BNWL-1329
UC-37

**DESIGN AND FABRICATION
OF A PORTABLE DEVICE
FOR NEUTRON RADIOGRAPHY**

J. L. Cason

March 1971

**AEC RESEARCH &
DEVELOPMENT REPORT**

BNWL-1329

BATTELLE

BATTELLE MEMORIAL INSTITUTE

NORTHWEST

PACIFIC NORTHWEST LABORATORIES

3000 STEVENS DRIVE, P. O. BOX 999, RICHLAND, WASHINGTON 99352

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

PACIFIC NORTHWEST LABORATORY

RICHLAND, WASHINGTON

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

3 3679 00061 9140

BNWL-1329
UC-37, Instruments

DESIGN AND FABRICATION OF A PORTABLE
DEVICE FOR NEUTRON RADIOGRAPHY

By

J. L. Cason(a)

Applied Physics and Instrumentation Department
Systems and Electronics Division

March 1971

BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORIES
RICHLAND, WASHINGTON 99352

(a) *Now employed by WADCO, a Subsidiary of Westinghouse
Electric Corporation under Contract No. AT(45-1)-2170*

Printed in the United States of America
Available from
National Technical Information Service
National Bureau of Standards,
U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.95

DESIGN AND FABRICATION OF A PORTABLE
DEVICE FOR NEUTRON RADIOGRAPHY^(a)

J. L. Cason

ABSTRACT

A research program is being conducted at Battelle-Northwest to determine the usefulness of ^{252}Cf as a source for portable thermal neutron radiography. Emphasis has been in developing a device using ^{252}Cf that could be used for laboratory, hot cell or field radiography.

A 268 μgm ^{252}Cf source (NS-1) was obtained from ORNL for experimental testing. This source has a neutron yield of 6.2×10^8 n/sec and was used in an experimental container designed for neutron radiography.

A first generation portable device which completely contains the ^{252}Cf has been designed and built and is presently being evaluated. Preliminary work included flux measurements and neutron radiographs.

The neutron camera is completely portable and can be used in the laboratory, hot cell or field. The shielding characteristics are such that it can be transported by common carrier per ICC regulations as outlined in 10 Code of Federal regulations.

(a) *This report is based on work performed under the United States Atomic Energy Contract AT(45-1)-1830.*

TABLE OF CONTENTS

LIST OF FIGURES	vii
LIST OF TABLES	ix
INTRODUCTION	1
DISCUSSION.	8
Shielding	8
Shielding Results.	9
Neutron Camera Containment Vessel	13
Fabrication Phases	14
Control and Monitoring of NC-1	28
CONCLUSIONS	30
APPENDIX A - Neutron Radiography Camera NC-1	A-1
APPENDIX B - Control Circuitry	B-1

LIST OF FIGURES

1	Comparison of Thermal Neutrons and X-rays Absorption for Various Elements	2
2	Comparative Neutron Sources	4
3	Decay Scheme for ^{252}Cf . The Effective Half- life of the Alpha Decay and Fission Combination Equals 2.58 yr	6
4	Energy Spectra of Neutrons from Different Sources	7
5	Shielding with B/E; Dose Rate Versus Material Thickness	10
6	Cut-away View of Neutron Camera	16
7	Rear Half of Shell, Inside Diameter (k in Figure 6)	17
8	Front Half of NC-1 Shell Showing Internal Drums (l in Figure 6)	18
9	Neutron Shielding in Place with Separation Layer	19
10	NC-1 Motor and Switch Control	20
11	NC-1 Control and Monitoring Circuitry	21
12	Collimator and Moderator Holder	22
13	Bottom Side of NC-1 and Collimator Mount	23
14	NC-1 Final Assembly on Laboratory Stand	24
15	Mock-up of ^{252}Cf Capsule	25
16	Insertion of ^{252}Cf into NC-1	26
17	Transporting NC-1 in NDT Mobile Van	27
18	Block Diagram of NC-1 Control	28
A-1	Cut-away View of NC-1	A-2
A-2	Shielding Positioning Within NC-1	A-4
A-3	Directional Properties of Parallel-Laminated 10 Ounce Cloth	A-9
B-1	NC-1 Control and Monitoring Circuitry	B-2
B-2	Block Diagram of NC-1 Control	B-3
B-3	Motor and Switch Control for NC-1	B-3

LIST OF TABLES

1	General Examples of Neutron Radiography Uses	3
2	Nuclear Properties of ^{252}Cf	5
3	Comparative Isotope Neutrons Sources	7
4	NC-1 Shielding Material Thicknesses	11
5	Neutron Dose Rate from ^{252}Cf	11
6	Total Gamma Dose Rate from ^{252}Cf	12
7	Comparative Neutron Containers	12
8	Summary of Mechanical and Physical Properties of Fiberglass	13
9	Comparative Data of 302 SS to Fiberglass	14
10	Equivalent Material Thickness for 302 SS to Fiberglass	14
11	Construction and Assembly Phases of NC-1	15
12	NC-1 Control Panel Functions	29
A-1	Advantages and Applications for Fiberglass	A-6
A-2	Design Cost/Performance Comparison for Materials	A-7
A-3	Physical Properties of the Raw Material Properties of Fiberglass "E" (Low Alkali)	A-8
A-4	Comparative Fatigue Strength	A-9

DESIGN AND FABRICATION OF A PORTABLE DEVICE FOR NEUTRON RADIOGRAPHY

J. L. Cason

INTRODUCTION

With the advent of easily obtainable neutrons an amazing volume of research and development work in nuclear applications has been accomplished in recent years. One of the newer areas of application is neutron radiography with isotope, generator and reactor sources. This report presents the design requirements for developing a device which uses ^{252}Cf for neutron radiography.

A new scope of investigation has opened to radiographers because of the differences in neutron interactions as compared to the absorption characteristics of x and gamma rays. Neutron radiography can be utilized in areas considered out-of-bounds, or at least of dubious value, by radiographers; for example, the lighter elements, many composites, rocket propellents, a great many aircraft components, electronic hardware, biological specimens and radioactive materials. Neutron radiography offers an evaluation method for nuclear reactor control and fuel materials for measurements of poisons, hydride, and enrichment levels. It also provides a usable radiographic tool for both pre- and post-irradiated materials to provide information as to component placement, swelling, rupture, and internal measurements.

It appears that neutrons may be utilized to qualitatively differentiate between elements in a material which may be closely related insofar as their x-ray absorption characteristics are concerned. This can be illustrated by a comparison of the absorption characteristics as a function of atomic number for x-rays and thermal neutrons as shown in Figure 1.

FIGURE 1. Comparison of Thermal Neutrons and X-ray Absorption for Various Elements

The rapid growth of applications (Table 1) has been hindered to some extent by the requirement that materials to be tested must be taken to a reactor or neutron generator for evaluation (Figure 2).

At this time ^{252}Cf is considered a very attractive candidate for providing a high flux neutron portable source of compact size. Californium-252 has a neutron yield of about 1×10^{12} n/sec/g with an effective half-life of 2.63 years. Some of the nuclear properties of ^{252}Cf are given in Table 2 with a decay scheme given in Figure 3. Another distinct

TABLE 1. General Examples of Neutron Radiography Uses

<u>Object</u>	<u>General Requirement</u>
Radioactive Heat Sources	Weld Evaluation Element Continuity Proper Material Constituents
Biological Studies	Tumor Location Thin Tissue Studies
Plastic Materials	Flaws Density Evaluation
Physics and Chemistry Basics	Inter-Metallic Diffusion Processes Gaseous - Metal Diffusion Characteristics
<u>Reactor Technology</u>	
Control Rods	Homogeneity Continuity Poison Levels Inclusions and Voids
Fuel Elements	Homogeneity Continuity Poison Levels Inclusions and Voids
Shielding Materials	Homogeneity Continuity Inclusions and Voids
<u>Rocket and Missile Technology</u>	
Rocket Fuel	Crack or Fissures
Rubber Tubing	Continuity
Organic Gaskets	Voids
Explosive Devices	Inclusions
Electronic Components	Material Definition

Neg 700360-1

FIGURE 2. Comparative **Neutron** Sources

TABLE 2. Nuclear Properties of ^{252}Cf

Isotope	Decay Half-Life of ^{252}Cf	
	Spontaneous Fission	α or β Decay
^{252}Cf	$(85.5 \pm 0.5)\text{y}$	$2.646 \pm 0.004 \text{ y}$

Alpha Radiation from ^{252}Cf		
Energy, MeV	Alpha Particles per Disintegration of ^{252}Cf	Energy per Disintegration, MeV
5.969	10.002	0.01
6.069	~0.155	0.94
6.112	0.845	5.16
Total		6.11

Gamma Rays from ^{252}Cf Decay

Energy, MeV	Abundance, Photons/sec (g of nuclide)
0.043	2.78×10^9
0.100	2.0×10^9

advantage of ^{252}Cf as compared to other isotope sources (Table 3) is the neutron energy spectra. The neutron spectrum for ^{252}Cf (Figure 4) closely resembles a reactor spectrum, meaning that one has the full energy spectrum (<0.1 MeV to >8 MeV) to moderate and filter as the needs for resonance radiography dictate.

Research is being conducted by Battelle-Northwest for the Atomic Energy Commission Division of Isotope Development to develop portable neutron radiographic devices and applications using ^{252}Cf .

FIGURE 3. Decay Scheme for ^{252}Cf . The Effective Half-Life of the Alpha Decay and Fission Combination Equals 2.58 yr

TABLE 3. Comparative Isotope Neutrons Sources

Source and Type	Half-life, yr	Neutrons		α Particles Neutron
		1000 Dis.	Microwatt	
<u>a,n Sources</u>				
^{210}Po Be	0.378	0.068	78	15,000
Ra Be	1,620	0.41	85	2,400
^{238}Pu Be	89	0.076	91	13,000
^{239}Pu Be	24,360	0.049	62	20,000
^{241}Am Be	458	0.054	67	19,000
^{242}Cm Be	0.346	0.11	83	9,100
^{244}Cm Be	17.6	0.081	83	12,000
<u>γ,n Sources</u>				
^{124}Sb Be	0.167	0.043	2,500	No α
<u>S. F. Sources</u>				
^{252}Cf	2.65	120	63,000	8.3

FIGURE 4. Energy Spectra of Neutrons from Different Sources

DISCUSSION

The design and fabrication of a portable device for neutron radiography was preceded by analytical and experimental studies.

Using the data thus generated, we were able to bypass an extensive characterization of an experimental device. We exposed subjects for radiography to a neutron beam obtained by inserting a collimator into a rather large isotope containment tank. An experimental device was constructed to verify the computer model. The results of agreement between the analytical predictions and the experiments aided in establishing design requirements for a first generation portable neutron camera.

Primary considerations were safety, size, weight, structural rigidity, simplicity and operability.

The fabrication of the device (NC-1) was followed by initial flux measurements and neutron radiographs which correlated with the previous analytical and experimental evaluation. When used with a 268 μgm ^{252}Cf source the device can be shipped per ICC regulations meeting the dose rate requirements (Ref 10 CFR).

SHIELDING

Experiments were performed to determine the optimum geometry and materials for shielding ^{252}Cf . The materials evaluated were: zirconium hydride, titanium hydride, paraffin, gadolinium oxide, cadmium, and a boron carbide/epoxy resin compound. We found that the boron/carbide epoxy resin (B/E) compound was the most effective shield for fast neutrons, with the additional advantage of being easy to mold or cast in any shape or size without special equipment. The epoxy resin provided enough hydrogen to moderate the fast neutrons and the

boron carbide captured the thermal neutrons. This shield proved more effective and versatile than paraffin, water or any of the metal hydrides evaluated. A half-value layer for fast neutrons of ^{252}Cf for the B/E was found to about 1 in. Plots of dose rate versus shielding thickness for the B/E compound are given in Figure 5.

Shielding considerations for the gamma radiation associated with the ^{252}Cf decay were determined by optimizing the following interrelated parameters: 1) the inverse square principle was utilized in the determination of the camera dimensions; 2) maximum gamma shielding obtainable (as provided by the neutron shielding and moderator materials) was considered; and 3) minimum use of depleted uranium rather than a larger volume of lead to cut the remaining dose not accounted for by distance and neutron shielding. The result is the minimal size and weight of the final device as compared to a conventional neutron container.

Neutron and gamma shielding were obtained by using the following materials (source-to-outside of containment vessel) as given in Table 4.

Table 5 gives the neutron dose rate from ^{252}Cf for one gram sources as a function of neutron energy distribution, and Table 6 gives the gamma dose rate.

SHIELDING RESULTS

The shielding used was effective and resulted in obtaining a surface dose rate the device of 200 mrem/hr neutron and 50 mrem/hr gamma for the source in the stored position; i.e., in effect, completely surrounded by the above composite thicknesses of materials.

FIGURE 5. Shielding with B/E; Dose Rate Versus Material Thickness

TABLE 4. NC-1 Shielding Material Thicknesses

<u>Material</u>	<u>Effective Thickness, cm</u>	<u>Shield Effects</u>
ZrH ₂	0.825	Fast neutrons + γ (neutron moderator + reflector)
Be	1.905	Thermal Neutron (neutron moderator + reflector)
UO ₂	0.635	Gamma
B/E	7.63	Fast and Thermal Neutrons
CH ₂ (paraffin)	15.08	Neutrons
Fiberglass Shell	1.27	Neutrons

TABLE 5. Neutron Dose Rate from ²⁵²Cf

<u>Energy, MeV</u>	<u>n/cm²-sec g at 1 meter</u>	<u>Conversion Factor, rad/hr n(cm²)(sec)</u>	<u>Dose Rate, rad/hr g at 1 meter</u>	<u>Conversion Factor, rem/hr n(cm²)(sec)</u>	<u>Dose Rate, rem/hr g at 1 meter</u>
0 - 0.5	2.2×10^6	5.8×10^{-6}	1.3×10^1	5.0×10^{-5}	1.1×10^4
0.5 - 1.0	2.9×10^6	1.2×10^{-5}	3.5×10^1	1.2×10^{-4}	3.5×10^2
1.0 - 2.0	6.1×10^6	1.5×10^{-5}	9.1×10^1	1.4×10^{-4}	8.5×10^2
2.0 - 3.0	3.7×10^6	1.6×10^{-5}	5.9×10^1	1.3×10^{-4}	4.8×10^2
3.0 - 4.0	2.2×10^6	1.7×10^{-5}	3.7×10^1	1.3×10^{-4}	2.9×10^2
4.0 - 5.0	1.3×10^6	2.0×10^{-5}	2.6×10^1	1.3×10^{-4}	1.7×10^2
5.0 - 6.0	4.5×10^5	2.3×10^{-5}	1.0×10^1	1.4×10^{-4}	6.3×10^1
6.0 - 7.0	3.2×10^5	2.5×10^{-5}	8.0×10^0	1.5×10^{-4}	4.8×10^1
7.0 - 8.0	1.0×10^5	2.5×10^{-5}	2.5×10^0	1.5×10^{-4}	1.5×10^1
8.0 - 10.0	7.9×10^4	2.6×10^{-5}	2.1×10^0	1.5×10^{-4}	1.2×10^1
10.0 - 13.0	1.8×10^4	2.5×10^{-5}	4.5×10^{-1}	1.5×10^{-4}	2.7×10^0
Total 284 rad/hr			Total 2,400 rem/hr		

TABLE 6. Total Gamma Dose Rate from ^{252}Cf

Energy, MeV	Photons/cm ² -sec g at 1 meter	Conversion Factor Photons/cm ² -sec rad/hr	Dose Rate, rad/hr g at 1 meter
0 - 0.5	3.7×10^7	2.2 2.2×10^6	1.7×10^1
0.5 - 1.0	4.5×10^7	7.4×10^5	6.1×10^1
1.0 - 1.5	1.4×10^7	4.7×10^5	3.0×10^1
1.5 - 2.0	6.1×10^6	3.7×10^5	1.6×10^1
2.0 - 2.5	1.8×10^6	3.1×10^5	5.8×10^0
2.5 - 3.0	8.8×10^5	2.7×10^5	3.3×10^0
3.0 - 3.5	4.5×10^5	2.4×10^5	1.9×10^0
3.5 - 4.0	2.4×10^5	2.2×10^5	1.1×10^0
4.0 - 4.5	1.4×10^5	2.0×10^5	7.0×10^{-1}
4.5 - 5.0	6.5×10^4	1.9×10^5	3.4×10^{-1}
5.0 - 5.5	3.9×10^4	1.7×10^5	2.3×10^{-1}
5.5 - 6.0	1.4×10^4	1.6×10^5	8.7×10^{-2}
6.0 - 6.5	8.0×10^3	1.5×10^5	5.3×10^{-2}
Total			1.4×10^2

The effectiveness of the composite shielding can be demonstrated by a comparative weight analysis between a standard shipping cask and the neutron camera (Table 7).

TABLE 7. Comparative Neutron Containers

Device (a)	Critical Dimensions	Approximate Weight
S/S and concrete neutron cask	36 in. diameter 48 in. height	4,400 lb
Neutron Camera (egg shape)	22 in. max. diameter 26 in. length	350 lb

(a) *The surface dose rate for neutron and gamma radiation is the same in both cases.*

NEUTRON CAMERA CONTAINMENT VESSEL

The camera is constructed so that modifications can be made for shielding, moderation and collimation. The device consists of an egg-shaped laminated fiberglass outershell, two internal metal drums, shielding and moderator materials, adjustable metal holder for collimators and moderators, and an electric motor drive/controller unit.

The camera is designed so that a ^{252}Cf source, when positioned within the inner drum, may be rotated by remote control or manually to two lockable positions. One position will allow a neutron beam to be selectively moderated and radiographs produced, the other position is for storage of the source in a shielded condition.

The construction material used in the camera case fabrication is a high strength fiberglass laminate. This material was selected because of its light weight, good physical characteristics, self-extinguishing fire characteristics, ease of molding, cheap cost and durability. Table 8 summarizes the chief advantages of the material for use as a neutron containment vessel. A discussion on material and camera properties is given in Appendix A.

TABLE 8. Summary of Mechanical and Physical Properties of Fiberglass

<u>Mechanical or Physical Property</u>	<u>Data</u>
Tensile	30×10^3 psi
Compressive Strength	30 to 50×10^3 psi
Flexural Modulus	1.2×10^6 psi
Specific Gravity	1.5 g/cm^3
Flammability	Self-Extinguishing

A comparison of the fiberglass material (Fabmat-2415) to an equal thickness of stainless steel 302 alloy given in Table 9 will further point out the advantages for using fiberglass.

TABLE 9. Comparative Data of 302 SS to Fiberglass

Material	Thickness	Tensile Strength	Material Cost, ¢/lb	Density, lb/in. ³	Space Filling, ¢/in. ³
Fiberglass	0.036	28 × 10 ³ psi	31	0.055	1.7
SS	0.033	30 × 10 ³ psi	57	0.290	16.5

The slight disadvantage in physical characteristics of the fiberglass was offset by using a laminate 0.500 in. thick. Table 10 presents calculated equivalent thickness for 302 SS for various normalized physical properties.

TABLE 10. Equivalent Material Thickness for 302 SS to Fiberglass

<u>Physical Property</u>	<u>Thickness of Fiberglass, in.</u>	<u>Equivalent Thickness of SS 302 Alloy</u>
Tensile strength	0.500	0.458
Bending strength	0.500	0.494
Stiffness	0.500	0.199
Tensile elongation	0.500	0.299

FABRICATION PHASES

The basic construction phases of the device are outlined in Table 11 and supplemented with Figures 6 through 17.

TABLE 11. Construction and Assembly Phases of **NC-1**

<u>Design and/or Construction Step</u>	<u>Figure</u>
Detail drawing of device	6
Case laminate (rear)	7
Installation of rotating and stationary (front) drums	8
Shielding in place	9
Motor drive and micro- switches for source positioning	10
Circuitry of source monitoring and control	11
Collimator/moderator holder	12
Position for collimator and front moderator holder and front half of camera	13
Final assembly prior to source installation	14
^{252}Cf source (a) mock-up with camera installation capsule (b)	15
Transfer to NC-1 of source	16
Transporting NC-1	17

- a - ^{252}CF POSITION * POSITION NO. 1, EXPOSE; POSITION NO. 2, STORE
- b - INNER ROTATING A1 DRUM
- c - OUTER STATIONARY DRUM
- d - SOURCE TRANSFER TUBE
- e - ADJUSTABLE FRONT MODERATOR
- f₁ - COLLIMATOR HOLDER
- f₂ - COLLIMATOR POSITION
- g - MODERATOR
- h - NEUTRON SHIELDING
- i - POWER DRIVE FOR ROTATING DRUM
- j - FIBERGLASS SHELL
- k - REAR HALF OF SHELL
- l - FRONT HALF OF SHELL

FIGURE 6. Cut-away View of Neutron Camera

Neg 0694673-1

FIGURE 7. Rear Half of Shell, Inside Diameter
(k in Figure 6)

Neg 0694673-3

FIGURE 8. Front Half of NC-1 Shell Showing Internal Drums
(1 in Figure 6)

Neg 0694673-51

FIGURE 9. Neutron Shielding in Place with Separation Layer

Neg 0694673-47

FIGURE 10. NC-1 Motor and Switch Control

FIGURE 11 NC-1 Control and Monitoring Circuitry

Neg 0694673-9

FIGURE 12. Collimator and Moderator Holder

Neg 0694673-5

FIGURE 13. Bottom Side of NC-1 and Collimator Mount

Neg 0694673-27

FIGURE 14. NC-1 Final Assembly on Laboratory Stand

Neg 0694673-21

FIGURE 15.

Mock-up of ^{252}Cf Capsule

Neg 0694673-40

FIGURE 16. Insertion of ^{252}Cf into NC-1

Neg 0694673-36

FIGURE 17. Transporting NC-1 in NDT Mobile van

CONTROL AND MONITORING OF NC-1

The neutron device (NC-1) can be operated manually, or with dc or ac power. At present it is operated with 110 V ac. The device is located in a typical x-ray radiographic cell which is provided with a door interlock for safety. The cell was chosen as a place for evaluation of NC-1 because it was convenient, easy to use and met the safety requirements on the testing of a prototype neutron device.

A block diagram of NC-1 with controls and monitoring components is given in Figure 18. The basic control as given in Table 12 is described by functions.

FIGURE 18. Block Diagram of NC-1 Control

TABLE 12. NC-1 Control Panel Functions

NC-1 Control Panel

- Controls position of source
- Monitors position of source
via 1. neutron level
2. mechanical position
- Interlock control to cell door
- Panel warning lights as a
function of
 - 1. neutron level near NC-1
 - 2. mechanical position
- Controls remote warning lights
(as a function)
 - 1. neutron level near NC-1
 - 2. mechanical position
- Panel interlock (key control)

A detailed description of the control circuitry is given in Appendix B.

CONCLUSIONS

The first generation portable neutron camera that has been constructed is presently being successfully used in neutron radiographic resolution and application studies.

Work to date indicates that a sufficient neutron flux (1×10^4 nv thermal) can be delivered at the object position providing satisfactory resolution capability. A measure of success can perhaps be emphasized by comparing the 4000 pound container in which the ^{252}Cf arrived at Battelle-Northwest with the 350 pound camera presently in use. Another major accomplishment is the portability as compared to an accelerator or reactor as a source of neutrons (Figure 2). The entire device is portable including structural and radiation containment, moderation, collimation and controls.

The device can be shipped or transported per ICC regulations for radioactive sources. An evaluation is underway at present to determine if the device meets the requirements for a special permit container (Ref 10 CFR. 71.63).

APPENDIX A

NEUTRON RADIOGRAPHY CAMERA NC-1

APPENDIX A

NEUTRON RADIOGRAPHY CAMERA NC-1SCOPE

The neutron radiography camera was developed to provide a portable, lightweight efficient and easy to operate unit for neutron radiography and neutron beam application using ^{252}Cf as a source of neutrons.

The camera design is such that any number of modifications can be made to shielding, neutron moderation and collimation.

GENERAL DESCRIPTION

The portable neutron camera consists of an egg-shaped laminated fiberglass outer case, two internal metal drums, shielding and moderator materials, adjustable metal collimator and moderator holder, and an electric motor drive and controller unit.

Figure A-1 shows a cut-away view of the neutron camera.

FUNCTION

The camera is designed so that a ^{252}Cf source, when positioned within the inner drum, may be rotated to two lockable positions remotely. In the expose position a neutron beam can be selectively moderated and radiographs produced; in the closed position the source is in a shielded condition.

COMPONENT DESCRIPTION

Outer shell: The outer shell is an egg-shaped, two-piece container of laminated fiberglass construction. The dimensions are 26 in. on the major axis and 22 in. on the

- a - ^{252}Cf POSITION * POSITION NO. 1, EXPOSE; POSITION NO. 2, STORE
- b - INNER, ROTATING AL DRUM
- c - OUTER, STATIONARY DRUM
- d - SOURCE TRANSFER TUBE
- e - ADJUSTABLE FRONT MODERATOR
- f₁ - COLLIMATOR HOLDER
- f₂ - COLLIMATOR POSITION
- g - MODERATOR
- h - NEUTRON SHIELDING
- i - POWER DRIVE FOR ROTATING DRUM
- j - FIBERGLASS SHELL
- k - REAR HALF OF SHELL
- l - FRONT HALF OF SHELL

FIGURE A-1. Cut-away View of NC-1

minor axis with a minimum wall thickness of 0.500 in. To allow for assembly, there is a flange 1 3/4 in. wide on both halves of the shell at the minor axis. There is a 5 in. diameter hole in the small end to accept the moderator and collimator holder.

METAL DRUMS

The two metal drums are in the front half of the outer shell (the half that has the 5 in. diameter hole). The drums are designed so that one drum will rotate inside of the outer drum which is fixed to the outer shell. The inner drum is fastened to a 1/2 in. diameter, stainless steel shaft that rotates in bearings in the outer drum. The shaft penetrates the outer shell with both ends and has provisions to connect to the motor drive unit and a hand crank for remote or manual rotation of the inner drum. Each drum has an access cover so shielding material can be changed. The ^{252}Cf source location is in a tube located at a perimeter position of the inner drum.

SHIELDING AND MODERATOR MATERIALS

The materials used for shielding and moderators are: boron carbide - epoxy compound, depleted uranium and paraffin for neutron and gamma shielding; zirconium hydride as a neutron moderator and reflection and beryllium for a neutron reflector. (Refer to Table 4 of text.) See Figure A-2 for their relative position.

ADJUSTABLE COLLIMATOR AND MODERATOR HOLDER

The collimator and moderator holder is a 5 in. diameter tube 4 1/2 in. long, closed on one end and internal threads on the other end. A 3 3/4 in. inside diameter by 5 1/2 in. long sleeve screws into the holder. (Actual photograph in Figures 12 and 13 of text.)

FIGURE A-2. Shielding Positioning Within NC-1

MOTOR DRIVE AND CONTROL

The electric motor drive is designed to rotate the inner drum from the exposed position to the shielded position. The drive assembly consists of a twentieth (20th) H.P. Bodine motor with a suitable gear reduction and a remote control. (See Figure 10.)

ASSEMBLY OF CAMERA (See Figure A-1.)

The two metal drums were mounted in the front half of the outer fiberglass shell. The collimator and moderator holders were located and fastened in through the 5 in. diameter hole in the front half of the outer case. Boron carbide-epoxy compound shielding material in vinyl bags was fitted between the collimator holder and the inner steel case.

Depleted uranium strips, (1/4 in. thick) were mounted to the outside of the outer drum. A 3 in. layer of boron carbide-epoxy compound was mounted over the outside of the outer metal drum and held in place with a thick coating of wax. The back half of the fiberglass shell was then bolted to the front half.

The motor unit was installed and the gears connected to the drive shaft for the inner rotating drum. The motor cover was then attached and the controls were activated to assure proper functioning of all parts. Actual operation of the service was simulated in over 50 tests prior to installation of the ^{252}Cf .

The ^{252}Cf capsule (a. in Figure 15) was mounted within an easily handled capsule (b. in Figure 15) prior to insertion into the camera. The transfer of the ^{252}Cf to NC-1 took place within a remote facility, (Figure 16). After transfer, the outer surface of the device was surveyed and dose measurements were established. The camera was then transferred to the NDT laboratory for experimental evaluation where it is presently being used (Figure 17).

FIBERGLASS CHARACTERISTICS

The fiberglass material used for the construction of the camera case has several advantages over typical materials such as 302 stainless steel. A few of these advantages were covered in the text and summarized in Tables 8 through 10.

Table A-1 outlines many of the advantages of the use of fiberglass over conventional materials which summarizes the general reasons for the choice of this particular material. Other considerations were design cost/performance comparison between standard materials for radioactive containment vessels and fiberglass. These results are summarized in Table A-2. The physical properties of the raw materials used in a fiberglass laminate are listed in Table A-3.

TABLE A-1. Advantages and Applications for Fiberglass

FRP Advantages	Transportation	Materials Handling	Protective Covers and Housings	Aerospace and Military Uses
Noncorrosives	x	x	x	x
Less Finishing	x		x	
Electrical Properties		x	x	x
Accurate Detail				x
Molded-in-Color			x	
Molded in Attachments	x	x	x	x
Molded in One Piece	x	x		x
Dimensional Stability				x
Light Weight	x	x	x	x
Low Maintenance	x	x	x	x

The directional strength properties of glass cloth is one of the most important characteristics of fiberglass as illustrated in Figure A-3. Note that strengths are greatest at 90° and 180°, dropping to the lowest point at 45°. This indicates that in design, reinforcement should be parallel to maximum stress.

TABLE A-2. Design Cost/Performance Comparison for Materials

Material	Glass Content by wt	Matl. Cost, ¢/lb (a)	Den- sity, lb/ in. ³	Space Filling ¢/in. ³ ,	Bending Strength		
					10 ³ psi	Thick- ness, in. (b)	Material Cost for 100 in. ² , ¢ (d)
Fabmat-2415 Layup	40%	31	0.055	1.7	35	0.093	15.8
Aluminum, 6061-0 Alloy		50	0.098	4.9	12	0.158	77.5
Steel, 1010 Alloy		7	0.238	2.0	28	0.103	20.3
Stainless Steel, 302 Alloy		57	0.290	16.5	35	0.092	152.0

	Stiffness			Tensile Strength			Tensile Elongation		
	Flexural Modulus, 10 ⁶ psi	Thick- ness, in. (b)	Material Cost for 100 in. ² , ¢ (d)	10 ³ psi	Thick- ness, in. (c)	Material Cost for 100 in. ² , ¢ (d)	Tensile Modulus, 10 ⁶ psi	Thick- ness, in. (c)	Material Cost for 100 in. ² , ¢ (d)
Fabmat-2415 Layup	1.8	0.223	37.9	28	0.036	6.2	1.5	0.067	11.4
Aluminum, 6061-0 Alloy	10.0	0.126	61.7	12	0.083	40.6	10.0	0.010	44.9
Steel, 1010 Alloy	30.0	0.087	17.2	28	0.036	7.1	30.0	0.003	0.6
Stainless Steel, 302 Alloy	28.0	0.089	147.0	30	0.033	54.5	28.0	0.004	6.6

a. Based on cost of materials selected at time of printing.

b. Thickness comes from calculation of a simple beam 2 in. by 1 in. with a concentrated load of 100 lb at the center.

c. Thickness comes from calculation of a simple beam (2 in. by 1 in.) with a 1000 lb load in tensile.

d. Cost is for a bar of material 100 in. by 1 in. by indicated thickness.

TABLE A-3. **Physical Properties of the Raw Material
Properties of Fiberglass "E" (Low Alkali)**

Properties	"E" Composition
Physical	
Specific Gravity	2.55 (bulk glass 2.58)
Hardness—Moh Scale	6.50
Angle of Contact (water)	"0° for clean glass"
Coefficient of Friction (with glass)	"1 for clean glass"
Mechanical	
Tensile Strength (single fibers)	500,000 psi
Modulus of Elasticity (tension)	5×10^6 psi
Bulk Modulus	
Poisson's Ratio	0.22
Hysteresis	None
Creep	None
Resilience Modulus	7,600 in.-lb/ft ³
Thermal	
Coefficient of Thermal Expansion	$2.6 \times 10^{-6}/^{\circ}\text{F}$
Coefficient of Thermal Conductivity	7.2
Specific Heat	0.19 BTU
Electrical	
Dielectric Constant	6.43 at 10^2 cycles
	6.11 at 10^{10} cycles
Loss Tangent	0.0042 at 10^2 cycles
	0.006 at 10^{10} cycles
Acoustic	
Velocity of Sound	18,000 ft/sec
Acoustical Impedance	1.4×10^6 g/cm ² /sec(a)
Velocity of Crack Propagation	5,040 ft/sec(a)
Optical	
Refractive Index at 550 millimicrons at 32 °C)	1.548
Reciprocal of Dispersive Power	-

a. Measured on bulk glass, but assumed to be accurate for the fibrous form.

FIGURE A-3. Directional Properties of Parallel-Laminated 10 Ounce Cloth

The fatigue nature of epoxide-glass cloth laminate is satisfactory for most applications. A laminate such as used for NC-1 should withstand 10^7 cycles at a load not exceeding one-fifth of its ultimate strength, providing that the laminate was not crazed on the initial application of the load. Table A-4 presents comparative data on specific fatigue at 10^7 cycles.

TABLE A-4. Comparative Fatigue Strength

<u>Specific Fatigue Strength</u>	<u>lb/in.² per lb/in.³</u>
Polyester-glass cloth laminate	150,000
Epoxide-glass cloth laminate	240,000
Aluminum alloy 75s-T6	90,000
Steel 18-8	180,000
Titanium 150-A	70,000

In the design of NC-1, an egg shape was considered the most practical so as to approximate conditions where the strengths would always be the greatest during compression and tension; i.e., impact due to a fall or collision.

In summary, the particular material chosen for construction on NC-1 has all of the advantages listed in this section. In the evaluations to date (i.e., tensile tests) the material conforms to expectations of being a very useful material for isotope containment. The actual tensile tests indicate that its strength is greater than that normally accepted* for laminates of this nature (>30,000 psi).

* *Private communication between author and Dow Chemical*

APPENDIX B

NC - 1 CONTROL AND MONITORING CIRCUITRY

APPENDIX B

NC-1 CONTROL AND MONITORING CIRCUITRY

The following discussion gives details of fabrication and operation of each component part for NC-1 control. A complete circuit is given in Figure B-1 and should be referenced for items mentioned in the discussion of Appendix B. Figure B-2 is a block diagram showing the relationship of the various components for NC-1 operation.

I. WARNING LAMP CIRCUIT**Source Position Indicating Circuit**

Switches SW-1 and SW-2 are three-pole, two-position microswitches and are mounted on the NC-1 such that when the source is in the fully shielded position, SW-1 is actuated and while in the fully exposed position, SW-2 is actuated. (See switch positions in Figure B-3.)

1. SW-1A (N.O.), when closed, allows current to flow through the "stored" (green) position indicator lamp.
2. SW-2A (N.O.) , when closed, allows current to flow through the "exposed" (red) position indicator lamp.*

II. NEUTRON DETECTOR CIRCUIT

A BF-3 neutron detector and count-rate-meter, located near the NC-1, monitors the neutron level within the neutron radiography cell. The output of the CRM is fed into a relay meter located on the NC-1 control panel.

* *In addition to the permanently mounted "exposed" indicator Lamp on the NC-1 control panel, an output is also provided for remote warning Lamps.*

B-2

FIGURE B-1 NC-1 Control and Monitoring Circuitry

BNWL-1329

FIGURE B-2. Block Diagram of NC-1 Control

FIGURE B-3. Motor and Switch Control for NC-1

When the source is in the fully shielded position, the neutron level within the cell is relatively low and the relay meter contacts are open. No current flows through the "low" (green) neutron level indicating lamp.

As the source is rotated to the "exposed" position, the neutron level within the cell increases and the meter relay contacts close. Current flowing through R-3 causes the normally open contacts to close and current flows through the "high" (red) neutron level warning lamp.*

III. DOOR INTERLOCK CIRCUIT

The radiography cell door is equipped with an interlock system to prevent accidental opening of the cell door while the neutron source is exposed. The circuitry is designed such that the cell door is operational only when the source is fully shielded. Current flows through R1 only when the source is fully shielded as determined by the position of SW-1A, and in turn the contacts of R-1 close. Note not only that current must flow through R-1 but that current must not flow through R-2 in order for the interlock circuit to be complete.

IV. KEY INTERLOCK CIRCUIT

The key interlock circuit is simply a series of four key-actuated switches connected such that all four switches must be turned "ON" before operation of the NC-1 control is possible. Each person entering the neutron radiography cell must remove and retain one of the four keys until he leaves the cell at which time the key is replaced.

* In addition to the permanently mounted red lamp on the NC-1 control panel, an output is also provided for remote neutron level warning lamps.

V. BRAKE CIRCUIT

A mechanical brake is employed to stop the rotation of the source at the desired position automatically.

1. When the source rotates to the "Stored" position, SW-1C (N.O.) closes and the current flows to the brake power supply energizing the brake.
2. When the source rotates to the "Exposed" position, SW-2C closes and the brake is actuated.
3. S-1 is used as a brake release switch and is mounted on the NC-1 control panel. This switch was employed such that it must be opened in order to move the source from one position to another.

VI. MOTOR CONTROL CIRCUIT

The motor control circuit used is a simple phase reversing A-C motor control. The position of S-2 determines the phase relationship between the voltages applied to the "RUN" and "START" windings. SW-1B and SW-2B are used to remove power from the motor when the source has rotated to the desired position.

In summary, the control circuitry for use of NC-1 functioned very well during testing and actual use of the device. In over 300 test or exposure runs, the equipment has functioned without a mishap.

DISTRIBUTIONNo. of
CopiesOFFSITE

1 AEC Chicago Patent Group
 G. H. Lee

213 AEC Division of Technical Information Extension

ONSITE

1 AEC Chicago Patent Group
 R. K. Sharp (Richland)

1 AEC Richland Operations Office
 M. R. Schneller

2 RDT Assistant Director of Pacific Northwest
Programs

2 WADCO

 C. B. Shaw
 C. D. Swanson

39 Battelle-Northwest

 G. J. Dau
 J. L. Deichman
 H. L. Henry
 C. N. Jackson
 J. M. Nielsen
 L. C. Schmid
 J. R. Sletager
 K. L. Swinth
 J. B. Vetrano (25)
 Technical Information Files (5)
 Technical Publications (1)