ARG PORTABLE NEUTRON RADIOGRAPHY

Final Report
April 1995

Prepared for
LOS ALAMOS NATIONAL LABORATORY

Subcontract 9-X73-0028E-1
Task 2 Phase 1 Part 2

Submitted by
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SPECIFIC NEUTRON RADIOGRAPHY MODELS

1. INTRODUCTION

In this report all available neutron radiographic data, including results of tests run at LANL, McClellan AFB, and University of Virginia, will be combined to outline specific transportable neutron radiography systems that could achieve the desired results as a complement to x-radiography capabilities for the Accident Response Group (ARG).

2. OBJECTIVES

2.1 GENERAL

One task is to determine the feasibility of using neutron radiography in a field situation to help determine the presence of high explosive powder entrapped in an internal joint of an aluminum alloy nuclear weapon, specifically in a region under consideration for on-site cutting or dismantlement.

A second task is to provide outline designs of alternative transportable neutron radiography systems that could be made available to the Accident Response Group (ARG) at Los Alamos National Laboratory to supplement the existing x-ray non-destruction testing capabilities.

A third task is to provide a cost-benefit analysis of the alternative systems including demonstration neutron radiographs showing the sensitivity that can be provided under the various conditions.

The preferred system outline design, together with the appropriate demonstration neutron radiographs, should be such that together they can provide the basis for a performance specification. This specification should be suitable for procurement of a system under a design-build contract. This would be similar to the way neutron radiography systems have been ordered recently at McClellan Air Force Base and the D.O.E. Pantex Plant.

2.2 POWDER IN CASE JOINT GAP

The following assumptions have been made concerning the object to be inspected.

- (1) The weapon is incased by a cylinder made of aluminum alloy similar to the dural from which the test arcs are constructed.
- (2) The diameter of the weapon case is in the range 12 to 14 inches, and the wall thickness is in the range 0.5 to 1.5 inches. These dimensions are represented by the test arc. The case (or test arc) will be neutron radiographed tangentially to the circumference.
- (3) The geometry of a circumferential case joint is as showing in Figure 1.
- (4) The quantity of high explosive powder that has to be revealed by neutron radiography if trapped in a deformed internal case-joint gap is as small as 0.050 x 0.25 x 1.5 inches (0.12 x 0.62 x 3.7 cm). This corresponds to 0.5 grams of H.E. ($0.27 \text{ cm}^3 \times 2 \text{ grams per cc}$).

2.3 RADIOGRAPHY REQUIREMENTS

The following assumptions have been made concerning the radiography:

- (1) The neutron radiography of the weapon may be performed in one of a range of weapon configurations as depicted in Figure 2.
- (2) The positions of the internal case-joint gaps will be apparent from an external visual examination of the weapon case.
- (3) The time that can be made available for on-site neutron radiography will be about four hours.

2.4 PROCEDURE ASSUMPTIONS

2.4.1 A typical neutron radiographic inspection might consist of a series of 24 neutron radiographs taken at different angles at a repetition rate (set up and exposure) of about 10 minutes.

2.4.2 Such a series of about 24 tangential neutron radiographs could provide extensive surveys of: (1) a particular joint region that is under consideration for a cutting operation; and (2) A particular joint

region at which the presence of entrapped H.E. in case joints is most likely.

2.5 TRANSPORTATION

One of the criteria by which alternative neutron radiography system designs will be compared concerns transportability. Standards for comparison are the vehicle mounted high energy x-ray system, or the Cobalt 60 gamma radiography system built to ARG specifications. It is assumed that a truck-mounted neutron radiography system could be moved by road, air, or sea to get as close as possible to the site of the weapon to be inspected. The movement of the neutron source between the vehicle and the actual weapon position would be a separate factor in the system design.

2.6 RELIABILITY FOR ARG

It is expected that the demand for ARG application will be very infrequent, but that if such demand arises, it will be urgent and without notice. System reliability is therefore an important criteria for comparison. For example a complex accelerator system, which may offer the advantage that it can be switched off when not in use, may compare poorly with an isotopic neutron source in terms of reliability of providing neutrons when needed.

2.7 AVAILABILITY FOR ALTERNATIVE APPLICATION AT LANL

With the Omega West Reactor at Los Alamos National Laboratory now shut down, the Nondestructing Testing Section does not have a practical on-site capability for neutron radiography to complement its other methods such as x-radiography. The shielded radiography room under construction at LANL could, at little extra expense, provide a neutron radiography capability using the same neutron source that is available on standby for almost immediate application to the ARG requirement. This dual-purpose design would offer a significant advantage in terms of effective reliability (including operator training).

2.8 COST BENEFIT CONSIDERATIONS

2.8.1 Government Surplus Equipment/Materials

Considerations of the cost of alternative systems should include the following facts:

- (1) Californium-252 has been available as a by-product of D.O.E. Basic Research Programs, and could be obtained at essentially no cost to the user (A small cost is associated with encapsulation, shipment, and replenishment of sources).
- (2) A transport cask may be available as government surplus equipment (licensing for use would require special consideration). We have contacted the Californium Center at Oak Ridge National Laboratory to discuss this.
- (3) An accelerator source type M.F. Physics A 711, was previously incorporated in a neutron radiography system built for the U.S. Navy. This equipment may be available as government surplus equipment, and we have contacted Mr. J. Rogerson at the Navy China Lake Center on this subject.

2.8.2 General Outline

The balance between cost of alternative systems and benefit of each system must consider the following:

- (1) System performance in terms of Neutron Radiographic Sensitivity: Options available such as collimator ratio, imaging method, exposure time, set up time.
- (2) System vehicle transportability
- (3) Ability to function with sufficient distance between vehicle and weapon.
- (4) Ability to perform radiographs at many angles around weapon.
- (5) Reliability
- (6) Ability to provide alternative neutron probe information at weapon.

- (7) Ability to provide a portable neutron radiography system for potential users other than the Accident Response Group - e.g., NEST, DOD, or police bomb squads.
- (8) Ability to make the neutron source routinely available to the Nondestructive Testing Section at Los Alamos National Laboratory for applications unrelated to ARG within LANL.

3. SUMMARY OF EXPERIMENTAL DATA

3.1 THE TEST ARC.

Three aluminum test arcs were used. Each consisted of five layers, any number of which could be assembled to represent sections of a weapon case with wall thickness in the range one quarter inch (1/4") to one and five sixteenths inches (1 5/16"). The three arc assemblies were identical except for the inclusions placed to represent entrapped high explosive powder.

The geometry of a Test Arc #5 using four layers is presented in Figure 3 and Figure 4.

The most important inclusion is a shim of plastic positioned centrally in between the halves of the split layer. (The split layer is the second from the inside). This plastic represents H.E. powder trapped in the orientation of the joint gap. The dimensions of the plastic were changed between certain experiments as recorded in Report #8.

3.2 NEUTRON BEAMS

Experiments were performed using the following:

- (1) MNRS CF-252 Source: 36 mg, CF-252, L:D = 30, 2×10^4 n/cm²-sec.
- (2) SNRS Triga Reactor: L:D = 100, Flux Variable with power.
- (3) University of Virginia: L:D = 30, Flux variable with power.

3.3 IMAGING DEVICES

Four different imaging devices have been evaluated:

- (1) Trimax-6 + Kodak TMH Film. (This is a medium speed Gadolinium oxysulfide screen).

- (2) NE426 + Kodak XRP Film (The NE426 is a mixture of LiF-ZnS.
- (3) NE426 + Polaroid 57 Film. (The film is a print type)
- (4) Electronic Imaging (Thomson Intensified, TV Camera, Processor).

3.4 SEPARATION BETWEEN INCLUSION PLANE AND IMAGING PLANE

The experiments on facilities MNRS and SNRS, at McClellan used a separation of 5 inches between the inclusion plane and image plane. (i.e. the image plane touched the edge of the arc).

The experiments on the University of Virginia Reactor used a separation of 6.5 inches which approximately equals the radius of a completed cylinder.

In practice, due to the curvature of the cylinder, the closest the image plan could be to the inclusion plane would be about 4 inches. However, separations greater than 4 inches will provide more latitude in positioning because the image of the inclusion will fall nearer the center of the image area.

For a collimator ratio of 30:1 and an object-image separation of 6.5 inches the geometric blur will be 216 mils (spread of a single object point at image plane). For a collimator ratio of 100:1 this blur will be 65 mils.

3.5 KEY DATA

A summary of key neutron radiography data is provided in Table 1. The image quality is a function of collimator ratio, imaging method, and neutron fluence. The neutron fluence is increased by (1) source strength increase; (2) collimator ratio decrease; and (3) exposure time increase. For a given collimator ratio the demonstration radiographs show the degree to which sensitivity is increased by changes in neutron fluence from 6×10^5 n/cm² to 1.6×10^7 n/cm² (i.e. exposure times of about 1 minute to 10 minutes for a 40 mg (CF-252 source).

The demonstration neutron radiographs confirm that a neutron fluence of about 10^6 n/cm² with a collimator ratio of 30:1 is capable of showing the presence of the 50 mil thick plastic inclusion in the orientation of the joint gap. This can be achieved by each of the three imaging methods: electronic

imaging, XRP transparency film, and polaroid print film (Table 1-5). For a neutron source strength equivalent to 40 mg. CF-252 this exposure time would be about 1 minute.

A significantly finer-grained radiograph could be provided by use of Trimax-6 screen with Kodak TMH Film with an exposure time extended to 13 minutes at the same 30:1 collimator ratio.

The highest sensitivity demonstrated uses a collimator ratio of 100:1 with the same Trimax-6 TMH Film, but in this case the required exposure time would be about two hours for 40 mg CF-252. This high sensitivity technique could be valuable if used to follow a preliminary survey using lower sensitivity, shorter exposure time neutron radiographs.

4. NEUTRON SOURCE TYPES - SHORT LIST

The choice of neutron source is the most important difference between alternative system possibilities. A large variety of isotopic source options and accelerator source options have been reviewed in earlier reports in this series. The four most practical options selected for comparison at this stage are: (1) 40 mg CF-252, (2) 0.4 mg CF-252, (3) accelerator type A 711 and accelerator type A 801. For any given source it is possible to change the collimator ratio, and the neutron imaging method with relatively little difficulty.

The chief differences between the californium and accelerator approaches are the reliability of the former, and the ability to switch off the latter. The chief difference between the high yield system (40 mg CF, A 711) and low yield systems (0.4 mg CF, A 801) is the change of performance capability for a given exposure time. A comparison of alternative source capabilities is given in Table 2.

5. SPECIFIC MODEL #1 (60-40 MG CF-252)

5.1 COMPONENTS

Source: 60 mg CF-252 (Decaying to 40 mg equivalent before 2 year replenishment)

Transport:	Dedicated vehicle.
Shielding:	Cask on or in the vehicle.
Collimator:	Small moderator-collimator unit. Positionable at weapon.
Imager:	Film, screen and cassette; or electronic imager and display.
Teleflex:	Cable to drive source remotely between shield and collimator.
Positioners:	Positioners for collimator and imager at weapon site.
Other:	Processing equipment for transparency film, video chain.

5.2 PROCEDURE

Inquiries to the Californium Center, Oak Ridge National Laboratory indicate that the 60 mg Californium-252 source could be obtained under the free loan scheme. Exchanges to replenish the source strength would be programmed each two years. Costs to LANL would be limited to encapsulation and shipment.

The chart of the elements including the actinide element Californium-252 is shown in Figure 5. The Californium source will be doubly encapsulated using the proven Model SA-CF-3000 as shown in Figure 6.

Prior to any ARG emergency the source would be stored in the Radiography Facility at LANL, to provide a routinely available neutron radiography capability.

A special vehicle (truck or trailer plus tractor) would be equipped with a transport cask for the source. The neutron radiography vehicle would be on permanent standby for the Accident Response Group use.

The transport casks that have been used satisfactorily for sources up to 80 mg CF 252 over the past several years weigh 9000 pounds and are known by the name Snowball (Figure 7). There are current plans to replace the Snowballs by a new cask. It is recommended that the cooperation of appropriate government authorities be sought to use these previously proven casks as government surplus property. If such a low cost approach is not possible, a second preference would be to utilize the design work now

underway for the cask replacement to assist relatively inexpensive cask manufacture.

When needed for ARG the source would be transferred from the LANL - NDT section Radiography Facility to the transport vehicle and cask using the teleflex cable technique as used for many years at other DOE and DOD centers. Procedures would be established to ensure this source loading could be rapid. The transfer vehicle complete with cask, source, and all associated equipment would be maintained ready for transport by road, or air cargo plane. The vehicle would be driven to a position close to the weapon.

Before the source is moved from the shield, a special moderator-collimator, designed to be suitably small and maneuverable, will be positioned to point the neutron beam in the required tangent to the weapon case-joint region of interest. The selected imaging device will also be placed in position at the weapon case (electronic or film imaging).

A teleflex cable source transfer arrangement will be used to move the source from the vehicle-shield to the collimator, and to return it after the required exposure time. During this source transfer and exposure an exclusion area will be defined to ensure personnel are not exposed to unacceptable radiation doses. Correct use of shielding may also be needed to ensure radiation exposure to the teleflex cable operator is kept to a minimum. A normal hand-crank source drive, such as is used for the Californium-252 source transfers at the McClellan Air Force Base Maneuverable Neutron Radiography System, should enable the transfer time to be kept to less than one minute. If necessary, a faster drive method could be used. Rapid source transfers will both lower personnel radiation exposure and lower total time between radiographs.

The electronics imaging display console and/or the film loading processing and inspection area will be set at a position sufficiently distant from the source to permit operation to work concurrently with source exposures.

5.3 SYSTEM CHARACTERISTICS

The neutron flux of 2×10^4 n/cm²-sec. at 30:1 collimation is sufficient to provide, in about 1 minute exposure times, radiographs of quality given by the demonstrations. Thus the dominant time is that needed for source transfer, and for repositioning of the collimator and imager. A repetition rate of about 10 radiographs per hour should be achievable if the source transfer and collimator repositioning time can be performed in about 5 minutes.

By extending the exposure times to about 10 minutes per radiograph, certain types of higher quality neutron radiographs are possible as shown by the demonstrations (Table 1). These include fine grain screen Trimax-6 with TMH Film, and higher collimator ratio (100:1) with the more grainy NE426-XRP Film. The repetition rate for such higher quality radiographs would permit about four radiographs per hour, or sixteen in the presumed four hour allotment.

6. SPECIFIC MODEL #2 (0.6 MG CF-252)

6.1 COMPONENTS

Source: 0.6 mg CF-252 (Decaying to 0.4 mg before 2 year replenishment)

Shielding: Transport cask smaller than the 9000 pound shield required for 60 mg system outlined above. The estimated cask weight for 0.6 mg CF-252 is about 1 ton.

Other components as for system described in 5.1 above.

6.2 PROCEDURE

Same as described in 5.2 above.

6.3 SYSTEM CHARACTERISTICS

The 0.4 mg Californium-252 source provides a neutron beam that is one hundred times less than the 40 mg system described in Section 5. This means that at a collimator ratio of 30:1 the minimum quality imaging technically require exposure times of 100 minutes. (e.g. electronic imaging

with 10^6 n/cm² fluence or NE426 + XRP film with 10^6 n/cm²). To obtain results with say 10 minutes exposures the collimator ratio would have to be reduced to 10:1 with the typical 6.5 inch separation between joint detail and image screen the geometric blur at 10:1 collimation would be unacceptable.

Higher quality imaging, such as Trimax-6 + TMH would be impractical with this source size, requiring about 20 hours per exposure at 30:1 collimation.

The 0.6 to 0.4 mg CF-252 system is included in the survey because it defines a nearly minimum source intensity that can provide one or two minimum quality neutron radiographs in a 4 hour time span. It is important to note that the weight of the transfer cask is reduced from about 5 tons for the 60 mg source to about 1 ton for the 0.6 mg source. Thus the advantage in transportability is not significant.

7. SPECIFIC MODEL #3 (ACCELERATION TYPE A 711)

7.1. COMPONENTS

Source:	Sealed tube Deuteron-Tritium Accelerator Type MF Physics A 711
Transport:	Dedicated vehicle
Shielding:	Not necessary (Source may be switched off and on)
Collimator:	The moderator-collimator will be significantly larger (or less efficient than that for systems using CF-252.
Imager:	Any of the range as for Systems 5 and 6.
Remote:	Cables of typical length 25 to 35 feet allow the sealed tube neutron source to be positioned at some distance from the more bulky power supply and coolant unit.
Positioners:	Equipment to position the moderator-collimator-sealed tube head as required to inspect the weapon case. Also positioners for the imagers.

Processing: Equipment required for electronic image processing and film processing.

7.2 PROCEDURE

Prior to any ARG emergency the accelerator would probably be housed in a radiography building at Los Alamos National Laboratory where it could be periodically maintained, tested, and used for unrelated nondestructive testing activities.

A special vehicle would be maintained nearby in standby condition on which the accelerator could be mounted at short notice. The vehicle, complete with all auxiliary equipment, would be prepared such that it could travel by air cargo plane and by road to be positioned as close as possible to the weapon to be inspected.

At the site of the weapon it would be determined whether the accelerator power supply and cooling unit can remain on the vehicle with the cable using the 25 to 35 foot long high tension cables to lead to the sealed tube source at the weapon position. If necessary the power supply and cooling unit should be capable of being moved from the vehicle towards the radiography site by means of a specially provided tractor. The accelerator auxiliaries would be linked to an electricity generator on the vehicle using long electrical leads.

A specially designed moderator-collimator, which houses the sealed tube neutron source will be positioned close to the weapon case. The orientation will be adjusted such that the neutron beam will pass in the location and direction required. Likewise the imaging system will be positioned to match the line of inspection.

With all equipment in place an exclusion area will be set up to ensure that any radiation exposure to operators is kept to a minimum.

The accelerator will be switched on, tuned, timed, and switched off to provide the required exposure using the remote accelerator control panel.

Previously prepared calculations will be used to determine the combination of distance and/or shielding that is necessary to keep radiation levels at the accelerator control panel to acceptable levels.

As for the systems described in Sections 5 and 6 above the electronic imaging console and/or the film processing area will be set at a sufficient distance from the source to permit operators to work concurrently with the neutron exposures.

The repetition rate possible will be determined by the exposure time required (typically 1 minute to 10 minutes) and the time needed after accelerator switch off to approach the moderator-collimator-source and reposition it along with the imager.

7.3 SYSTEM CHARACTERISTICS

There is valuable experience with the design and operation of neutron radiography systems utilizing the D-T type MP Physics A 711 accelerator. In particular trials with the A 711 System built by Science Applications International Corporation for the U.S. Navy were conducted at McClellan Air Force Base. They showed that the neutron radiography beam at a given collimator ratio (30:1) is approximately equal to that of a 40 mg CF-252 System.

The 40 mg CF-252 source has a total neutron yield (before moderation) of about 8×10^{10} n/sec with a spectrum of neutron energies peaking at about 2 MeV. The D-T Accelerator has a total neutron yield that is in the range 10^{11} n/sec to 5×10^{10} n/sec depending on sealed tube target degradation and accelerator tuning. The neutrons from the D-T reaction essentially all have energy of 14 MeV. This significantly higher energy causes several differences:

- (1) The moderator surrounding the D-T sealed tube needs to be significantly larger than for 60-40 mg CF-252 both because of the higher energy of the original neutrons, and because of the displacement caused by the relatively large sealed tube.

- (2) Even of a moderator volume of unrestricted size was possible, the ratio of peak thermal flux at the collimator entrance to fast neutron yield (the inverse thermalization factor) would be smaller (inferior) for a D-T source. This is simply because 14 MeV neutrons cannot be moderated as compactly as lower energy neutrons.
- (3) The reduction in peak thermal neutron flux can be compensated by placing a volume of natural or depleted uranium around the sealed tube neutron source. The 14 MeV neutrons react with the uranium through the fast fission process giving a boost to the fast and thermal yield.
- (4) The uranium booster, if used, would require extra attention concerning licenses that might be needed for interstate and international transport. Also, attention will be needed during repetitive operation to ensure that induced radioactivity has decayed sufficiently for an operator to approach the source for repositioning.
- (5) Comparing CF-252 and D-T neutron sources of equal fast neutron yield (e.g., $8 \times 10^{10} \text{ n/sec}$) it should be noted that the 14 MeV neutrons are more difficult to shield from personnel and produce greater biological damage on a per neutron basis.

If a uranium boosted D-T accelerator design is used the neutron exposure times required will be essentially the same as with the 40 mg CF-252 system. If uranium is not used, the exposure times required would be about twice as long (e.g. 26 minutes for a Trimax-6 TMH Film at 30:1 collimation).

8. SPECIFIC MODEL #4 (ACCELERATOR TYPE MF PHYSICS - A 801)

8.1 COMPONENTS

Source - Small D-T accelerator type MF Physics A 801.

Other - As for system outlined in Section 7, above.

8.2 PROCEDURE

The procedure would be as for Section 7, above, with the following critical exceptions. The neutron yield of the A 801 accelerator is less than that of the A 711 accelerator described in Section 7 by a factor of about 100. (The 801 yields 5×10^8 n/sec but tube causes much less moderator displacement.)

It is therefore unlikely the accelerator could be of value for routine neutron radiography requirements at LANL prior to any ARG requirement.

More importantly the exposure times for weapon case inspections would be 100 times longer than those given for a 40 mg CF-252 source. A single neutron radiograph could require upward of 100 minutes exposure and be of minimal quality (very low collimator ratio, very high graininess). Thus, the system would be of little practical value.

8.3 SYSTEM CHARACTERISTICS

The A 801 accelerator has a tube dimension 24" x 4" diameter. The target is less than 6" from the end. The yield in continuous mode is 5×10^8 n/sec (10^8 n/pulse x 5 pps at 100% duty). Thus two could be purchased for \$70K and used head-to-head or side-by-side. Yield 10^9 n/sec. (only about 50 x less than 711 at 5×10^{10}). Moreover, the small diameter should give much improved thermalization.

Cable length is limited to about 30' or 35' as for A 711 but the power supply is much lighter (140 pounds with console). Console can be separate, at any distance.

Replacement tubes are about \$12K. Shelf life is about 1 year. Therefore, operation maintenance cost would be about 24K/yr for tubes.

9. INDUSTRY SURVEY

9.1 INTRODUCTION

It is recommended that procurement of a custom designed neutron radiography system could be organized by the user (LANL) in a way similar

to that used for other recent neutron radiography systems at government centers (McClellan Air Force Base, Pantex, etc.), such that a solicitation is issued to permit any and all qualified industries to compete through submission of bids. As for the previous government procurements, a preliminary survey of known industry suppliers is an important step to ensure that the possible solicitation for bids is founded on the best available knowledge concerning industry capabilities and costs. In this industry survey information has been sought primarily from certain centers that might supply neutron sources; and from companies that have previously undertaken the prime-contractor responsibility to design, integrate, and build neutron radiography systems custom designed to meet the users performance specifications.

9.2 CALIFORNIA CF-252 SOURCE

Points of contact are:

Dr. Joe Knauer
Associate Manager
Radiochemical Engineering Development Center
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, Tennessee 37831-6384
Phn: (615) 574-5909 Fax: (615) 576-6312

Also at the same address:

Dr. John Bigalow	(615) 574-6926	
Dr. Chuck Alexander	(615) 574-7071	
Ms. Kathy Simmons		Licensing of transport casks
Mr. Paul Balo	(615) 574-7071	Custom Liaison - CF-252
Ms. C.M. Simmons	(615) 574-7071	New cask project coordinator

There has been a substantial history in the supply of Californium-252 sources for neutron radiography systems. These include:

- (1) 50 mg CF-252 - Mound Facility, Ohio (DOF) 1980 - 1992 Approximately.
- (2) 100 mg CF-252 - McClellan Air Force Base, California 1989 - Present.

(3) 150 MG CF-252 Pantex Plant (DOE) under construction.

In each of these situations: (1) the sources have been provided without cost to the user (except for encapsulation and shipment costs); and (2) the teleflex cable technique is used to move sources out of the transport cask to a remote position.

The costs quoted in July 1994 to the Pantex Plant were:

Source Fabrication (per source)	\$17,000
Shipment (per source)	\$10,000
Miscellaneous Loan Fee, etc.	\$20,000

Assuming one source of 60 mg is used and exchanged each 2 years to compensate the 2.5 year half life, the initial cost would be about \$50K and the estimated annual cost would, in 1995 dollars, be approximately \$25K, to maintain acceptable source strength.

9.3 CALIFORNIUM-252 TRANSPORT CASKS

There are two identical casks routinely used by Oak Ridge National Laboratory for transport of up to 80 mg of CF-252. They have been named Snowball casks (See Figure 7). They weigh 4.5 Tons (there is also a so-called cannon-ball cask which is heavier). At the present time a design is under way at ORNL for a replacement cask. When the replacement is built, licensed, and put into use it is anticipated that the Snowball casks would become government surplus equipment.

Two possibilities are foreseen for the LANL project:

- (1) Seek special licensing exemption or authority (DOD, DOE, NRC or IAEA) to use one of the surplus but well proven Snowball casks in standby capacity for nuclear weapons emergencies.
- (2) Take advantage of the new ORNL design in licensing approvals for that design to simply have an extra copy manufactured by the lowest bidder for use in the LANL project.

The estimated cost of using a surplus Snowball is near zero. The estimated cost of materials and manufacture for a copy of the new ORNL is

under \$300,000.

Concerning licensing of the Snowball, the following points should be considered:

- (1) The source shipments between ORNL and LANL would be the newly license ORNL cask, the surplus Snowball would only be used if and when there is a nuclear weapon emergency. Therefore, it seems possible it might receive special DOD/DOE licensing exemptions as would be appropriate for nuclear weapons shipments themselves.
- (2) The snowball casks have been proven over many years of use, and this use has included air cargo flights for shipments to Amersham in England.
- (3) The existing license for the Snowball cask is expected to expire, which is the reason the new design work is underway.
- (4) Although the Snowball is routinely placed on a long flat bed trailer for road transport, the ORNL staff see no reason why it could not be fitted into a much smaller vehicle, enclosed or otherwise, such as might form the basis of a dedicated LANL-ARG transportable system.

Concerning the new cask under design by ORNL the following can be noted:

- (1) The design will feature a primary shield and secondary shield such that in a major fire situation the primary shield will provide much stronger resistance.
- (2) The design will be for 60 mg CF-252. Weight will be about 5 tons.
- (3) Materials under consideration include tungsten, boronated water extended polyester (WEP), or Bisco, a product of Nuclear Insurance Corporation. Dose rates will be 120 Mr/hr in contact, and 7.5 mr/hr at 2 meters.
- (4) ORNL staff think the most practical license approach might be NRC, DOT and IAEA. The option of license by DOE (involving Argonne National Laboratory) is a second choice at this time.

9.4 ACCELERATOR NEUTRON SOURCES (NEW)

Points of contact are:

Mr. Manfred Frey
M.F. Physics Corporation
5074 List Drive
Colorado Springs, CO 80919
Phn: (719) 598-9545 Fax: (719) 598-2599

Dr. W. Hamn
ACC SYS Technology, Inc.
1177 Quarry Lane
Pleasanton, CA 94566
Phn: (510) 462-6949

Mr. S. Cluzeau
Sodern
20 Avenue Descantes
94451 Limeil-Brevannes
France
Phn: 33-1-45-95-70-66 Fax: 33-1-45-69-1402

The A 711 type generator can be purchased new from MF Physics at a cost of \$125,000. The accelerator sealed tube has a guaranteed life of 2000 m amp hours. Replacement tubes cost \$18,000. The standard cable length between high voltage supply and tube is 25 feet, but a maximum of 35 feet is possible. The weight of the power supply could be reduced from the present 900 pounds to about 300 pounds at a cost in development money of about \$200,000. Likewise, the weight of the coolant unit could be reduced to about 300 pounds.

The accelerator Type A 911 has been developed for time of flight work, and is more expensive than the A 711. The accelerator type A 801, yields 10^8 neutrons per pulse at five pulses per second, averaging 5×10^8 n/sec. Weight of power supply and control unit is about 120 pounds. Normal cost is \$50K but two can be purchased now for a total of \$70K.

9.5 ACCELERATOR NEUTRON SOURCES (SURPLUS)

Points of contact are:

Mr. Frank Bergamo
6120 Moorfield Avenue
Colorado Springs, CO 80919
Phn: (719) 531-6559 Fax: (719) 531-0192

Mr. Donald Jon Rogerson
U.S. Navy China Lake
Code 6211, NAWS
China Lake, CA 93555
Phn: (619) 939-7497

Mr. Bergamo can provide an A 711 type accelerator that has been reconditioned at a price about 70 percent of a new machine.

Mr. Rogerson anticipated that the A 711 and other equipment delivered by SAIC to the Navy will soon become surplus. It will require some minor reconditioning to put back into working order. (Estimated at \$30K).

9.6 SYNERGISTIC DETECTOR DESIGN (SYSTEMS INTEGRATOR FOR NEUTRON RADIOGRAPHY)

Points of contact:

Dr. A. Rogers
Synergistic Detector Designs (SDD)
5055 Brandin Court
Phn: (510) 438-9001 Fax: (510) 438-9007

This company won the contract (in competition with GA) for the new NR system at the DOE Pantex Plant. This is a design build contract for a turnkey system built to a performance specification (N.R.E. consultant to user). In a review of the systems proposed for the ARG application at LANL, Dr. Rogers found no problems with the design concept and provided a cost estimate that is consistent with the budget for the complete turnkey system based on 60 mg CF-252.

9.7 SCIENCE APPLICATIONS INTERNATIONAL INCORPORATED

Points of contact:

Dr. V. Orphan
SAIC
4161 Campus Point Ct.
San Diego, CA 92121
Phn: (619) 458-5102 Fax: (619) 458-5140

This company won the contract (in competition with LTV) to provide the neutron radiography system (based on the A 711 accelerator) for the U.S. Navy North Island. This was a design build contract for a turnkey system built to performance specifications (N.R.E. Consultant to user).

In a review of the systems proposed for the ARG application at LANL, Dr. Orphan also found no problems with the design concepts. On the question of cost, it was the SAIC view that the design should be as simple as possible to keep within budget (Design costs could otherwise be high).

9.8 GENERAL ATOMICS COMPANY

(SYSTEM INTEGRATOR FOR NEUTRON RADIOGRAPHY)

Point of contact:

Dr. W. Whittemore
General Atomics
P.O. Box 85608
San Diego, CA 921186-4784
Phn: (619) 455-3276 Fax: (619) 455-4169

This company won the contract to provide the neutron radiography system-SNRS (Based on a Trigh Reactor) for McClellan A.F.B. This also was a design-build contract for a turnkey system built to performance specification (N.R.E. consultant to user).

Dr Whittemore reviewed the technology of the systems proposed for the ARG application at LANL and found no major problems. He did add data on the subject of reciprocity law failure for long duration film exposures. He also emphasized the advantage of keeping object-film separation to a minimum to limit blue^l. On the questions of whether General Atomics would be interested to bid as a potential prime contractor, Dr. Whittemore suggested that only a sole source contract would be of interest as they could not afford

the proposal effort needed if lower priced companies stood that competitive advantage. (They have recently bid and lost several similar projects for government centers.)

10. CHARACTERIZATION OF SYSTEMS BY SIZE AND WEIGHT, ETC.

The size, weight, site-reach, and similar parameters of the systems are compared in Table 3. The following points are important:

- (1) The size and weight of the moderator-collimator-source (MCS) for the Californium-252 systems can be reduced to permit practical maneuverability and angulation at different orientations to the weapon case. The MCS for the accelerator A 711 will be significantly larger and heavier. There are two reasons. First the tube is larger (24' long, 10" diameter) and therefore it displaces considerable moderator. Secondly, the neutrons are high energy (14 MeV) and take much room to slow to thermal energy. The MCS is therefore far less practical.
- (2) Because teleflex cables can be operated over large distances there is practically no limit on the reachability between the vehicle for a Californium-252 source system and a weapon site which cannot be closely approached by the vehicle. By comparison, the high tension cables needed to link the A 711 accelerator head to the heavy and bulky high voltage power supply unit and coolant unit is limited to about 35 feet. Therefore, the reachability for the A 711 accelerator system is significantly less practical
- (3) The size and weight of the equipment to be mounted on the transport vehicle falls within a practical range for each of the four systems being compared. The relatively heavy transport cask (about 9,000 pounds) puts the 60 mg CF-252 system at no significant disadvantage in comparison with the other systems because the cask can be easily included as part of the vehicle design, and the procedure does not required that the cask at any time be removed from the vehicle.

11. COST ANALYSIS

11.1 INTRODUCTION

The cost analysis of the four alternative system models is summarized in Table 4. Factors that effect the total cost of a system include procurement costs and operations costs.

Procurement costs include initial cost of source and cost of a fixed price contract to a prime contractor for design-build, installation, acceptance tests and operator-maintenance training. Possible allowance for use of government surplus equipment is identified in Table 4 but is not included in the procurement cost total.

Operating costs include replacement of sources of accelerator parts, personnel costs for maintenance, licensing costs, decommissioning costs if any (annualized) and operator training with health physics support costs (annualized). Possible allowance for credit due to dual use of the ARG system is identified but not included in the operation cost and depreciation cost annualized total.

11.2 INITIAL COST OF NEUTRON SOURCE

For System #1 (60 mg CF-252) and System #2 (0.6 mg CF-252 (the Californium-252 is available on the government users loan program providing that the original source is returned to the supplier (Oak Ridge National Laboratory) at replacement intervals. This is because the decay products, not the Californium-252, are the isotopes of prime value to ORNL. The costs of borrowing the Californium-252 to the user (LANL) are therefore relatively low; about \$20K for encapsulating and \$30K for other services including shipment.

For System # 3 (A 711 accelerator), the cost of a new machine is \$125K and a further \$75K will cover miscellaneous installation, training, and spare parts costs. For System #4, we would recommend purchase of the two available A 801 Systems for use together to double the neutron yield and increase reliability that at least one will be in operational condition at any time

of emergency need. (The accelerator target is less than six inches from the end of the four inch diameter accelerator tube, which could therefore be placed end-to-end or side-by-side.

11.3 TOTAL COST OF DESIGN-BUILD CONTRACT

In addition to the neutron source, the components to be provided by a system integrator under a design-build contract include the vehicle, the source shield-transport cask (for CF-252), the teleflex cable (for CF-252, the moderator-collimator, the imager, positioner for MCS, positioner of imager, and image processing equipment. In the industry survey the total cost of the design-build contract was estimated to be about \$600,000, including the cost of cask (CF-252) or the accelerator (for a A 711). The low yield System #2 and System #4 would not be significantly different in price.

11.4 GOVERNMENT SURPLUS EQUIPMENT

The possibility to use a Californium-252 transport cask (Snowball) that will soon be government surplus equipment could provide reduction in the cost estimate. Alternatively, it is assumed that the new cask design and licensing, underway at ORNL, can be utilized, limiting the cask costs to simply materials and manufacture.

If the System #3 were selected, the possibility should be researched that one of three A 711 accelerators previously used for neutron radiography could be used. These were at AMREC, LTV-VOUGHT, and Navy China Lake. In addition, a reconditioned A 711 source is available privately for purchase. (See Progress Report #3, Appendix 3D). Use of surplus equipment could provide savings estimated at \$100K minimum.

11.5 DEPRECIATION

Certain components of each system will have a relatively rapid rate of depreciation (e.g. 10 years life for the vehicle, 2 years for the batteries in the vehicle, one year for the accelerator tubes of the D-T accelerators). The allowance for depreciation per year is an aggregate of all such components.

Because the major cost components of Systems #1 and #2 are items

such as transport cask, and teleflex cable, whereas the major cost components for System #3 and #4 are complex electrical equipment, it is estimated that the average effective life for depreciation of Systems #1 and #2 is longer (about 20 years) as compared with the life for Systems #3 and #4 (about 10 years).

11.6 REPLACEMENT OF SOURCE

The Californium-252 decays with a half life of 2.5 years. Therefore, each two years there will be the expense of \$50K for source encapsulation and shipment. This is \$25K per year. The accelerator tube heads have a shelf life limited to about one year. Even if not used to generate neutrons, the accelerator tube replacement costs will be \$20K per year for one A 711 tube and \$24K per year for two A 801 tubes, assuming the System 4 is designed to use two type A 801 accelerators. If the systems are used to generate neutrons for extensive periods, tube replacements will be needed after operation for 100 hours (System 3) or 24 hours (System 4).

11.7 MAINTENANCE COST

The cost to maintain the systems can be divided into the costs of any replacement parts necessary, and the costs of labor. It is estimated that the dominant maintenance cost will be the cost of the fraction of personnel time allocated to servicing the equipment. On an annualized basis it is estimated that the maintenance cost will be significantly less for the Californium-252 systems (\$20K per year) than for the accelerator systems (\$100K per year).

11.8 LICENSING AND ADMINISTRATION COSTS

After the initial licensing and other administrative costs have been covered in the capital cost of procurement there will be an ongoing but low level cost for such support throughout the life of the system. It is estimated that this ongoing cost need not exceed \$20K per year for each of the alternative systems. (Representing a fraction of the time of one full time employee).

11.9 DECOMMISSIONING COSTS

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While it is necessary to consider decommissioning costs, it is not anticipated that there will be any significant cost liability in this category. Allowance has been made elsewhere for the shipment of any Californium-252 sources back to ORNL or the shipment of accelerator tubes (containing tritium) back to the supplier.

11.10 OPERATOR TRAINING COSTS

Again, after initial system procurement and operator training there will be a need for a continuing periodic training of personnel including operations staff and physics staff. This is estimated to require a fraction of a full man year each year, and to not exceed \$40K per year for any of the four alternative systems.

11.11 CREDIT FOR DUAL AVAILABILITY OF NEUTRON SOURCE

A neutron source of 60 mg Californium-252, while in standby readiness for the ARG requirement, could provide Los Alamos National Laboratory with a valuable resource for neutron radiography and other application requiring a neutron source of steady and reliable output. This benefit is particularly timely given the recent permanent shutdown of the Omega West Nuclear Reactor at LANL, and given the plans to construct a new radiography facility to provide primarily x-ray nondestructive testing capabilities. The 60 mg CF-252 could, in fact, provide inhouse neutron radiographs of a quality equalling the reactor quality gadolinium metal-singler ^{finer} fine grain film neutron radiographs at 10:1 collimator as perfected at Aerotest, Inc., or similar neutron radiography specialty centers. Although it could be appropriate to allow some credit for this benefit against both the capital cost of the ARG System #1 and the operating cost of the ARG System #1. The cost analysis data presented in Table 5 lists the possibility of a credit only against operating costs. A somewhat smaller operating cost credit is listed for the System #3 based on the A 711 type neutron generator. For System #2 and #4, the neutron source strength would be too low to be of significant value in providing standby neutron radiographic capability at LANL.

12. COST-BENEFIT ANALYSIS

12.1 RADIOGRAPHIC PERFORMANCE

The radiographic performance characteristics of the alternative systems are compared in Table 5. Note that for the System#1 which is based on Californium-252, the data is for the worst case situation where the system is needed when the source strength has decayed from 60 mg CF equivalent to 40 mg DF equivalent. (0.4 mg for System #2). This contrasts with the best case assumptions used for the accelerator data. (Uranium booster assumed for A 711 accelerator, two generators increase yield for A 801 accelerator).

12.2 COMPARATIVE CHARACTERIZATION OF THESE 4 MODELS

The System #1 based on 60 mg CF-252 is the one most strongly recommended. System #2 (0.6 mg CF) and System #4 (low yield accelerator type A 801) provide neutron fluxes that are so low that the systems could not provide neutron radiographs sufficient in both quality and quantity.

System #3 (Accelerator Type A-711) is a workable alternative but in comparison with 60 mg CF-252 there are multiple disadvantages listed below in order of decreasing importance.

- (1) The moderator-collimator will be larger than needed for good accessibility to all weapon case orientations, due to the large volume of the sealed D-T tube, and the high energy of the fast neutron (14 MeV).
- (2) The moderator-collimator source may not be located far from the bulky power unit and coolant unit due to limits on practical high tension cable lengths.
- (3) There can be no assurance that the accelerator will work exactly when required. Although the accelerator is well proven and reliable relative to most other types of accelerators, it is still a complex set of high voltage electrical equipment, and it in no way can compete with the isotopic source system for reliability.
- (4) The tritium and the possible uranium booster are special nuclear materials which may raise problems for licensed international travel.

- (5) The shielding of the operator will be more difficult than the 60 mg CF-252 system due to the high energy neutrons (14 MeV).
- (6) The accelerator system will require more specially trained operators and maintenance personnel than the isotopic source system. Without suitably skilled personnel, the accelerator system will be unavailable for use.

12.3 OVERALL MERITS OF SYSTEM MODELS

In Table 6, the various merits of the alternative systems are compared. The System #1 based on an initial 60 mg Californium-252 (or an eventual 40 mg CF-252 after decay) is clearly the preferred approach when all aspects are taken into account of the cost versus benefits analysis: radiographic performance, transportability, versatility in the field, ability to operate without specialist maintenance engineers, reliability to operate without specialist maintenance engineers, reliability, and value of neutron source for dual uses - ARG and LANL NDT capability. A schematic outline of the recommended system is shown in Figure 8.

TABLE 1 (SECTION 3.5)

SUMMARY OF KEY NEUTRON RADIOGRAPHY TEST DATA OBTAINED FOR ALUMINUM ARC 1 1/16" THICK WALL, 0.050" THICK INCLUSION

COLLIMATOR RATIO L:D	NEUTRON FLUX N/CM ² -SEC.	IMAGER TYPE	CONVERTER SCREEN	IMAGING DISPLAY	NEUTRON FLUENCE N/CM ²	EXPOSURE TIME MINUTES (APPROX)	SENSITIVITY TO 50 MIL INCLUSION ARG TEST	*QUALITY OF IMAGE*	DEMONSTRATION RADIOGRAPH R = REPORT # E = EXP #	SOURCE DATA	
30:1	2 X 10 ⁴	Transparency	Trimax-6	TMH	1.6 x 10 ⁷	13	Yes	High	R4, E6	CF, 36 mg	
"	"	"	NE426	XRP	10 ⁸	1	"	Medium	R5, E6	Reactor U of Virg.	
"	"	Print Film	?	57 Polaroid	6 x 10 ⁵	0.5	"	Low	R4, E7	CF-36 mg.	
"	"	Electronic	GD ₂ O ₂ S	2048 Frames	1.6 x 10 ⁶	1	"	Medium	R4, E8	CF-36 mg.	
"	"	"	"	512 Frames	4 x 10 ⁵	0.3	"	Low	"	"	
100:1	2 x 10 ³	Transparency	Trimax-6	TMH	1.6 x 10 ⁷	130	"	Very High	R4, E10	Reactor SNRS	
"	"	"	NE426	XRP	10 ⁸	10	"	"	"	"	Extrapolated Data
"	"	Print Film	?	57 Polaroid	6 x 10 ⁵	5	"	"	"	"	"
"	"	Electronic	GD ₂ O ₂ S	2048 Frames	1.6 X 10 ⁶	10	"	"	"	"	"
"	"	"	"	512 Frames	4 x 10 ⁵	3	"	"	"	"	"

Note (1) This neutron flux for the same collimator ratio would be provided by either 40 mg CF-252 or Acceleration Type A 711 with uranium booster. A source starting at 60 mg CF-252 and replenished at 2 year intervals would exceed the 40 mg CF-252 performance.

TABLE 2

**EFFECT OF DIFFERENT SOURCE CHOICES
COMPARISONS USING CONSTANT IMAGING METHODS**

NEUTRON SOURCE TYPE	NEUTRON SOURCE SIZE OR MODEL	COLLIMATOR RATIO L:D	NEUTRON FLUX N/CM ² -SEC.	IMAGER TYPE	IMAGE DISPLAY	NEUTRON FLUENCE N/CM ²	EXPLOSIVE TIME (MINUTES)	REFERENCE TO DEMONSTRATION RADIOGRAPH
CF-252	40 mg	30:1	2×10^4	Electronic or NE426	1024 Frames XRP	10^5	1	R4 Exp 8
		100:1	2×10^3	"	"	"	10	R8 Exp 6
"	0.4 mg	30:1	2×10^2	"	"	"	100	"
Accelerator	M.F.P. A 711	30:1	2×10^4	"	"	"	1	"
		100:1	2×10^3	"	"	"	10	-
Accelerator	M.F.P. A-801 Two Generators	10:1	2×10^3	"	"	"	10	-
		30:1	2×10^2	"	"	"	100	"

TABLE 3 (SECTION 10)**SIZE, WEIGHT, AND PRACTICALITY CHARACTERISTIC OF SYSTEMS**

SYSTEM MODEL #	1	2	3	4
NEUTRON SOURCE	40 mg CF	0.4 mg CF	Accelerator A 711	Accelerator A 801
MODERATOR-COLLIMATOR-SOURCE (MCS) To be positioned at weapon SIZE DIAMETER (Estimated) INCHES	6	6	24	12
WEIGHT (Estimated) POUNDS	20	20	100	100
SUPPORT UNITS NEEDED NEARBY HIGH VOLTAGE POWER UNIT (POUNDS)	N/A	N/A	900	100
COOLANT UNIT (POUNDS)			600	100
LIMIT TO SEPARATION BETWEEN SUPPORT UNITS AND MCS. (FEET)	N/A	N/A	35	35
(NEED FOR TRACTOR)	NO	NO	YES	NO
OPERATOR CONSOLE-NEED FOR SHIELD OR LARGE DISTANCE TO REDUCE RADIATION	POSSIBLE	NO	YES	NO
VEHICLE MOUNTED CHARACTERISTICS SIZE OF EQUIPMENT OR CASK (FEET DIAMETER)	8	5	15	8
WEIGHT OF EQUIPMENT OR CASK (POUNDS)	9000	1,500	3,000	1,000
OVERALL FLEXIBILITY AND UTILITY OF SYSTEM FROM SIZE & WEIGHT PERSPECTIVES	EXCELLENT	EXCELLENT	POOR	OKAY

TABLE 4 (SECTION 11)
COST CHARACTERISTICS OF SYSTEMS

NEUTRON SOURCE		60 mg CF	0.6 mg CF	Acc A 711	Acc A 801 x 2
CAPITAL COSTS (PROCUREMENT)					
INITIAL COST OF NEUTRON SOURCE					
CF-252 (Encapsulation) Acc. (Purchase)	K\$	20)	20)	125)	70)
CF-252 (Shipment) Acc (Commissioning)	K\$	30) 50	30) 50	75) 200	30) 100
TOTAL SYSTEM ESTIMATE COST OF DESIGN-BUILD CONTRACT	K\$	600	500	600	500
SAVINGS IF GOVERNMENT SURPLUS EQUIPMENT CAN BE USED					
CF-252 (Transport Cask), Acc(A 711-Navy)	K(\$)	100	-	100	-
TOTAL PROCUREMENT COST ASSUMING NO USE OF SURPLUS EQUIPMENT	K\$	650	550	800	600
TOTAL PROCUREMENT COST ASSUMING USE OF SURPLUS EQUIPMENT	K\$	550	550	700	600
ANNUALIZED CAPITAL COST					
ESTIMATE OF LIFE (Years over which cost amortized).	Yrs.	20	20	10	10
DEPRECIATION COST PER YEAR	\$/Yr.	30	25	50	50
ANNUALIZED OPERATING COSTS					
REPLENISHMENT/REPLACEMENT COSTS PER YEAR					
CF-252 (Source exchange), Acc (Tube exchange)	K\$	25	25	20	24
OTHER MAINTENANCE COST (Personnel cost, etc.)	K\$/Yr.	20	20	100	50
LICENSING AND ADMINISTRATIVE COSTS	K\$/Yr.	20	20	20	20
DECOMMISSIONING COSTS IF ANY	K\$	0	0	0	0
OPERATOR TRAINING COSTS PER YEAR	K\$	40	40	40	40
SAVINGS IF CREDIT TAKEN FOR DUAL USES AT LANL	K(\$/Yr)	50	0	20	0
TOTAL ANNUALIZED OPERATING COST ASSUMING NO CREDIT FOR DUAL USE		105	105	180	134
TOTAL ANNUALIZED OPERATING COST ASSUMING CREDIT FOR DUAL USE		55	105	160	134

TABLE 5 (SECTION 12)

PERFORMANCE CHARACTERISTICS OF SYSTEMS

SYSTEM MODEL #	1	2	3	4
NEUTRON SOURCE	40 mg CF	0.4 mg CF	Accelerator A 711 + URANIUM	Accelerator A 801 x 2
FAST NEUTRON YIELD N/SEC II	8×10^{10}	8×10^{10}	8×10^{10}	$2 \times 5 \times 10^8$
NEUTRON ENERGY MeV. (Mean)	2	2	14	14
PEAK THERMAL NEUTRON FLUX n/cm ² -sec	4×10^8	4×10^6	4×10^8	4×10^6
THERMAL FLUX AT COLLIMATOR OUTPUT (30:1)	2×10^4	2×10^2	2×10^4	2×10^2
TRIMAX-6 TMH FILM AT 30:1 EXPOSURE TIME (MINS)	13	N/A	13	N/A
NE426 XRP FILM AT 30:1 EXPOSURE TIME (MINS)	1	100	1	100
ELECTRONIC 512 FRAMES AT 30:1 EXPOSURE TIME (MINS)	0.3	30.	0.3	30
TRIMAX-6 + TMH AT 100:1 EXPOSURE TIME (MINS)	130	N/A	130	N/A
NE426 - XRP AT 100:1 EXPOSURE TIME (MINS)	10	N/A	10	N/A
ELECTRONIC 512 FRAMES AT 100:1 EXPOSURE TIME (MINS)	3	5 HRS	3	5 HRS

TABLE 6 (SECTION 12)**BENEFITS OF ALTERNATIVE SYSTEMS**

SYSTEM MODEL #	1	2	3	4
NEUTRON SOURCE	40 mg CF-252	0.4 mg CF	A 711 + URANIUM	A 801 x 2
RADIOGRAPHS TYPE $10^6\text{N}/\text{CM}^2$, 30:1 L/D PER 4 HOURS	40	2	40	2
RADIOGRAPHS TYPE $1.6 \times 10^7\text{N}/\text{CM}^2$, 30:1 L/D PER 4 HOURS	12	NO	12	NO
RADIOGRAPHS TYPE $1.6 \times 10^7\text{N}/\text{CM}^2$, 100:1 L/D PER 4 HOURS	2	NO	2	NO
EASE OF TRANSPORTING SYSTEM TO SITE	GOOD	GOOD	GOOD	GOOD
EASE OF EXTENDING SOURCE FROM VEHICLE	GOOD	GOOD	LIMITED	LIMITED
EASE OF POSITIONING MCS AT WEAPON CASE	GOOD	GOOD	LIMITED	LIMITED
EASE OF OPERATING WITHOUT SPECIALIST EXPERIENCE	GOOD	GOOD	NO	NO
RELIABILITY	GOOD	GOOD	LIMITED	LIMITED
OVERALL MERIT RANK FOR ARG REQUIREMENT	BEST	POOR	MODERATE	POOR
OVERALL MERIT FOR DUAL APPLICATION AT LANL	BEST	POOR	MODERATE	POOR

FIGURE 1

CIRCUMFERENTIAL JOINT IN NUCLEAR WEAPON CASE

FIGURE 2

DIFFERENT CONFIGURATIONS FOR NUCLEAR WEAPON
AT THE PLACE WHERE INSPECTION IS DESIRED

2.1 FLAT ON GROUND

2.2 EXCAVATION POSSIBLE

2.3 INCLINED - PROTRUDING

2.4 LOCAL HOIST OR CRANE
USED TO RAISE WEAPON

MATERIAL = DURAL

INCLUSIONS

Four holes drilled from inner surfaces of split layer each with depth = diameter (as shown). Each filled with H.E. simulated.	
Simulated H.E. Powder	280" x 250"
⊙	100" x 100"
⊙	200" x 200"
⊙	160" x 160"
--- Plastic Shim 0.050 c 0.25 x 0.75"	

FULL SCALE

FIGURE 4

RADIOGRAPH

PART OF TEST ARC - SIDE VIEW

GAP IN SPLIT LAYER HAS SAME ORIENTATION AS GAP IN A STRAINED CASE JOINT I.E., CIRCUMFERENTIAL.

PLAN VIEW OF SPLIT LAYER (#2)

FULL SCALE

FIGURE 5

FIFTH EDITION

PERIODIC CHART OF THE ELEMENTS

(Based on Carbon-12)

Period

1

2

3

4

5

6

7

I^A

1

2

3

4

5

6

7

Sub-Group

GROUP

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FIGURE 6. MODEL SR-CF-3000 CALIFORNIUM CAPSULE

ORNL DWG 88-6603

- PLAN -
SCALE: 1" = 2"

FIGURE 7. SNOWBALL SHIPPING CASK

REDC SHIPMENT NO. 1488

ORNL 4.5 TON CF SHIPPING CONTAINER, SERIAL NO. L-23413
USNRC CERTIFICATE OF COMPLIANCE USA/6642/BC 3, REV. 5

FIGURE 8. SCHEMATIC OUTLINE OF ARG NEUTRON RADIOGRAPHY SYSTEM

COMPONENTS

VEHICLE
SHIELDING CASK
TELEFLEX CABLE AND DRIVE
MODERATOR-COLLIMATOR SOURCE(mcs)
IMAGER (ELECTRONIC)
VIDEO CHAIN FOR IMAGE DISPLAY
IMAGER (FILM-SCREEN-CASSETTE)
FILM PROCESSING AND VIEWING EQUIPMENT
POSITIONER FOR MCS
SUPPORT FOR IMAGER CLAMPED TO MCS
HEALTH PHYSICS MONITORS
MISCELLANEOUS ITEMS

LOWER DRAWINGS - LARGER SCALE