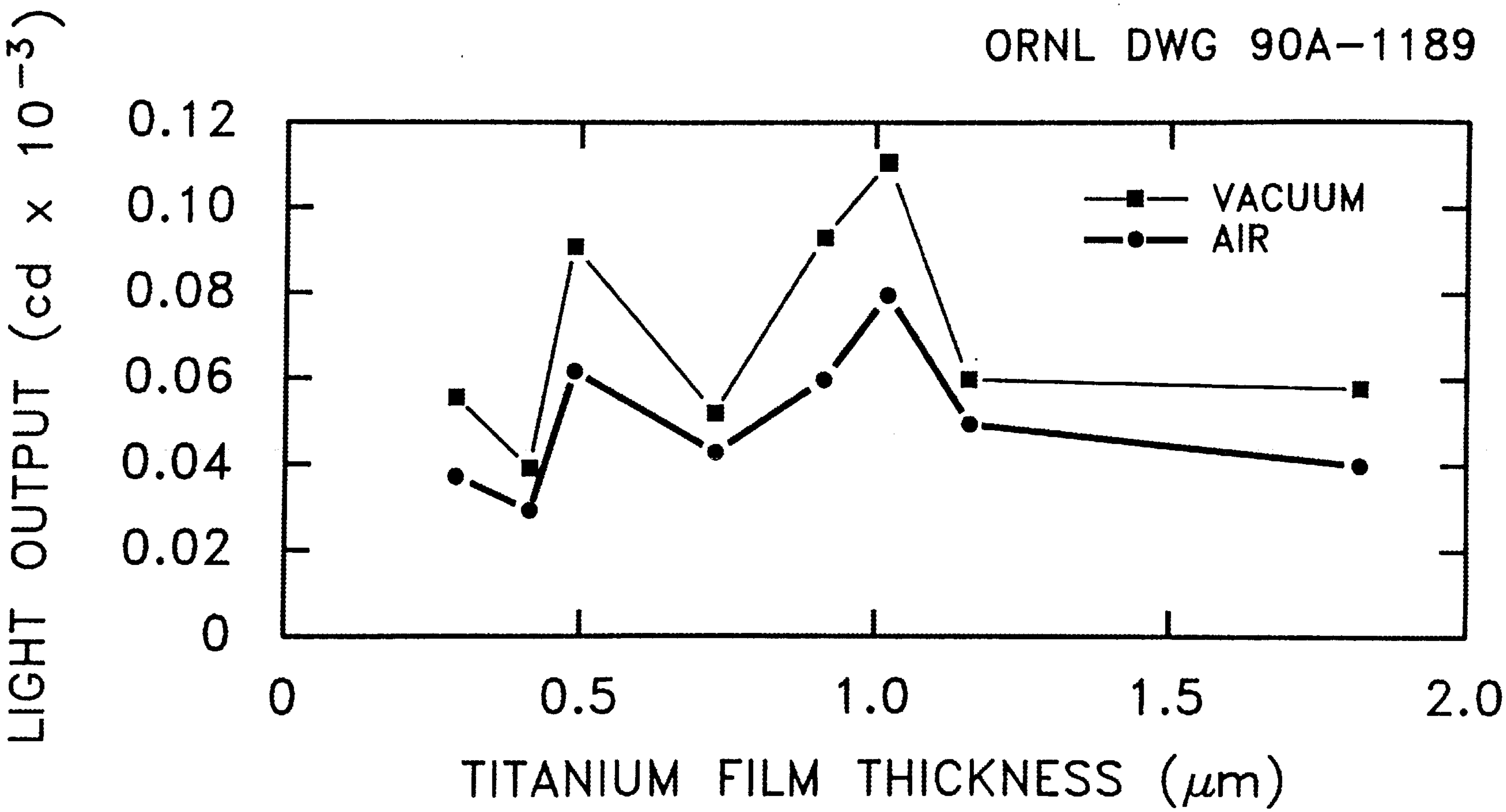


Fig. 5. Tritiated titanium light source for phosphor screen thickness of 6 mg/cm^2.

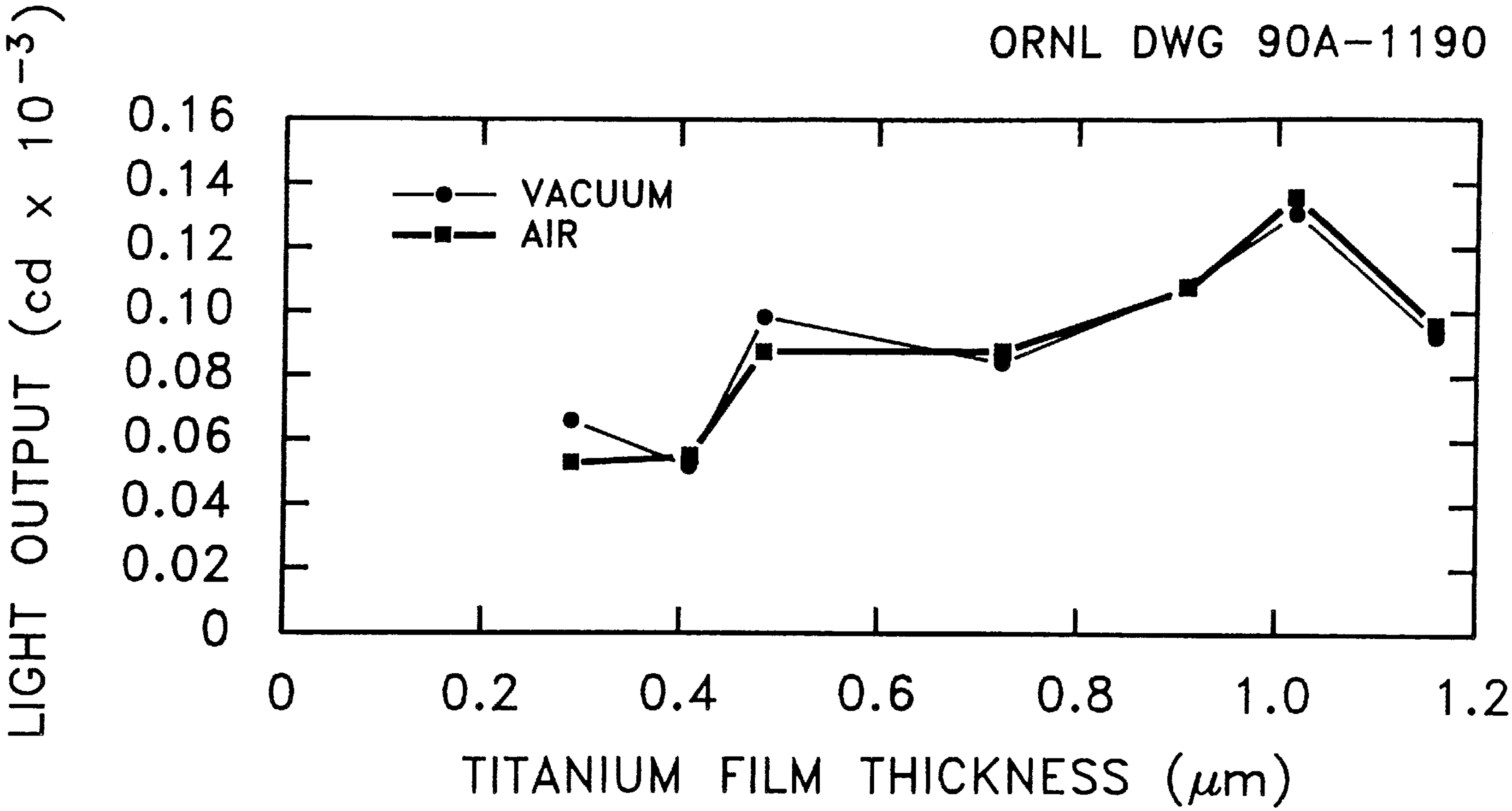


Fig. 6. Tritiated titanium light source for phosphor screen thickness of 8 mg/cm^2.

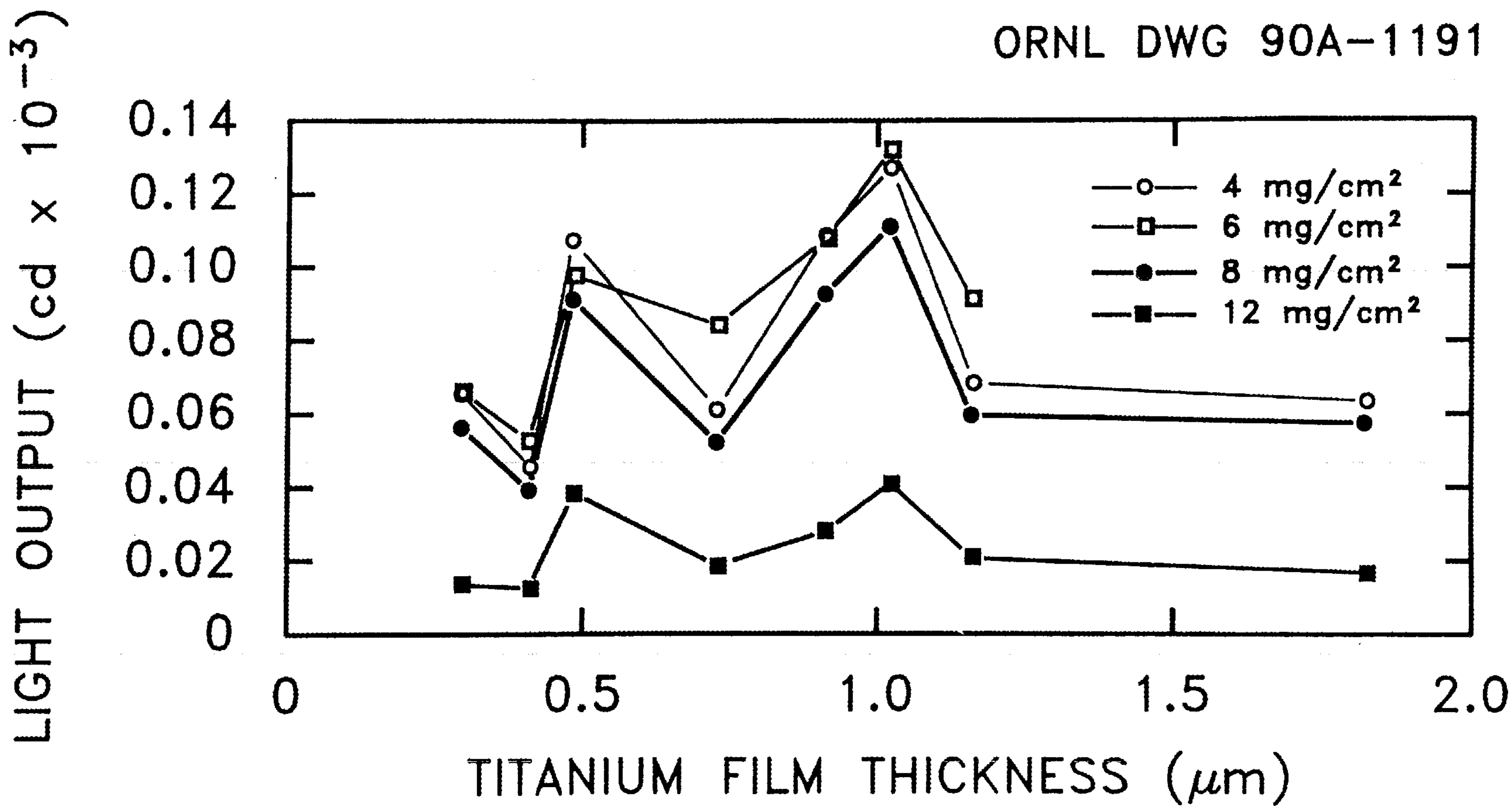


Fig. 7. Tritiated titanium light source for phosphor screen 4 - 12 mg/cm^2.

surface area to correlate with the light output. The resulting coupons were coated with titanium (0.49 to 1.04 μm thick) and tritiated. The light output that each source generated was measured using the same 8-mg/cm^2 GTE 1261 phosphor screen used in previous experiments. All the measurements were made in a vacuum. The results of this experiment are presented in Table 2 and plotted in Fig. 8.

Table 2. Tritide light source data with increased surface area discs

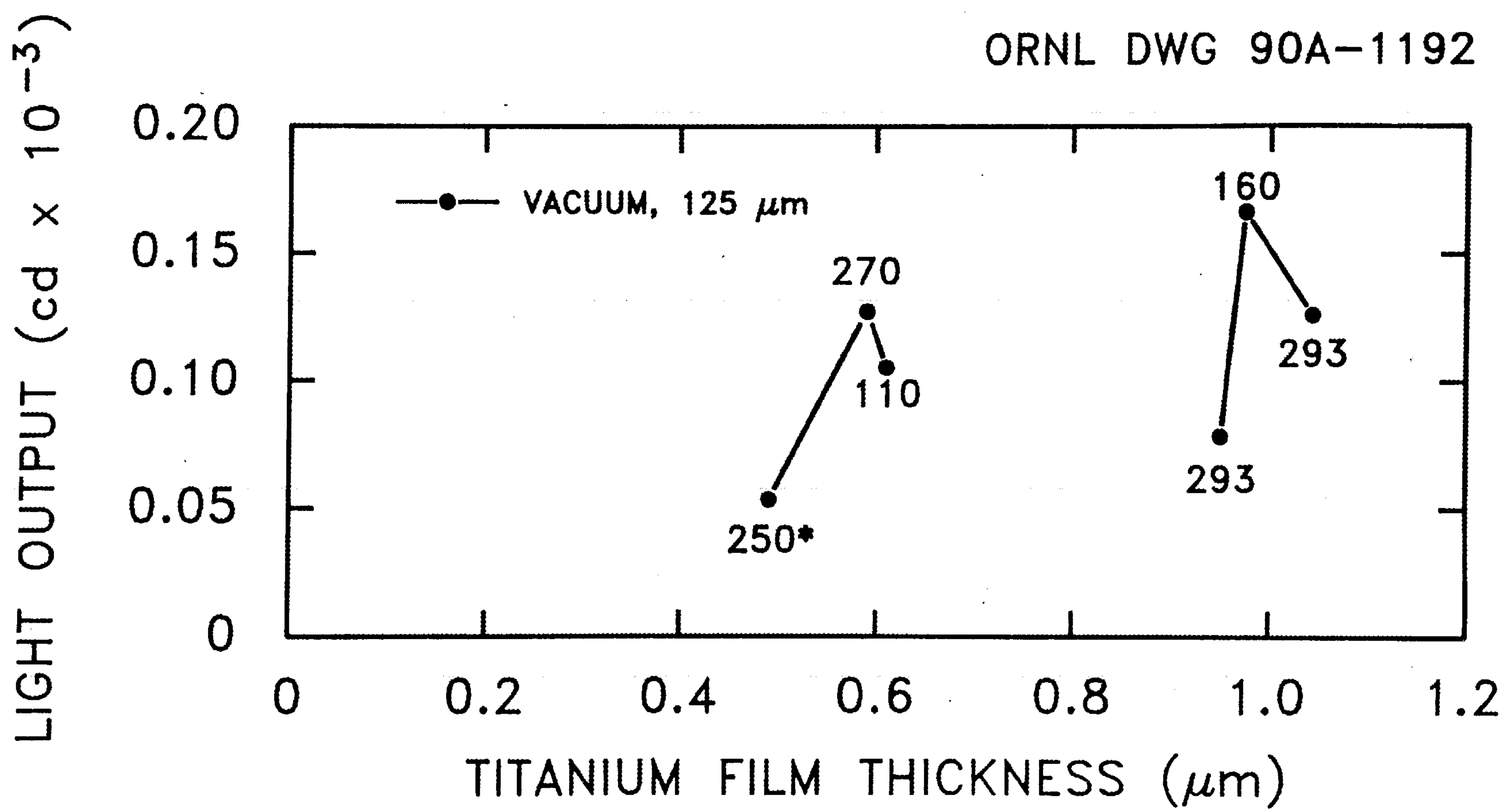
Disc no.	Ti coating thickness (μm)	Profile (lines/in.)	Light output, cd(10^{-3})[a]
1-1	0.95	293	0.078
1-2	1.04	293	0.126
2-1	0.49	250	0.054
2-2	0.59	270	0.127
3-1	0.97	160	0.166
3-2	0.61	110	0.105

[a]Luminous intensity measured in candela using a GTE 1261, phosphor screen thickness of 8 mg/cm^2. All measurements taken in a vacuum of <200-μm pressure.

The results of the experiment are similar to the results obtained from the smooth coupons. There appears to be no correlation between increased surface area and increased light output as well as no overall increase in light output. It should be noted that the maximum brightness that has been measured from the tritide light samples is an order of magnitude lower in brightness than the lights currently being produced commercially with the latest gas-filled tube technology.

One additional experiment with coupon 3-2 was made to determine if the variability in the samples measured was a result of the failure to make good contact between the phosphor screen and the tritiated coupon. Phosphor powder was spread over the surface of the coupon and placed against the same phosphor screen used in the above experiments. There was no change in the maximum light output observed.

The only extension of this work to airfield lighting applications thus far is the glass coupon phosphor-tritide overcoat. The high ratio of surface area to brightness may allow this geometry to generate the brightness needed. An experiment was conducted utilizing a glass fixture coated with phosphor and then overcoated with tritide-forming material. In this case, titanium was deposited directly onto a phosphor-coated glass fixture and then exposed to tritium. The IRML staff was successful in preparing phosphor-coated glass samples and successful in coating them with titanium. These samples were then tritiated. The question of whether the phosphor coating would still adhere to the glass after being exposed to tritium turned out to be a valid concern. After tritiation, greater than 95% of the phosphor coating peeled off of the glass substrate. The fact that titanium undergoes a change



* NUMBERS INDICATE LINES PER INCH

Fig. 8. Tritide light source data with increased surface area disks.

in the lattice parameters (dimensional changes) when tritium is absorbed is the probable cause for this peeling problem. The remaining material (5%) did not appear to be glowing.

3.8 TESTS OF AN ORGANIC TRITIUM GETTER MATERIAL

During the RL light workshop in Phoenix, Arizona, during November 1988, information was presented by SNL personnel on an organic getter material that will react with tritium absorbing 8% by weight at room temperature. Tests indicated that the material works well in air. The material is an organic compound [1,4 bis(phenyl-ethylnyl) benzene] called DEB. The material is deposited on an alumina or carbon carrier and catalyzed with 5% platinum. Three uses were proposed for DEB: RL lighting, tritium monitoring, and tritium and/or hydrogen containment. ORNL was selected by DOE Headquarters (DOE/HQ) to perform the light development work and explore other uses of DEB.

Several experiments were performed in monitoring for tritium in the ORNL Tritium Gas Facility. The original objectives of the experiments were to eliminate radioactive, hazardous tritium gas from an enclosed space, to getter tritium in both slow leak and massive one-time leak situations, to maintain tritium in a solid nondispersible form without the release of radioactive volatile materials or biologically dangerous tritiated water, and to demonstrate the capability to function in a variety of atmospheres. The requirements of these experiments were that no wet chemistry was to be performed with radioactive materials, tritiation of the material was to be performed only by exposure to tritium gas, and minimum waste disposal volumes and costs were to be experienced. The experiments involved inserting DEB-coated filters into a tritium air monitor outlet line. The initial experiments were conducted with very low indication of tritium ($<1\ \mu$Ci) on the air monitor, and analysis of the DEB samples showed no indication of tritium above background levels. Additional experiments with this material were canceled due to lack of funding.

Experiments conducted with DEB sedimented onto phosphor-coated glass coupons showed very little radioluminescence. Much of the coating peeled away from the glass substrate after being exposed to tritium.

An experiment was conducted in which DEB was combined with an organic scintillator and, after tritiation, generated a tritide RL light. The DEB tritide RL light that was made had a light output ranging from 0.1 to 0.19 ft-L. Work on DEB reaction kinetics was also planned as part of this work but was canceled due to lack of funding.

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APPENDIX A
Proposals for Additional United States Air Force (USAF) Radioluminescent (RL) Light Work

STATEMENT OF WORK

PROPOSAL FOR UNITED STATES AIR FORCE (USAF) RADIOLUMINESCENT (RL) VISUAL APPROACH SLOPE INDICATOR (VASI) DEVELOPMENT

1.0 SCOPE

The scope of the project includes development of criteria for the RL Visual Approach Slope Indicator (RL-VASI), optical system development, fabrication of advanced RL light sources, prototyping fabrication of the complete system, and field testing of the units.

The Oak Ridge National Laboratory (ORNL), managed by Martin Marietta Energy Systems, Inc.—a prime contractor of the United States Department of Energy (DOE)—will be the technical contractor for this work.

2.0 BACKGROUND

2.1 RL Lighting. In 1987, a state-of-the-art RL lighting system was procured for the United States Air Force (USAF) by ORNL. RL lighting systems are portable, self-contained units requiring no electrical power. These systems are not affected by changes in temperature and have shelf lives on the order of 6 to 8 years.

2.2 Procurement of RL Lighting. Procurement of the RL lighting system required specification development, prototype testing, fabrication, quality assurance, and a field demonstration. The report[9] describing the field demonstration indicated one deficiency of the system was a lack of glide-slope information provided to the pilot.

2.3 Visual Approach Slope Indicator. A VASI is the typical device for providing glide-slope information to the pilot. Commercial VASI systems use incandescent light sources to form narrow channels of light of varying color. These channels of light are placed so that aircraft approaching the threshold of an airfield can determine if the angle of approach is too steep or too shallow.

2.4 RL Visual Approach Slope Indicator. A bar-type RL-VASI system (using ORNL panels) has been tested in the past using USAF crews for system evaluation. The primary problem observed with this equipment was a lack of precision in defining the glide-slope angle. This lack, combined with the large surface area of the panel light sources, led to indistinct broad glide-slopes that resulted in a minimal margin of safety. Pilot experience with the RL-VASI system was also required for effective operation.

2.5 Development of an RL-VASI System. This task proposes to develop an RL-VASI system to provide glide-slope information to tactical aircraft pilots. The system would be self-contained and operate within the constraints of the present RL lighting system. This system will not attempt to present exactly the same visual representation of approach angle information (high-amber, correct-green, low-red) as is currently used, but it would offer similar information to the pilot.

3.0 TECHNICAL REQUIREMENTS

The technical requirements for the RL-VASI system are stated below.

3.1 Criteria Established. The criteria for successful deployment of an RL-VASI system cannot be modeled on the existing standards developed for high-intensity incandescent airfield VASI. The relevant question becomes what are the minimum luminous intensity and viewing angles required to develop an RL-VASI for tactical aircraft guidance that is compatible with the RL edge lighting system demonstrated at Eglin AFB. The starting point for such an evaluation is to establish the total airfield acquisition distance requirements. Approximately 3.2 nautical miles (F-4 aircraft) were observed for conditions at Eglin AFB during a field demonstration. The maximum size and brightness of the required sources, within the context of an optically collimated system, must be determined to define the extent to which light source development will be necessary. The eight parameters outlined below define the primary criteria:

1. minimum system recognition distance,
2. source brightness,
3. horizontal angle of acceptance,
4. vertical angle of acceptance,
5. color differentiation necessary,
6. maximum angle subtended by the source,
7. maximum angular overlap, and
8. the value of positional information.

3.2 Optical System Identification. Once the primary criteria are determined, various optical configurations will be evaluated. An optical design consultant will be contracted to generate a maximum number of optical configuration alternatives. Existing and advanced technologies will be evaluated. Deciding factors used to determine the best design will be performance, cost, tritium activity levels, safety, and portability. One method of evaluation employed will be computerized ray tracing. This technique offers a timely comparison of the relative efficiency of the optical component in channeling light into the narrow angles required. Alternative optical configurations evaluated will include, but not be limited to, layered optical light pipes, deep parabolic mirrors, and collimating screens. Program sponsor shall concur with optical system selection.

3.3 RL Light Source Development. DOE has begun the initial phases of this effort with funding for advanced light source technology development. DOE laboratories are conducting research that, if successful, will lead to significantly brighter light sources. This subtask will select the optimum light source technology after the proof-of-principle work has been completed. Light source technologies involving metal tritides, zeolites, polymers, glass microencapsulation, and advanced gas-filled tube technology are being examined. Criteria for light source evaluation will include performance, cost, and safety. Information derived from subtask 3.2 will establish dimensional guidelines for the light source. Program sponsor will be notified of selection and concurrence will be sought. Once the optimum light source technology is selected, light sources sufficient for one prototype will be fabricated and evaluated.

3.4 System Prototyping. The purpose of this subtask is to integrate the optical system and light source development into a complete light source package. The goal is to produce a full-scale prototype unit that, when deployed in sufficient numbers, will meet the RL-VASI system criteria developed in subtask 3.1. Optical system components must be fabricated from the design criteria generated in subtask 3.2. Components will be redesigned as necessary to accommodate the specific capability of the improved light source. Sufficient optical components will be fabricated for one unit. The optical and RL components will be assembled and evaluated in the laboratory to determine if the overall system design criteria are met. An evaluation by the program sponsor will be required before continuing the overall task activities. Testing of the assembled prototype will include field observations at distances of at least one-half mile. Optimization of the prototype unit will be completed prior to the start of subtask 3.5.

3.5 Procure Operational Units. The optimized, modular unit fabricated in subtask 3.4 will be procured in sufficient quantities to allow a full-scale test evaluation. The fabrication of these light sources will be accomplished by commercial vendor, if gas-filled tubes are used. It is doubtful if the commercial sources will be able to fabricate any of the other advanced source forms in the time frame required. DOE will contribute 100,000 Ci of light-source grade tritium for use in fabricating one full-scale system. Initiation of this subtask will require and evaluation and concurrence by the program sponsor.

3.6 Full-Scale Testing. Initial testing of the system will use general aviation aircraft to establish VASI system parameters. After successful completion and optimization of the assembled RL-VASI, a field test involving tactical aircraft will be scheduled to determine if system goals have been met. The evaluation of the RL-VASI system will be made by the program sponsor. This test will be conducted in conjunction with other major RL tests or demonstrations to minimize program costs. Alternatively, immediate full-scale testing could be scheduled with an increase in program sponsorship. This decision must be made in a timely manner to allow completion and reporting of the task in FY 1989.

3.7 Transition to Operational Units. After successful demonstration of the RL-VASI system, ORNL will compile documentation for presentation to the USAF Radioisotope Committee (RIC) for licensing, deployment, shipping, and storage of the units. Since the light sources contain DOE stock tritium, the RL-VASI system will remain property of DOE until the USAF is granted a license approval by the USAF RIC.

3.8 Previous Work in This Field. ORNL as a DOE contractor has participated in RL airfield system research, design, and field evaluations since 1980. See references given below.

a. *Kr-85 Powered Lights for Airfield Applications*, U.S. Air Force Report ESL-TR-80-55, F. N. Case and K. W. Haff, November 1981.

b. *Testing of Tritium Powered Runway Distance and Taxiway Markers*, U.S. Air Force Report ESL-TR-81-45, K. W. Haff, F. N. Case, F. J. Schultz, and J. A. Tompkins, May 1981.

c. *Evaluation of Arctic Test of Tritium Radioluminescent Lighting*, U.S. Air Force Report ESL-TR-82-35, K. W. Haff, J. A. Tompkins, and F. N. Case, August 1983.

d. *Radioisotope Powered Light Sources*, U. S. Air Force Report ESL-TR-82-12, K. W. Haff, J. A. Tompkins, and F. N. Case, August 1984.

e. *Radioluminescent Lighting for Alaska Runway Lighting and Marking*, PNL-5328, G. A. Jensen and L. E. Leonard, March 1984.

f. *Evaluation of Radioluminescent Lighting System*, DOT/FFA/CT-TN84/49, T. H. Paprocki, November 1984.

g. *Radioluminescent Airfield Lighting System (RAFLIS) Test*, 2nd Lt. J. M. Pfieffer and Mark Arbona, September 1987.

h. *Improved Radioluminescent Airfield Lighting System*, J. A. Tompkins, K. W. Haff, and F. J. Schultz, March 1988.

i. *Testing of Tritium Powered Runway Distance and Taxi Markers*, K. W. Haff, J. A. Tompkins, F. J. Schultz, and F. N. Case, August 1981.

3.9 Billing. All vouchers for payment submitted by ORNL's accounts receivable office shall be accompanied by explanation of work performed and a cost summary.

3.10 Deliverables. In summary, the following items are considered to be deliverables for this project.

- The RL-VASI system criteria will be established. These criteria shall include minimum luminous intensity and viewing angles required for tactical aircraft guidance (Sect. 3.1).
- The best design for optical system will be chosen (Sect. 3.2).
- An optimum light source technology will be selected (Sect. 3.3).
- The light source prototype will be fabricated. Subsequently, there will be laboratory testing/evaluation and small-scale field testing of the light source prototype (Sect. 3.4).
- Sufficient light source units will be procured in order to conduct full-scale evaluation (Sect. 3.5).
- A full-scale test of the RL-VASI system will be conducted (Sect. 3.6).
- USAF licensing documentation will be required (Sect. 3.7).

4.0 REPORTING

4.1 Report Preparation. ORNL shall prepare a final technical report that shall include all data, calculations, and analyses required in this technical effort. In addition, ORNL shall include detailed descriptions, fabrication techniques, and/or drawings of the final fixture design, fabrication techniques, shipment limitations, installation techniques, and instructions on erection and installation of the lighting system. The final technical report shall include complete system performance which shall be limited to the actual field observations of the ORNL team during the field testing of the system unless information gathered by USAF observers is provided by Headquarters Air Force Engineering Services Center (HQ AFESC) with instructions to include it in the report.

4.2 Guidelines for Preparation. The final technical report shall be written in accordance with DID S-3591A. Two (2) copies of the final draft of the report will be submitted within thirty (30) days after completion of work. A reproducible original of the final technical report will be submitted thirty (30) days after receipt of the sponsor's comments on and approval of the draft. The approving authority will be HQ AFESC. The reproducible original will be a "camera-ready" copy, reference MIL-STD-847B as amended by Appendix to CDRL of April 10, 1984. The final technical report shall be published as a joint AFESC/ORNL report.

5.0 SCHEDULE AND FUNDING REQUIREMENTS

5.1 Significant Events. The listing of significant events of the various parts of this project are shown below:

- criteria established (Sect. 3.1),
- optical systems identified (Sect. 3.2),

- RL source developed (Sect. 3.3),
- optical system prototype fabricated (Sect. 3.4),
- operational system procured (Sect. 3.5),
- full-scale testing (Sect. 3.6),
- transition to USAF operational use (Sect. 3.7), and
- final report issued (Sect. 4.1).*

5.2 Funding. The elements requiring funding for this work are listed below:

- criteria established (Sect. 3.1),
- optical systems identified (Sect. 3.2),
- RL source development (Sect. 3.3),
- optical system prototype fabricated (Sect. 3.4),
- operational system procured (Sect. 3.5),
- full-scale testing (Sect. 3.6), and
- transition to USAF operational use (Sect. 3.7).

6.0 SPECIAL ACTION

6.1 Security Classification. It is anticipated that the security classification of this project will remain UNCLASSIFIED. If uncertain of the classification of the material, ORNL will tentatively classify the material "CONFIDENTIAL" until a final determination is made by the appropriate federal security authority.

6.2 Release of Information. All information concerning developments under this contract shall be reported to other agencies through HQ AFESC. Until public release of the final technical report by the USAF, there shall be no briefings, presentations, publication, or information relative to this technical effort transmitted by ORNL without prior approval by HQ AFESC.

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*ORNL will provide periodic informal status reports, schedules, and program reviewed as required by AFESC.

STATEMENT OF WORK

PROPOSAL FOR UNITED STATES AIR FORCE (USAF)
RADIOLUMINESCENT (RL) RUNWAY DISTANCE REMAINING (RDR) MARKER DEVELOPMENT

1.0 SCOPE

The scope of the project includes development of design criteria for the Radioluminescent Runway Distance Remaining (RL-RDR) Marker, prototype fabrication and evaluation, fabrication of the complete system, and field testing of the units.

The Oak Ridge National Laboratory (ORNL), operated by Martin Marietta Energy Systems, Inc., a prime contractor of the United States Department of Energy (DOE), will be the technical contractor for this work.

2.0 BACKGROUND

2.1 History. In 1987, a state-of-the-art RL lighting system was procured for the USAF by Oak Ridge National Laboratory (ORNL). RL lighting systems are portable, self-contained units requiring no electrical power. These systems are not affected by changes in temperature and have shelf-lives on the order of 6 to 8 years.

2.2 Procurement. Procurement of the RL lighting system required specification development, prototype testing, fabrication, quality assurance, and field demonstration. The report[9] describing the field demonstration indicated a deficiency of the system—a lack of RDR information for the pilot.

2.3 RDR Markers. A RDR marker is the typical device for providing remaining distance information to the pilot. Standard RDR systems use incandescent light sources to backlight large, white numerals.

2.4 Purpose of this Task. This task proposes to develop a RL-RDR system to provide distance remaining information for tactical aircraft. The system would be self-contained and compatible with the present RL lighting system. This system will not attempt to duplicate conventional electrical RDR marking systems. The system would offer the same information but in a different form.

3.0 TECHNICAL REQUIREMENTS

The technical requirements are stated below.

3.1 Criteria Development. The criteria for successful deployment of a RL-RDR system cannot be modeled on the existing standard developed for high-intensity incandescent airfield lighting. The relevant question becomes what are the minimum luminous intensity, numeral size, and color to safely use a RL-RDR for tactical aircraft ground-roll-out guidance. The starting point for such an evaluation is embodied in the five criteria listed below:

1. minimum system recognition distance,
2. source brightness,
3. numeral size,
4. color differentiation, and
5. the value of positional information.

3.2 System Prototyping. The purpose of this subtask is to produce a full-scale prototype unit that will meet the RL-RDR system criteria developed in subtask 3.1. Optimization of the prototype unit will be completed prior to the start of subtask.

3.3 System Fabrication. To adequately outfit a 5000-ft runway, 20 units will be fabricated.

3.4 Full-Scale Testing. The optimized RL-RDR produced in subtask 3.3 will be fabricated in sufficient quantities to allow a full-scale evaluation. The fabrication of these light sources will be accomplished by commercial vendor, if gas-filled tubes are used. Initial testing of the system will use ground vehicles to evaluate system recognition distances. Further testing with aircraft to establish RDR system performance will await a full-scale test of other system components.

3.5 Previous Work in this Field. ORNL as a DOE contractor has participated in RL airfield system research, design, and field evaluations since 1980. See references given below.

a. *Kr-85 Powered Lights for Airfield Applications*, U.S. Air Force Report ESL-TR-80-55, F. N. Case and K. W. Haff, November 1981.

b. *Testing of Tritium Powered Runway Distance and Taxiway Markers*, U.S. Air Force Report ESL-TR-81-45, K. W. Haff, F. N. Case, F. J. Schultz, and J. A. Tompkins, May 1981.

c. *Evaluation of Arctic Test of Tritium Radioluminescent Lighting*, U.S. Air Force Report ESL-TR-82-35, K. W. Haff, J. A. Tompkins, and F. N. Case, August 1983.

d. *Radioisotope Powered Light Sources*, U.S. Air Force Report ESL-TR-82-12, K. W. Haff, J. A. Tompkins, and F. N. Case, August 1984.

e. *Radioluminescent Lighting for Alaska Runway Lighting and Marking*, PNL-5328, G. A. Jensen and L. E. Leonard, March 1984.

f. *Evaluation of Radioluminescent Lighting System*, DOT/FAA/CT-TN84/49, T. H. Paprocki, November 1984.

g. *Radioluminescent Airfield Lighting System (RAFLIS) Test*, 2nd Lt. J. M. Pfieffer and Mark Arbona, September 1987.

h. *Improved Radioluminescent Airfield Lighting System*, J. A. Tompkins, K. W. Haff, F. J. Schultz, and F. N. Case, August 1981.

3.6 Billing. All vouchers for payment submitted by ORNL's accounts receivable office shall be accompanied by explanation of work performed and a cost summary.

3.7 Deliverables. The following deliverables are required by the terms of this project:

- Development of a RL-RDR system criteria. These criteria shall include minimum system recognition distance, source brightness, numeral size, and color differentiation (Sect. 3.1).
- Fabrication of a full-scale RL-RDR system (Sect. 3.2).
- Fabrication of 20 RL-RDR units to adequately outfit a 5,000-ft runway (Sect. 3.3).
- Full-scale testing of the RL-RDR system will be conducted (Sect. 3.4).

4.0 REPORTING

4.1 Report Preparation. ORNL shall prepare a final technical report that includes all data, calculations, and analyses required in this technical effort. In addition, ORNL shall include detailed descriptions, fabrication techniques, and/or drawings of the final fixture design, fabrication techniques, shipment limitations, installation techniques, and instructions on erection and installation of the lighting system. The final technical report shall include complete system performance that shall be limited to the actual observations of the ORNL team during the field testing of the system unless information gathered by USAF observers is provided by HQ AFESC with instructions to include it in the report.

4.2 Guidelines for Preparation. The final technical report shall be written in accordance with DID S-3591A. Two (2) copies of the final draft of the report will be submitted within thirty (30) days after completion of work. A reproducible original of the final technical report will be submitted thirty (30) days after receipt of the sponsor's comments on and approval of the draft. The approving authority will be HQ AFESC. The reproducible original will be a "camera-ready" copy, reference MIL-STD-847B as amended by Appendix to CDRL of April 10, 1984. The final technical report shall be published as a joint AFESC/ORNL report.

5.0 SCHEDULE AND FUNDING REQUIREMENTS

5.1 Significant Events. The listing of significant events of the various parts of this project are presented below:

- criteria development (Sect. 3.1),
- system prototyping (Sect. 3.2),
- system fabrication (Sect. 3.3),
- system testing (Sect. 3.4), and
- issue of final report (Sect. 3.5).*

5.2 Funding. The elements requiring funding are presented below:

- criteria development (Sect. 3.1),
- system prototyping (Sect. 3.2),
- system fabrication (Sect. 3.3), and
- system testing (Sect. 3.4).

6.0 SPECIAL ACTION

6.1 Security Classification. It is anticipated that the security classification of this project will remain UNCLASSIFIED. If uncertain of the classification of the material, ORNL will tentatively classify the material "CONFIDENTIAL" until a final determination is made by the appropriate federal security authority.

6.2 Release of Information. All information concerning developments under this contract shall be reported to other agencies through HQ AFESC. Until public release of the final technical report by the USAF, there shall be no briefings, presentations, publication, or information relative to this technical effort transmitted by ORNL without prior approval by HQ AFESC.

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*ORNL will provide periodic informal status reports, schedules, and program reviews as required by AFESC.

STATEMENT OF WORK

PROPOSAL FOR UNITED STATES AIR FORCE (USAF)
RADIOLUMINESCENT (RL) AIRFIELD LIGHTING
TRANSITION IMPLEMENTATION

1.0 SCOPE

The scope of this project shall consist of transition implementation of RL airfield lighting for the United States Air Force (USAF) to include safety evaluations, license preparation, preparation of operation, handling and maintenance manuals, training materials preparation and unlicensed system demonstrations for RL airfield lighting systems.

The Oak Ridge National Laboratory (ORNL), operated by Martin Marietta Energy Systems, Inc., a prime contractor of the United States Department of Energy (DOE), will be the technical contractor for this work. The major areas in which ORNL will concentrate are preparation of information packages to support safety evaluations, transportation, licensing, and unlicensed site demonstrations. The technical information packages would be based on calculational and/or experimental data.

2.0 BACKGROUND

2.1 History. The USAF has for many years, investigated alternate airfield lighting systems. In addition to high electric power costs, current runway edge and threshold lights use incandescent bulbs that require frequent maintenance and replacement. The use of RL airfield lights eliminates electricity costs and should greatly reduce maintenance requirements.

2.2 Requirements. Mission planners desire a self-contained, lightweight lighting system for tactical, bare-base deployment that can be readily adapted to permanent airfields during periods of contingency.

2.3 Recent Developments. RL airfield light fixtures were most recently field tested by ORNL and the Test Wing, USAF Armament Development Laboratory, during an April 26 - May 18, 1988, demonstration at Eglin AFB, Florida. The field test demonstrated airfield acquisition distances of 3.2 - 7.8 nautical miles.
United States Air Force Engineering and Services Center (AFESC) - sponsored research at ORNL has resulted in substantial technology development, including significant brightness and efficiency improvement in RL airfield lighting systems.

2.4 Future Development. While a satisfactory system has been demonstrated, more work is needed. The integration of the new RL airfield lighting system into the operational environment of the USAF will require several institutional issues to be addressed. ORNL, under the auspices of DOE, is uniquely qualified to assist the USAF with this work. Transition to operational use will require additional safety studies to satisfy USAF-Radioisotope Committee (RIC) requirements, Nuclear Regulatory Commission (NRC), and state licensing regulations. In addition, complete handling documentation must be compiled and integrated into USAF operational format. Included in this documentation will be specifications for: instructions for routine handling procedures, health and safety procedures, maintenance instruction, procedures for handling accidents, decontamination and clean up, and disposal of broken devices. Training materials must be prepared to educate support and handling personnel. During the transition period, compilation of technical information packages, licensing packages, and further field demonstrations of unlicensed systems will be required.

3.0 TECHNICAL REQUIREMENTS

The technical requirements are stated below:

3.1 Safety Evaluations. ORNL will provide safety evaluations to include the following:

a. **Accident Simulations.** Experimental evaluations of simulated fire, crushing, and vehicular accidents are required to fill voids which exist in several accident scenario's calculational data. Conditions required for release from the lighting device will also be documented.

b. **New Device Testing and Evaluations.** New device testing to verify compliance with ANSI-N540, Class 4 (as modified by ORNL) and U.S. Department of Transportation (DOT) Type A shipping package requirements will be required by the various licensing authorities. Testing to meet more rigorous requirements for air drop capability may also be required.

c. **Diffusion Studies.** Tritium diffusion studies to determine actual permeation rates from assembled devices will be performed. Measured permeation rates will allow more accurate Health Physics calculations resulting in refinement of emergency handling practices and resolution of emergency shipping and disposal issues.

d. **Device Storage and Monitoring Evaluations.** Inexpensive, easy-to-operate, sensitive air monitoring methods for detection of airborne contamination will be required. To establish adequate confidence levels, laboratory validation of the monitoring methods is crucial. It is conceivable that monitoring of bulk storage will be required biannually. Storage and handling containers for the light devices will be designed and fabricated.

e. **Transportation Package Evaluations.** Rapid deployment requires bulk shipping and readily accessible manual removal of the devices from the container. Design and evaluation of those shipping containers will be required.

3.2 License Compilations and Review. ORNL will provide compilation and review of material required for new device license permit applications by USAF users.

3.3 Training Courses. ORNL will design training courses for handling, maintenance, accident, disposal, and deployment of the RL lighting units.

3.4 Field Demonstration and Support. ORNL will support further field demonstrations by providing for transportation and packaging of RL devices; safety, security, and test plans; and assistance for obtaining demonstration site permits.

3.5 Previous Work in this Field. ORNL as a DOE contractor has participated in RL airfield lighting system research, design, and field evaluations since 1980. See references below.

a. *Kr-85 Powered Lights for Airfield Applications*, U.S. Air Force Report ESL-TR-80-55, F. N. Case and K. W. Haff, November 1981.

b. *Testing of Tritium Powered Runway Distance and Taxiway Markers*, U.S. Air Force Report ESL-TR-81-45, K. W. Haff, F. N. Case, F. J. Schultz, and J. A. Tompkins, May 1981.

c. *Evaluation of Arctic Test of Tritium Radioluminescent Lighting*, U.S. Air Force Report ESL-TR-82-35, K. W. Haff, J. A. Tompkins, and F. N. Case, August 1983.

d. *Radioisotope Powered Light Sources*, U.S. Air Force Report ESL-TR-82-12, K. W. Haff, J. A. Tompkins, and F. N. Case, August 1984.

e. *Radioluminescent Lighting for Alaska Runway Lighting and Marking*, PNL-5328, G. A. Jensen and L. E. Leonard, March 1984.

f. *Evaluation of Radioluminescent Lighting System*, DOT/FFA/CT-TN84/49, T. H. Paprocki, November 1984.

g. *Radioluminescent Airfield Lighting System (RAFLIS) Test*, 2nd Lt. J. M. Pfieffer and Mark Arbona, September 1987.

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i. *Testing of Tritium Powered Runway Distance and Taxi Markers*, K. W. Haff, J. A. Tompkins, F. J. Schultz, and F. N. Case, August 1981.

3.6 Billing. All vouchers for payment submitted by ORNL's accounts receivable office shall be accompanied by explanation of work performed and a cost summary.

3.7 Deliverables. The following items constitute the deliverables:

- documentation of evaluations of simulated accidents and conditions required for release (Sect. 3.1.a),
- ANSI-N540 testing of devices and documentation of results (Sect. 3.1.b),
- measurements of tritium permeation rates (Sect. 3.1.c),
- validation of airborne contamination detection and of storage and handling containers (Sect. 3.1.d),
- design and evaluation of bulk shipping containers (Sect. 3.1.e),
- compilation and review of material required for new device license application, when requested by sponsor (Sect. 3.2),
- designing the training course (Sect. 3.3), and
- providing support, when requested by the sponsor, for field demonstrations, device transportation, safety, security, and test plans; and demonstration site permits (Sect. 3.4).

4.0 REPORTING

4.1 Report Preparation. ORNL shall prepare a final technical report that shall include all data, calculations, and analyses required in this technical effort. In addition, ORNL shall include detailed descriptions, fabrication techniques, and/or drawings of the final fixture design, fabrication techniques, shipment limitations, installation techniques, and instructions on erection and installation of the lighting system. The final technical report shall include complete system performance that shall be limited to the actual observations of the ORNL team during field testing of the system unless information gathered by USAF observers is provided by HQ AFESC with instructions to include it in the report.

4.2 Guidelines for Preparation. The final technical report shall be written in accordance with DID S-3591A. Two (2) copies of the final draft of the report will be submitted within thirty (30) days after completion of work. A reproducible original of the final technical report will be submitted thirty (30) days after receipt of the sponsor's comments on and approval of the draft. The approving authority will be HQ AFESC. The reproducible original will be a "camera-ready" copy, reference MIL-STD-847B as amended by Appendix to CDRL of April 10, 1984. The final technical report shall be published as a joint AFESC/ORNL technical report.

5.0 SCHEDULE AND FUNDING REQUIREMENTS

5.1 Significant Events. The listing of significant events and of the various parts of this project are presented below:

- safety evaluations - accident simulations, new device testing and evaluations, diffusion studies, device storage and monitoring, and transportation packages evaluation (Sect. 3.1);
- license compilation and review (Sect. 3.2);
- training courses (Sect. 3.3);
- field demonstration and support (Sect. 3.4); and
- final Report (Sect. 4.1).

5.2 Funding. The elements requiring funding for this proposal are shown below:

- safety evaluations - accident simulations, new device testing and evaluations, diffusion studies, device storage and monitoring, and transportation package evaluations (Sect. 3.1);
- licensing compilation and review (Sect. 3.2);
- training courses (Sect. 3.3); and
- field demonstration and support (Sect. 3.4).

6.0 SPECIAL ACTIONS

6.1 Security Classification. It is anticipated that the security classification of this project will remain UNCLASSIFIED. If uncertain of the classification of the material, ORNL will tentatively classify the material "CONFIDENTIAL" until a final determination is made by the appropriate federal security authority.

6.2 Release of information. All information concerning developments under this contract shall be reported to other agencies through HQ AFESC. Until public release of the final technical report by the USAF, there shall be no briefings, presentations, publication, or information relative to this technical effort transmitted by ORNL without prior approval by HQ AFESC.

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*ORNL will provide periodic status reports, schedules, and program reviews as required by the program sponsor.

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