LA-UR- 96-1975

CONF- 9606223--2

Title: MULTI-PURPOSE NEUTRON RADIOGRAPHY SYSTEM

Author(s): J. P. Barton, L.E. Bryant, P. C. Berry

Submitted to: 5th world conf./Neutron Radiography, Berlin, Germany
June 17-20, 1996

Los Alamos
NATIONAL LABORATORY

MULTI-PURPOSE NEUTRON RADIOGRAPHY SYSTEM

J. P. Barton (1), L. E. Bryant (2), P. Berry (2)

(1) NRE Inc., 1422 Vue Du Bay Ct., San Diego, CA 92109, USA.
Fax: 619-488-8812.

(2) Los Alamos National Laboratory, MS C914 Los Alamos, NM 87545, USA.
Fax: 505-667-0433

Keywords: Neutron Radiography System, In-house Neutron Radiology, Transportable Neutron Radiology, Californium-252, Neutron Radioscopy, Neutron Induced Gamma Spectroscopy.

ABSTRACT

A conceptual design is given for a low cost, multi-purpose radiography system suited to the needs of the Los Alamos National Laboratory (LANL). The proposed neutron source is californium-252. One purpose is to provide an in-house capability for occasional, reactor quality, neutron radiography thus replacing the recently closed Omega-West Reactor. A second purpose is to provide a highly reliable standby transportable neutron radiography system. A third purpose is to provide for transportable neutron probe gamma spectroscopy techniques. The cost is minimized by shared use of an existing x-ray facility, and by use of an existing transport cask. The achievable neutron radiography and radioscopy performance characteristics have been verified. The demonstrated image qualities range from high resolution gadolinium - SR film, with L:D = 100:1, to radioscopy using a LIXI imager with L:D = 30:1 and neutron fluence 3.4 x 10^5n/cm^2.

INTRODUCTION

Los Alamos National Laboratory (LANL), like similar laboratories, may have occasional needs for an in-house neutron radiographic capability. Until its recent closure, the 8 MW reactor provided this capability. Typical radiographic parameters were L:D 187:1 and flux 6 x 10^5n/cm^2-sec. This paper shows that neutron radiographs of similar quality could be provided by a stand-by system using ^{252}Cf loaned from Oak Ridge National Laboratory (ORNL). Moreover, if a surplus Snowball transport cask becomes available, this could provide for additional transportable neutron radiology and neutron probe capabilities. To commence the study, a systematic review was undertaken covering a wide range of non-reactor neutron sources.

ACCELERATORS

Numerous centers have used accelerator based neutron sources for neutron radiography; including the Pantex Plant which used a Van de Graff (1) for some 20 years before changing to californium-252. Accelerators can be switched off when not needed, but are inferior to isotopic sources for reliability. We reviewed a range of accelerators starting from small D-T types yielding about 10^8n/sec (MF Physics A-210, A-320, A-801) up to larger RFQ machines and cyclotrons. The low yield, accelerators have insufficient neutron yield to provide reactor quality neutron radiographs in reasonable exposure times. The higher yield accelerators have higher costs and poorer transportability.

A surplus deuteron-tritium sealed tube accelerator (MF Physics A711 type) that was previously selected for a US Navy neutron radiography system is available(2). The accelerator yield is about 10^{11} n/sec of 14 MeV neutron energy. It has a uranium booster and optimized moderator-collimator (MC). At 30:1 collimator ratio the beam flux is 3×10^4n/cm^2-sec, which is similar to the 50 mg ^{252}Cf based MNRS (3). However, for the stationary high neutron fluence application repeated long exposures over 24 hours would not be practical. For the transportable application, the high mass of moderator needed for 14 MeV neutrons, and the electric cable limit to 20 meters length, would restrict reachability.

ISOTOPIC SOURCES

The neutron source ^{252}Cf is available on free loan from ORNL while it is decaying to the lower isotopes for which it is needed. Before selecting ^{252}Cf, the full range of alternative isotopic neutron sources have been reviewed. These included the following: ^{210}Po-Be, $T_{1/2}$ 4.5 months, ^{241}Am-Be, $T_{1/2}$ 458 years; ^{241}Am-^{242}Cm-Be, $T_{1/2}$ 5 months; ^{244}Cm-Be, $T_{1/2}$ 18 years; and ^{239}Pu-Be, $T_{1/2}$ 24,000 years.

Two types of switchable on-off neutron sources were also considered: Sb-Be and ^{242}Cm-Be but each was found to be impractical at the needed yield (4).

IN-HOUSE SYSTEM

The low cost system designed to provide a permanent, stand-by, in-house neutron radiography capability would add to the existing x-radiography facility without detracting from its availability for other purposes (Fig. 1 & 2). A source of 60 mg ^{252}Cf was selected because this can produce radiographs each week equal in quality to those typically produced by a reactor system. The 60 mg size is also the upper limit for a single shipment in the existing cask. The source transfer between cask and system takes place outside the building using teleflex cable technology. The moderator-collimator is the proven McClellan design.(3) The geometry, with source permanently below ground, and beam divergent upwards, is based on the system manufactured for the Pantex Plant (5). It utilizes space efficiently, provides for fail safe radiation shielding, and enables the parts for radiography to be conveniently positioned on a horizontal aluminum neutron window.

The standard collimator ratio is 100:1, which matches that used for high quality neutron radiography at reactors. The length L is fixed at 250 cm but the aperture diameter D is changeable from its standard value of 2.5 cm. The divergence over 250 cm enables an array of four standard size film cassettes (432 mm x 355 mm) to be exposed simultaneously. The exposure position is near floor level in the corner of the existing larger x-ray facility, so that the surrounding shield and beam stop form a convenient work bench, without significant impact on the independent use of the facility for x-ray work. The beam stop and side shields are such that entry to the x-radiography facility is not restricted either with the neutron beam on or off.

There are only three moving parts, all simple and hand operated. To initiate a neutron radiography exposure after placement of parts and cassettes the access door is closed, the shutter is rolled from the top of the collimator, and the source is moved from the lower store position to the beam on position. Termination is the reverse process.

The source, which decays with a 2.6 year half life, will be exchanged every two years to keep it above 40 mg equivalent. One choice of screen-film combination will be Trimax-6, Gd_2O_2S, plus Kodak TMH film, as used routinely at McClellan (3). A set of four such films could be exposed in about 1.5 hours (neutron fluence $1.6 \times 10^7 n/cm^2$). A set of four reactor quality gadolinium screen-Kodak SR film radiographs at L:D = 100:1 can be provided in an exposure time of 7 days ($2 \times 10^9 n/cm^2$). Short and long exposures may, of course, be mixed provided the longer exposure is not disturbed.

TRANSPORTABLE SYSTEM

The neutron source installed for the in-house system can be extracted at any time for use in a standby transportable system (Fig. 3). The vehicle carries the operators and all of the equipment except the source which is towed in the transport cask. The moderator-collimator (MC), designed for collimator ratios as low as 30:1 is light-weight and can easily be hand maneuvered. A versatile positioner will be provided to clamp the MC in chosen orientations at the object to be inspected. A choice of neutron imaging devices will be provided including the small, robust LIXI electronic imaging system, a fast NE 426 scintillator usable with Polaroid film, and Gd_2O_2S Trimax 6 screen film combinations such as are used with flexible cassettes at McClellan Air Force Base.(3)

One key part of the transportation system design is the highly reliable, motor driven, teleflex cable source transfer systems. The first use is to transfer the source from the in-house facility to the transport cask. After arrival at the field radiography location the MC and imaging device are set in position and the source is transferred from the cask to the MC. This shuttle between cask, MC, and back can be repeated for a series of collimator orientations and/or a series of screen-film exposures. For all source transfers, personnel will be sufficiently far away that no radiation shielding is required. The teleflex cable technology has been extensively used for industrial gamma radiography. The diverter box technology has been proven at McClellan AFB(3) and magnetic source coupling is based on the Pantex design (5).

The source transfer technology makes it possible to provide any desired reach between the cask at the vehicle and the MC position by reusing a set of cables in a relay method.

DEMONSTRATIONS OF PERFORMANCE

The sensitivity possible with the proposed in-house and transportable systems has been demonstrated in a series of experiments. Neutron radiology sensitivity is primarily a function of collimator ratio and neutron fluence. For a given collimator ratio and imaging system, the sensitivity will also vary between systems due to beam purity and other quality factors. By starting with measurements using a 35 mg ^{252}Cf system, such beam quality variations between the test systems have been shown to be negligible.

The test object for all demonstrations was a shim of plastic measuring 1.27 mm x 25 mm as projected to the beam line, and 6.35 mm deep (weight 0.2 gram). The plastic inclusion was set in the center of 160 mm aluminum alloy, with a separation of 125 mm between the inclusion and the image plane.

The first system used for the sensitivity demonstration was the Maneuverable Neutron Radiography System (MNRS) at McClellan Air Force Base.(3) Key parameters for the trials were: Source 35 mg ^{262}Cf, collimation 30:1, flux at imager $2.1 \times 10^4 n/cm^2$.

sec. A minimum resolution image that could detect the 0.2 gram plastic inclusion used the Thomson image intensifier and video chain, 512 frame integration (17 seconds) and 3.6 x 10^5n/cm^2 neutron fluence. A medium resolution image was demonstrated using Trimax 6 (Gd_2O_2S) screen and Kodak TMH film, exposure time 13 minutes, 1.6 x 10^7n/cm^2 neutron fluence.

The second system used to demonstrate sensitivity was the SNRS reactor at McClellan AFB, with collimation 100:1, and flux at imager 4.6 x 10^6n/cm^2-sec at 250 kW. (6) A similar Trimax 6-TMH film was exposed to 1.6 x 10^7n/cm^2 neutron fluence, this time showing results for L:D = 100:1. The 100:1 beam was also used to demonstrate a high resolution image using gadolinium and Kodak SR film, 1.2 x 10^9n/cm^2 neutron fluence.

The third system used was the University of Virginia reactor beam with a collimator ratio of 30:1. By lowering the reactor power, tests were made at neutron fluxes corresponding to a small source of 0.7 mg ^{252}Cf. The very fast screen film combination NE-426 LiFZnS(Ag) plus Kodak XRP film was able to detect the inclusion at an exposure time of 5000 seconds (2 x 10^6n/cm^2 fluence). This test confirmed that for transportable neutron radiography 0.7 mg is inferior to 60 mg ^{252}Cf. The cask weight for 60 mg is a towable 4000 kg, whereas at 0.7 mg, a cask weight of over 1000 kg would still be needed. The loss of image quality or the increase in exposure time (including reciprocity failure) weigh heavily against the use of the small source alternative.

The fourth system used to demonstrate the sensitivity range was the University of Michigan reactor beam with a collimator ratio of 40:1. By lowering the power the flux was adjusted from 3.2 x 10^6n/cm^2-sec at 2 MW to 6.4 x 10^5n/cm^2-sec and also to 1.6 x 10^5n/cm^2-sec. The LIXI imager tested is light weight (under 2 kg), robust, inexpensive and therefore, attractive for a transportable system application in which the 5 cm diameter field of view is sufficient. As for the much larger and more expensive Thomson image intensifier, good images of the 0.2 gram plastic test inclusion were obtained with a neutron fluence as low as 3.4 x 10^5n/cm^2.

TRANSPORTABLE ISOTOPIC NEUTRON SPECTROSCOPY

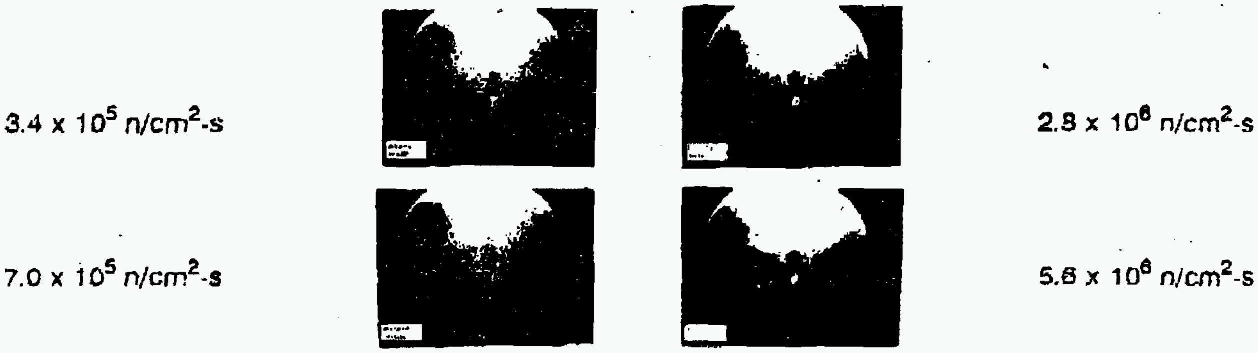
If neutron radiography shows there is no unexpected discontinuity in the neutron attenuation through the object, this is usually both necessary and sufficient information. However, in cases where an increase in attenuation is apparent, neutron radiography alone cannot identify the chemical composition of the material causing the attenuation. For example, the inclusion in the test object may be any of a variety of neutron attenuating materials.

The same neutron source that is used for radiography may be used also to help identification of chemical composition using gamma emission spectroscopy. In this technique neutrons interact with the elements and the gamma rays generated are interpreted using a sensitive detector (typically high-purity germanium cooled by liquid nitrogen) and a multichannel analyzer. Even with a small microgram source ^{252}Cf can distinguish between elements such as hydrogen, nitrogen, chlorine, sulphur, and iron in large quantities of material (kilograms), as it has been demonstrated with portable isotopic neutron spectroscopy (PINS)(7). By increasing the source size to 60 mg much smaller quantities of material could be analyzed using either the in-house arrangement or the transportable system.

SUMMARY

Many times in the past, an urgent need for an in-house system or a

Fig.4 Sensitivity at low neutron fluence



Inclusion 0.2 g plastic, 1.27 mm wide
at mid depth of 160 mm aluminum
Collimator 40:1, LIXI imager, frame averaged
Photos of monitor printed at reduced scale
(50mm LIXI output, 35 mm film contact print)

transportable system has met with the response that no system exists. This paper recommends preparation now of a standby capability in the interest of readiness. It is low in capital cost using a loaned ^{252}Cf, shared facility, and a surplus cask. Operating cost and maintenance costs will also be low. Reliability is high because of the design simplicity and the proven technology. Transportability and reachability are special features of the design. High sensitivity has been demonstrated for radiography image options ranging from fluences about 10^9n/cm^2 to 10^5n/cm^2. Specificity can be enhanced by development of neutron induced gamma spectroscopy.

ACKNOWLEDGEMENTS

Sincere thanks are offered to staff who provided assistance at each of the following facilities: McClellan AFB MNRS (B. Shaw, D. Correll), SNRS (W. Richards, K. Shields), University of Virginia (J. Brenizer), and University of Michigan (J. Lindsay).

REFERENCES

1. Cassidy, J.P., "Application of Neutron Radiation Inspection at the Pantex Plant", Neutron Radiography: Proc. of the First World Conf., 1981, Published by D. Reidel Co., Holland, ISBN. 90-277-1528-9.
2. Orphan, V.J., et al., "Neutron Radiography of Aircraft Components Using Mobile Neutron Radiography system.", Neutron Radiography: Proc. of the Third World Conf. 1989, Published by Kluwer Publishers. The Netherlands. ISBN 0-7923-0632-8.
3. Stokes, J.A. et al., "MNRS Design Principles and Measured Performance.", Neutron Radiography: Proc. of the Fourth World Conf., 1992, as above.
4. DeVolpi, A. et al., "A Switchable Radioactive Neutron Source for Portable Radioscopy.", This proceedings.
5. Barton, J.P. et al., "Pantex Neutron Radiography System.", This proceedings.
6. Richards, W. et al., "Nuclear Performance Characteristics of the SNRS Core and NR Facility.", Neutron Radiography: Proc. of the Fourth World Conf., 1992. As above.
7. Caffrey, A.J. et al., "PINS Chemical Assay System.", Idaho National Engineering Laboratory Report EGG-PHY-9816 (1991).

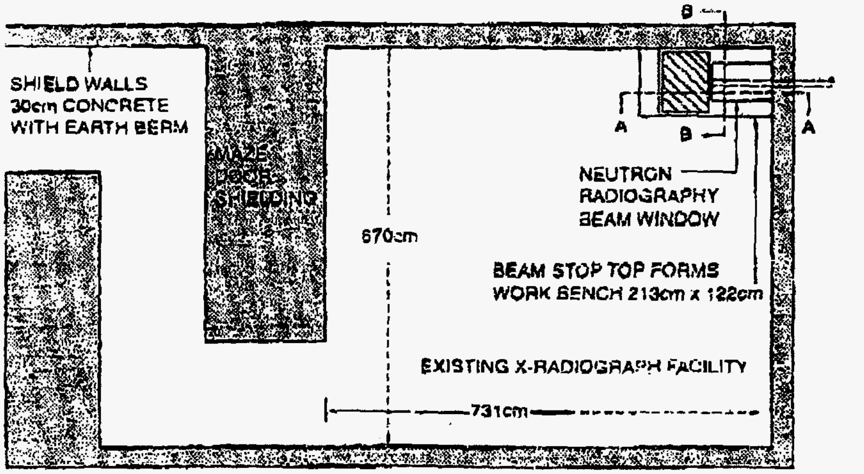
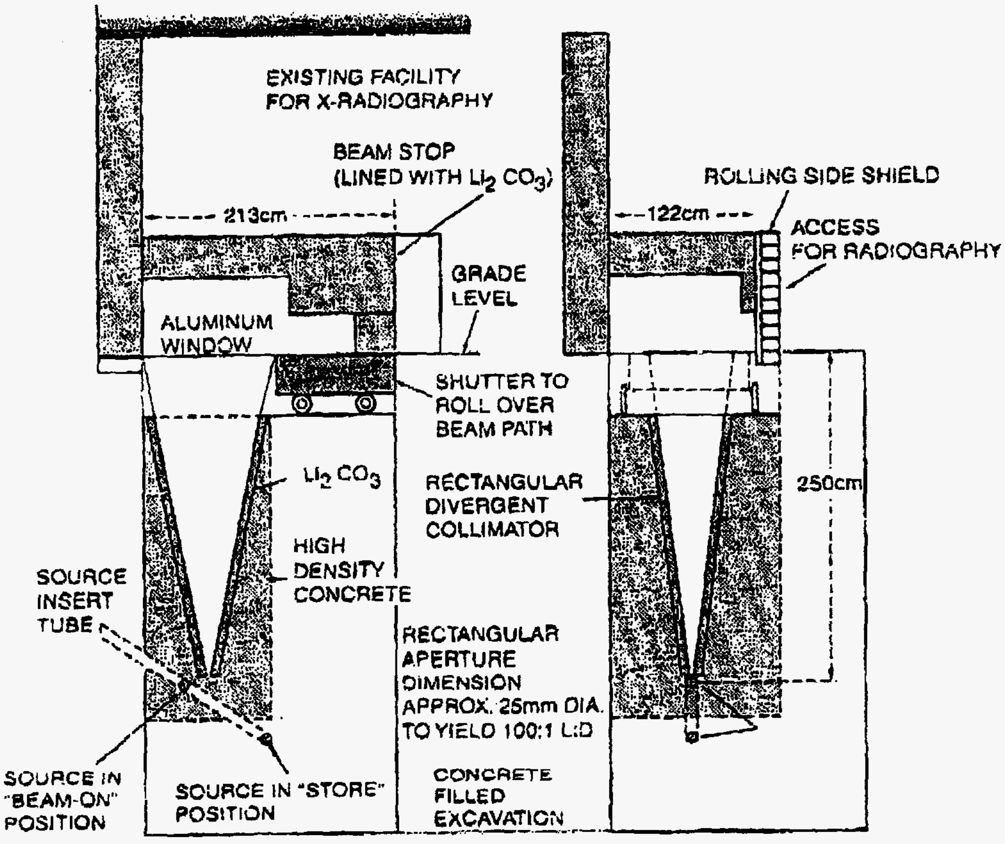


Fig.1 Plan of proposed neutron beam stop in corner of existing x-ray facility



SECTION A-A

SECTION B-B

Fig.2 Elevations of proposed neutron below and above grade level

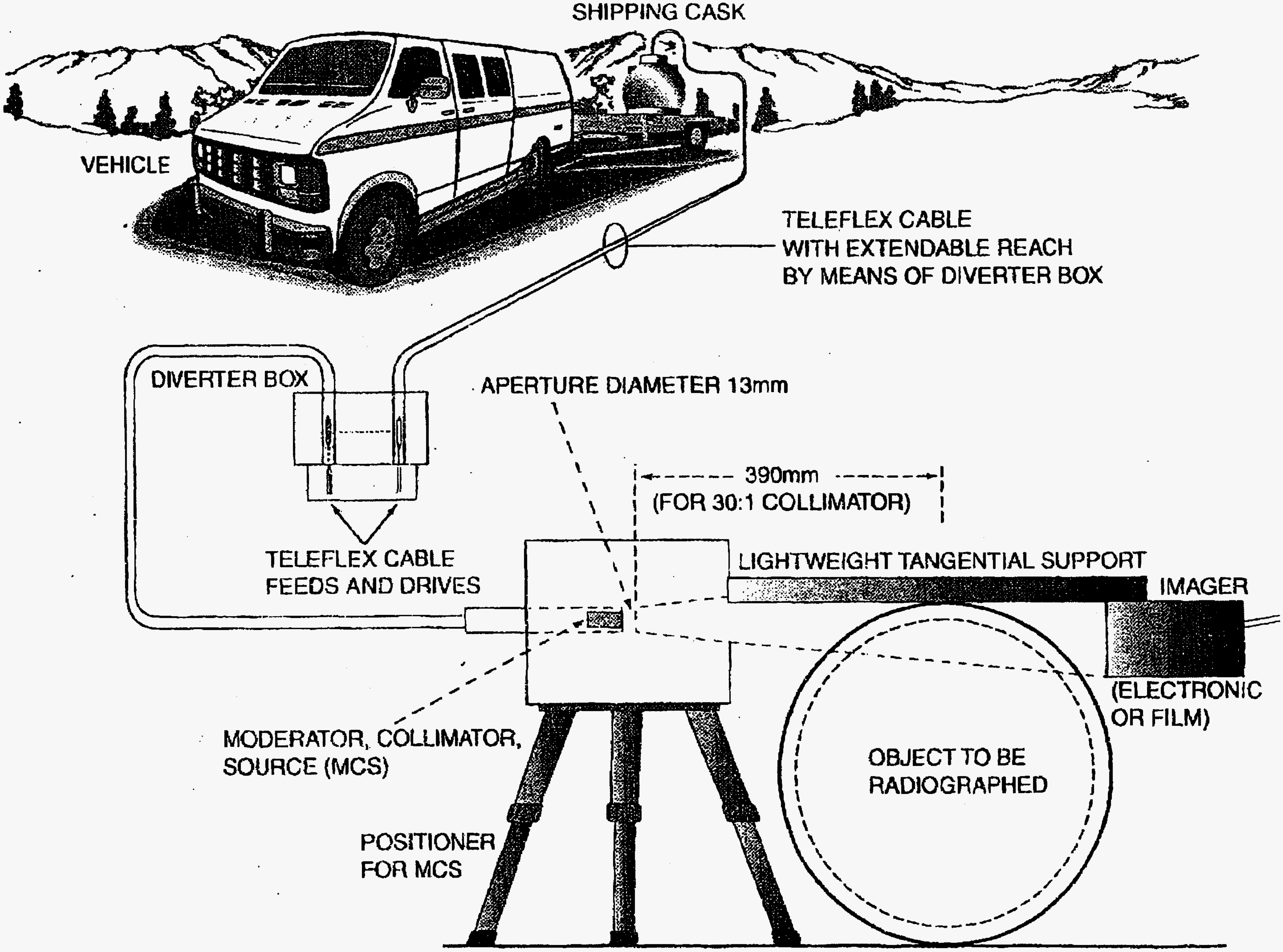


Fig.3 Transportable neutron radiography system