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Results from Preliminary Checks on AmBe Neutron Source #71

Arthur Eleftherakis and Martin Kocan

Human Protection and Performance Division
Defence Science and Technology Organisation

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ABSTRACT

This report describes preliminary checks performed on AmBe neutron source #71 consisting of wipe testing and visual inspection for the purpose of determining if the source capsule was in good condition and leak tight for continued use within the laboratory. Wipe samples obtained from the AmBe neutron source and inside its transport container were tested by DSTO and also independently by Australian Radiation Services. The results of both tests conclude there was no detectable contamination and that the AmBe neutron source was still leak tight. Visual inspection of the AmBe source capsule indicated it was still in good condition for continued use within a controlled laboratory environment.

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506 Lorimer St
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Telephone: (03) 9626 7000
Fax: (03) 9626 7999

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Results from Preliminary Checks on AmBe Neutron Source #71

Executive Summary

This report describes preliminary checks performed on AmBe neutron source #71 consisting of wipe testing and visual inspection for the purpose of determining if the source capsule was in good condition and leak tight so it can continue to be used in the laboratory.

DSTO personnel collected 5 wipe samples on 20/01/2011. Testing performed by DSTO personnel on the wipe samples indicated that there was no detectable alpha, beta or gamma contamination present. The wipe samples were dispatched to Australian Radiation Services (ARS) for independent testing. ARS subsequently provided a wipe test report that also concluded there was no detectable contamination present in any of the wipe samples. This together with visual inspection of the source capsule indicates that AmBe source #71 is in good condition for continued use within a controlled laboratory environment.

Authors

Arthur Eleftherakis
Human Protection and Performance Division

Arthur Eleftherakis is a Defence Scientist working in the Human Protection and Performance Division. He joined DSTO in 1990 and gained his PhD in Safety Science from the University of NSW in 1999. His interests are in nuclear and radiological defence and radiation detection instrumentation.

Martin Kocan
Human Protection and Performance Division

Martin Kocan obtained his PhD from the University of Aachen, Germany in 2003 and subsequently worked as a research scientist at the University of Goettingen, Germany, at the University of Western Australia and at Solar Systems Pty Ltd. He has been working in the Human Protection and Performance Division at DSTO since 2010.

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1. Introduction

DSTO has an AmBe neutron source (#71, ARPANSA License ID no: Blue SS130) which was purchased in 1978 that as of 2011 is 33 years old. ARPANSA guidance[1] assigns AmBe sources a recommended working life of 15 years. Given the age of the source, the concern is that a portion of the alpha particles produced by the decay of Am-241 will lose all their kinetic energy, acquire two electrons and will form helium gas which remains trapped within the source capsule. Over time the build up of pressure may result in the capsule casing being cracked or breached. In order to allow continued use of this source it has to be shown that the source casing is intact and in good condition and furthermore wipe testing must be performed to confirm that the source capsule is not leaking any radioactive material.

ARPANSA guidance[1] on the use of sealed sources beyond their recommended working life recommends that radiation sources are wiped tested on a six monthly basis and that continued use of sources beyond a second recommended working life requires a written submission to ARPANSA seeking its approval. The ARPANSA guidance also specifies that if wipe testing reveals contamination levels in excess of 200 Bq, the source is not considered leak tight and should be withdrawn from use.

This report describes the procedure used to perform preliminary checks on the DSTO AmBe neutron source #71 in two phases and also covers safety calculations and provides an estimate of the worst case dose to personnel. Phase one involved taking various dose rate readings while the AmBe source remained housed within its transport container and performing in-situ wipe testing to determine if any leakage of radioactive material had occurred. If no leakage was found during the phase one work, phase two would proceed involving removal of the AmBe source capsule from its container so it can be remotely inspected using CCTV and wipe tested directly using a remote handling tool. For phase two, water-filled containers (each having dimensions of 28 cm x 28 cm x 38 cm) were used to construct a "wall of water" up to 56 cm thick to shield personnel from the AmBe source's neutron radiation and additional lead shielding was used to shield against gamma radiation emissions.

Electronic dosimeters, the MGP DMC2000GN and Thermo EPD-N2, with the ability to measure both gamma and neutron doses were used to monitor the doses received by personnel in real-time. Additionally, the AN/VDR-2 gamma radiation meter and the Meridian Model 5085 neutron meter were used to measure and monitor the gamma and neutron dose rates at all times.

This report will form part of the submission that will be made to ARPANSA seeking approval for continued use of the AmBe source.

2. Background Information on Americium-Beryllium

AmBe sources produce neutrons through the Be(α,n) interaction, where an alpha particle (i.e. Helium nucleus) emitted by Am-241 interacts with Be-9, producing C-12, a neutron and gamma radiation (from de-excitation of C-12) as shown below:

$^{241}Am_{95} \rightarrow {}^{237}Np_{93} + {}^{4}\alpha_{2}$
$^{9}Be_{4} + {}^{4}\alpha_{2} \rightarrow {}^{12}C_{6} + {}^{1}n_{0} + \gamma$
Americium-241 used in the AmBe source has a half-life of 432.2 years.

The Amersham catalogue[2] of 1977/8 provides the following useful information on the AmBe neutron source:

AmBe source composition	A compacted mixture of americium oxide with beryllium metal, doubly encapsulated in stainless steel capsules that are welded closed.
Activity during manufacture	5 Ci
Neutron emissions	1.1×10^{7} n/sec
Capsule type	X.14
(Amersham) Code	AMN.24
Neutron emission	~ 2.2×10^{6} n/sec per Ci
Gamma exposure rate	~ 2.5 mR/h at 1 m per Ci ~ 25 μSv/h at 1 m per Ci
Neutron dose rate	~ 2.2 mrem/h at 1 m per Ci ~ 22 μSv/h at 1 m per Ci

The Amersham catalogue[2] 1977/8 provides a descriptive diagram of the AmBe neutron spectrum, see Figure 1 below, which shows that AmBe neutron energies range from ~ 2 MeV to 10 MeV and indicates that there are approximately 23% of neutrons below 1 MeV.
The average neutron energy of AmBe is 4.4 MeV[6].

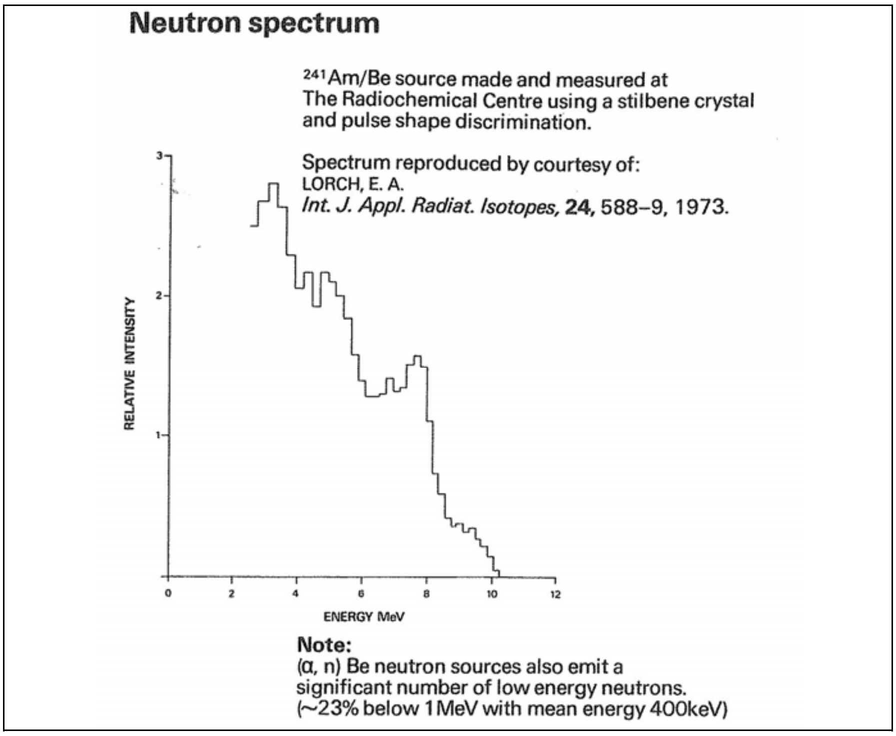

Figure 1. AmBe neutron spectrum

Prior to 1990 the International Commission on Radiological Protection (ICRP) recommended a general quality factor of 10 for neutrons in its publication, ICRP 26[3]. This publication was superseded in 1990 by a new publication, ICRP 90[4], where the term "quality factor" was replaced with the term "radiation weighting factor" and the following revised neutron radiation weighting factors were recommended:

Neutron energy range	**ICRP 60** **Radiation weighting factor, w_R**
energy <10 keV	5
10 keV to 100 keV	10
> 100 keV to 2 MeV	20
> 2 MeV to 20 MeV	10
> 20 MeV	5

It is not clear from the Amersham catalogue[2] 1977/8 how the neutron dose rate was derived and whether or not the old neutron quality factor of 10 that was applicable during the 1970s was used in its derivation. Given that the AmBe neutron spectrum in Figure 1 shows that a significant portion of neutrons have energies between 100 keV to 2 MeV, the best approach was to adopt a radiation weighting factor of 20 and apply this to the Amersham neutron dose rate of **22 μSv/h at 1 m per Ci** to derive a worst case neutron dose rate of **440 μSv/h at 1 m per Ci**. This was used in sections 4.3 – 4.5 to calculate the worst case dose estimates for personnel handling the AmBe source and performing the wipe tests on it.

3. Method

3.1 Equipment

Gamma radiation dose rates were measured using a calibrated AN/VDR-2 gamma survey meter (S/N: 031A) used in conjunction with its standard gamma/beta probe.

Neutron radiation dose rates were measured using the Meridian Model 5085 neutron meter (S/N: 585203)

Alpha radiation readings were measured using two instruments:

a. the AN/PDR-77 radiation meter (S/N: 396007) used in conjunction with a 10 cm x 10 cm alpha probe; and
b. the iSolo alpha/beta counting system (Model: SOLO300G, S/N: 04056022).

Personnel wore blue ARPANSA TLD badges to record their gamma and neutron dose. To allow real-time monitoring of doses the DMC2000GN (S/N: 007395) and EPD-N2 (S/N: 07106323) electronic dosimeters were employed as these both are able to measure and record gamma and neutron doses.

Given that the phase 2 work (described in section 3.2.2) required the removal of the AmBe source from its transport container it was considered necessary to construct improvised shielding using items and materials available in the laboratory to reduce both the gamma and neutron radiation levels and hence minimise the doses received by personnel.

To reduce the neutron radiation level, ten water-filled containers and an additional water-filled cylindrical container were arranged to construct what is referred to in this report as a "**wall of water**". Each container had dimensions of 28 cm x 28 cm x 38 cm. The cylindrical container had dimensions of 60 cm length and 10 cm diameter. The wall of water shown in Figure 2 consisted of two layers. The rear layer behind which personnel would stand had 2 x 3 containers (6 containers in all) and the front layer which was nearest to the neutron source had 2 x 2 containers (4 containers in all) and the additional water-filled cylindrical container. The water-filled containers were placed on a mobile trolley and tied closely together using cloth tape to minimise air gaps between adjacent containers. The front layer of containers (nearest the source) was offset both vertically and horizontally to maximise overlapping and ensure there were no line-of-sight air gaps between the rear and front wall layers. This meant there was at least 28 cm of water shielding around the edges of the containers but up to 56 cm of water towards the centre of the containers. Minimising air gaps and maximising the amount of water neutrons had to travel through would assist in attenuating the number of neutrons passing through the wall of water and minimising the neutron dose to personnel. The half-thickness of water for 4 MeV neutrons is 5.4 cm (reference 7). Therefore, 28 cm of water (equivalent to approximately 5 half-thicknesses) will reduce the neutron dose rate by a factor of 32 and in cases where the water is up to 56 cm thick (equivalent to approximately 10 half-value thicknesses) the neutron dose rate will be reduce by a factor of 1024. The actual neutron dose rate penetrating through the wall of water will be measured using the Meridian Model

5085 neutron meter to ensure the neutron levels are low and that doses received by personnel do not exceed dose limits discussed in section 4.1.

Figure 2. Water-filled containers or "wall of water" mounted on a mobile trolley (the left photo shows a view of the 2 x 2 front layer along with the cylindrical container; the centre photo shows a side view of the front and rear layer;, the right photo shows a view of the 2 x 3 rear layer)

Figure 3 shows the 1 metre neutron source long handling rod and a wooden frame with V-shaped cut-outs for supporting the handling rod on the left. One end of the neutron source handling rod has a threaded end for attaching to the AmBe neutron source. On the right in Figure 3 is a close up of the wooden frame with the V-shaped cut-outs.

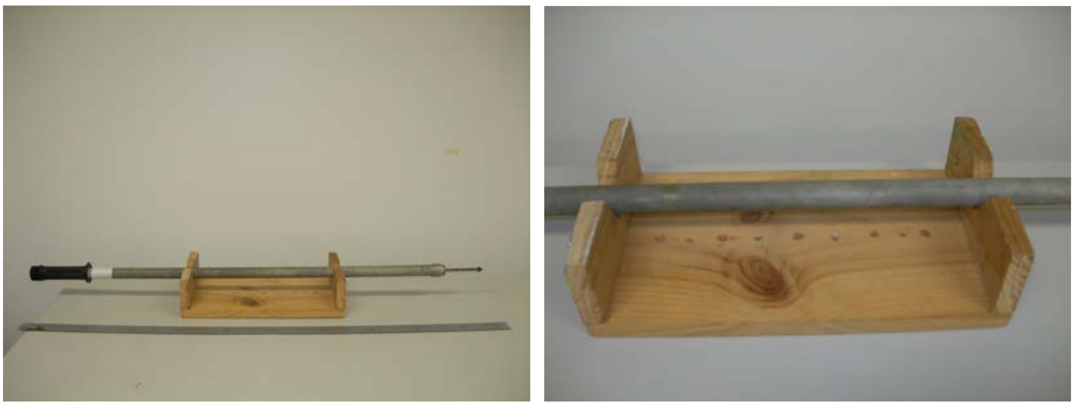

Figure 3. Neutron source handling rod and wooden frame with V-shaped cut-outs

A metal-frame trolley shown in Figure 4 was used to construct an improvised setup for holding the neutron source and performing the wipe-testing.

Figure 4. Metal-frame trolley

Figure 5 shows a close up of the neutron source testing location assembled on a lower shelf of the metal-frame trolley. A small lead brick enclosure was constructed around the position where the neutron source would be located to attenuate gamma radiation emissions. As a precaution, plastic sheeting was attached to the lead bricks to collect any radioactive material if it were found to be leaking from the AmBe source capsule. This figure shows the 1 m long neutron source handling rod with a dummy source attached. The handling rod is resting on the wooden support frame with V-shaped cut-outs (shown at bottom left of Figure 5).

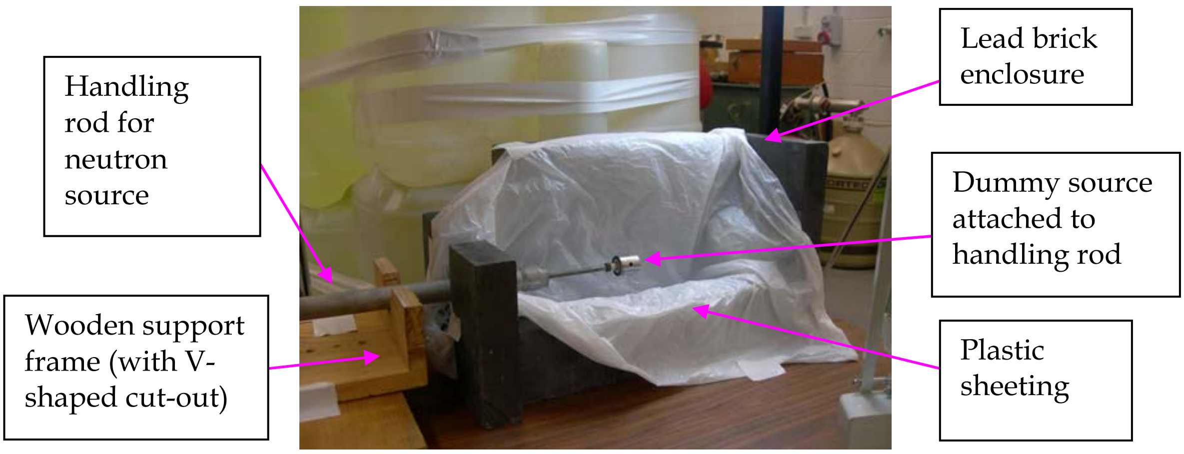

Figure 5. Neutron source wipe testing location built on a shelf of the metal-frame trolley

Figure 6 is a side view of the metal-frame trolley showing the neutron source wipe testing location on a lower shelf. Note that the neutron source handling rod is inserted and removed horizontally from the side of the metal-frame trolley shown in Figure 6. The handling rod is carefully placed on or removed from the wooden support frame with the V-shaped cut-outs.

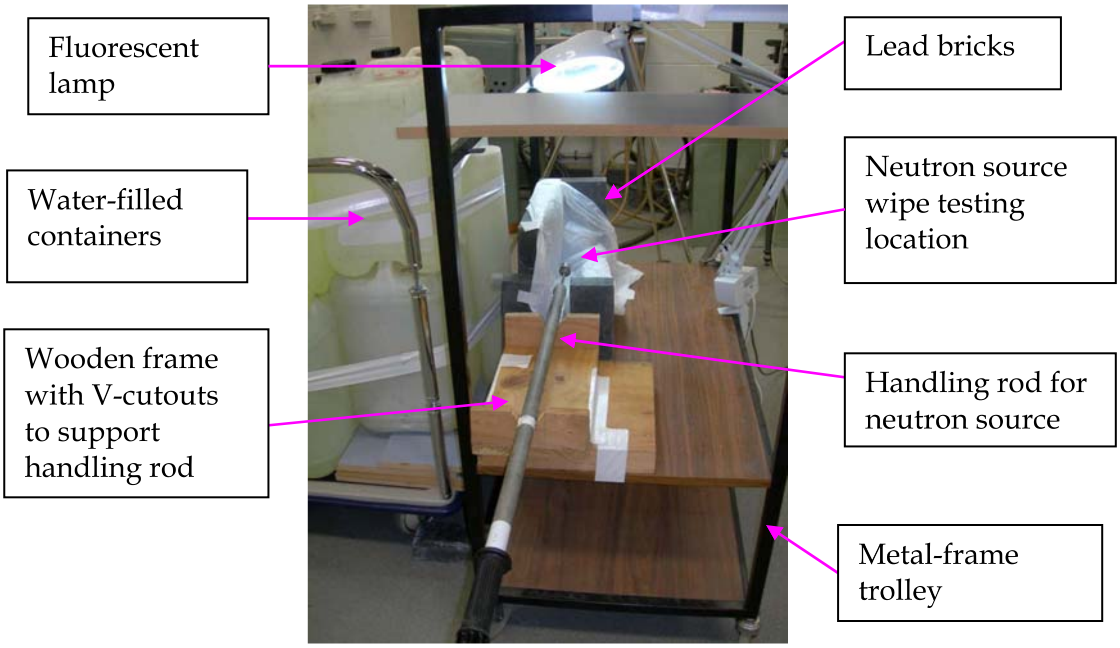

Figure 6. Side view of the neutron source wipe testing location on the metal-frame trolley

Figure 7 shows a view of the neutron source wipe testing location from behind the CCTV camera position. The CCTV camera had both pan, tilt and zoom capability so that the source capsule could be inspected remotely from the adjacent control room. A fluorescent lamp was used to illuminate the testing location. An angled mirror attached to the top of the metal-frame trolley allowed the AmBe source to be viewed safely from inside the laboratory.

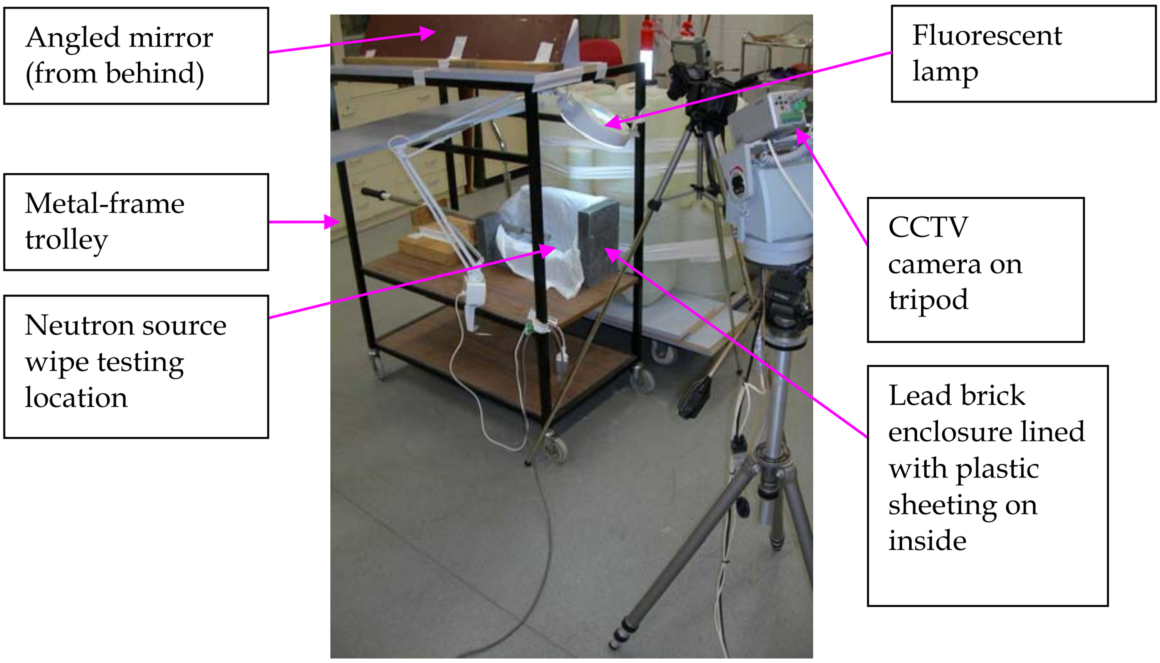

Figure 7. View of the neutron source wipe testing location from behind the CCTV camera position

To facilitate attachment of the AmBe source capsule to the handling rod and minimise dose to the operator's head, an angled mirror attached to a metal stand was placed on the transport container as shown and weighted down with a lead brick as shown in Figure 8. The mirror allowed the AmBe source to be viewed safely while it was still resting at the bottom of the well inside the transport container without the need to place one's head directly over the source to view it while attaching the handling rod. The source was accessed by unlocking and lifting the lockable lid and removing the plug insert. As a precaution, in case there was any leakage of radioactive material from the AmBe source when transferring it, plastic sheeting was taped to the floor between the transport container and neutron source testing location on the metal frame trolley. Figure 9 is a close up photograph of the top of the transport container showing the lockable lid and beneath it is a ~30 cm long plug insert which seals the source within the container. The plug has a handle so it can be removed and inserted easily and quickly. A small crane was used to suspend gamma and neutron radiation instruments above the AmBe transport container to measure gamma and neutron dose rates at a distance of 1 metre from the AmBe neutron source.

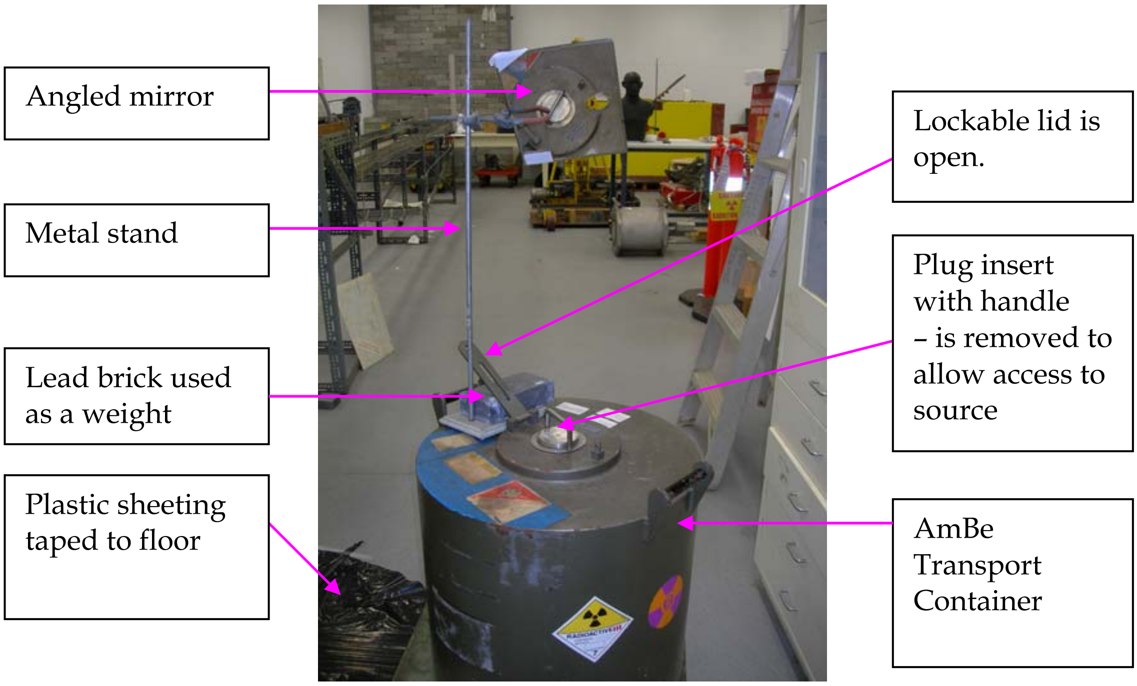

Figure 8. Angled mirror on transport container

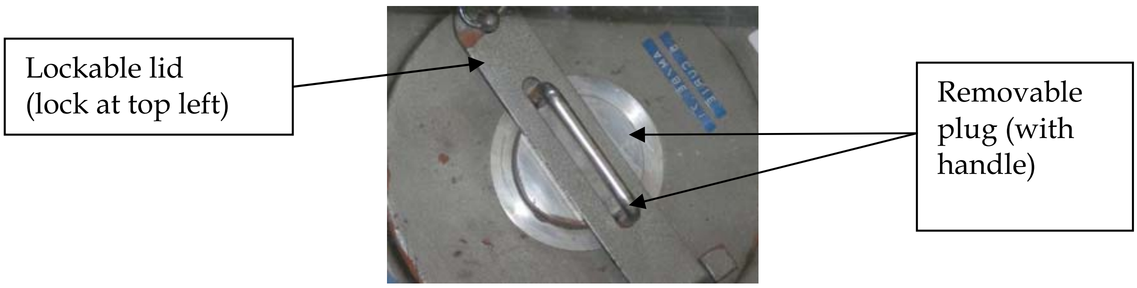

Figure 9. Lid and plug on top side of transport container

Figure 10 shows a U-shaped remote handling tool that was used to perform wipe testing. This handling tool was ideal as it allowed an operator to wipe the AmBe neutron source from behind the safety of the wall of water shielding. The operator used an angled mirror attached to the top of the metal-frame trolley (see Figure 7) to view the source while wiping it.

Figure 10. U-shaped remote handling tool

The wipes used for wipe testing the AmBe source were a filter paper Model No. FP-4.0L manufactured by F&J Specialty Products Inc. This filter paper can be used in conjunction with the iSolo alpha/beta counting instrument.

3.2 Procedure for Preliminary Checks

The procedure for conducting the preliminary checks on AmBe #71 consisted of two phases described in the sub-sections 3.2.1 and 3.2.2

3.2.1 Phase 1 – AmBe source remains in its shielded container

a. With the source still locked in its container, the gamma and neutron dose rates were measured from the side of the container and from above the container at 1 metre from the AmBe source, and also directly on the top surface of the container using the AN/VDR-2 gamma survey meter and the Meridian neutron meter.

b. The top of the container was opened and the actual unshielded gamma and neutron dose rates were measured above the container with the plug removed and at 1 metre from the AmBe source. This was done as there was some doubt on the reliability of the gamma and neutron dose rates listed in the Amersham catalogue[2] of 1977/8 and in particular how Amersham derived its neutron dose rate and whether or not a radiation weight factor for the neutrons was applied.

c. With the top of the container opened and the plug removed, an angled mirror and a digital camera were used to view and record the condition of the neutron source while it remained in the container.
   - Any visual signs of damage, corrosion, cracks or obvious leakage of material would be noted and documented using the digital camera.
   - If any such problems were noted, the AmBe source container would be sealed, and the Radiation Safety Advisory Panel would be notified immediately.

d. The U-shaped remote handling tool was used to perform wipe testing on the top side of the AmBe source while it remained in the container. This was achieved by using the U-shaped tool to take hold of a wipe and then carefully wipe the source and container. An angled mirror was used to view the source during the wiping process. Radiation workers wore disposable plastic gloves for this and subsequent steps.

e. Alpha radiation detection equipment, i.e. the AN/PDR-77 with alpha probe and iSolo alpha/beta counting system, were used to determine if there was any gross alpha contamination present on the wipes. Gamma radiation equipment, i.e. AN/VDR-2 survey meter, was used to measure for the presence of gamma radiation from any Am-241 contamination on the wipes.
   - If no obvious contamination was found, phase 2 would be conducted.
   - If any contamination was detected, the AmBe source container would be sealed, and the DSTO Radiation Safety Advisory Panel would be notified immediately.

3.2.2 Phase 2 – AmBe source is removed from its container

a. A shielding wall consisting of water containers and lead bricks was built as described in section 3.1 in a suitable area of the radiation laboratory. Plastic was laid out at the location where the source would be inspected and wipe tested as a precaution, in case there was any leakage of radioactive material. Radiation workers wore disposable plastic gloves for this and subsequent steps.

b. The 1 metre long neutron source handling rod was attached to the AmBe source. An angled mirror attached to a metal stand was positioned above the container opening to allow the handling rod to be carefully guided down and attached to the neutron source.

c. An improvised neutron source wipe testing setup described in section 3.1 and shown in figures 5 – 7 was constructed. This enabled the AmBe source to be rotated and visually inspected using closed-circuit TV and a digital camera.
   - Any visual signs of damage, corrosion, cracks or obvious leakage of material would be noted and documented using a digital camera.
   - If any such problems were noted, the AmBe source would be returned to its container and sealed. The DSTO Radiation Safety Advisory Panel would be notified immediately.

d. The U-shaped remote handling tool was used to take hold of wipes and carefully wipe the AmBe source capsule as well as the inside of the transport container.

e. Alpha radiation detection equipment (i.e. AN/PDR-77 with alpha probe and iSolo alpha/beta counting system) were used to determine if there was any gross alpha contamination present. Gamma radiation equipment (i.e. AN/VDR-2 survey meter) was used to measure the low energy gamma emissions and perhaps identify Am-241 assuming there is measurable Am-241 contamination is present.
   - If any contamination was detected, the AmBe source container would be sealed, and the Radiation Safety Advisory Panel notified immediately.

f. When the preliminary work on visually inspecting and wipe testing the AmBe source was completed, the wipes that were collected were doubly sealed in individual plastic bags and dispatched to Australian Radiation Services via overnight courier for confirmation that no alpha contamination was present.

4. Safety Issues

4.1 Dose Limits

The following are the internationally accepted dose limits for ionising radiation listed in ARPANSA publication RPS1[5].

Description	Dose Limits
For occupationally exposed workers (averaged over a period of 5 consecutive calendar years, and no more than 50 mSv in any one year).	20 mSv per year
For members of the public	1 mSv per year
Equivalent dose limit in the lens of the eye in the skin in the hands and feet	 150 mSv per year 500 mSv per year 500 mSv per year

Within DSTO, the annual dose limit for radiation workers is in line with the annual public dose limit of 1 mSv. This is to ensure that personnel keep the doses they receive "As Low As Reasonably Achievable". This is the ALARA principle. ALARA can be achieved by using the radiation protection principles of TIME, DISTANCE and SHIELDING.

Each calendar year several activities (typically up to five) are undertaken involving use of radiation sources. In order to keep doses received by personnel within the 1 mSv annual dose limit, it is prudent to set a maximum whole body dose limit for each project that is 20% of the 1 mSv limit or 200 μSv per person. However, it is considered desirable to keep doses to within 100 μSv per person (i.e. 10% of the annual public limit). These maximum and desirable limits applied for the work described in this report involving wipe testing of the AmBe source.

To minimise doses to the hands it was considered prudent to impose a dose limit of 1.5 mSv per person for the hands. This was 0.3% of the maximum dose limit of 500 mSv for the hands.

4.2 AmBe Dose Rates

The gamma and neutron dose rate data from the Amersham catalogue[2] of 1977/8 are as follows:

i. gamma dose rate ~ 25 μSv/h at 1 m per Ci
ii. neutron dose rate ~ 22 μSv/h at 1 m per Ci

In chapter 2, a "worst case" neutron dose rate was derived by adopting and applying a neutron radiation weighting factor of 20 to the Amersham neutron dose rate.
i.e. 20 x 22 μSv/h = 440 μSv/h at 1 m per Ci

The original activity of the AmBe source when it was purchased in Feb 1978 was 5 Ci (or 185 GBq). On 19/1/2001, prior to conducting the wipe testing, the activity was calculated to be 4.74 Ci (or 175.5 GBq). Multiplying the above dose rates by the activity of 4.74 Ci allows the gamma and neutron dose rates for the AmBe source to be calculated. The following table summarises the calculated gamma, neutron and combined (i.e. gamma + neutron) dose rates based on the Amersham data and the worst case dose rates.

	Amersham Dose Rates	**Worst Case Dose Rates**
Gamma dose rate	~ 118.5 μSv/h at 1 m	~ 118.5 μSv/h at 1 m
Neutron dose rate	~ 104.3 μSv/h at 1 m	~ 2086 μSv/h at 1 m
Combined gamma + neutron dose rate	~ 222.8 μSv/h at 1 m	~ 2204.5 μSv/h at 1 m

The above dose rates are used to estimate doses in sections 4.3 and 4.4 for phase 1 and phase 2 work, respectively. Section 4.5 summarises the estimated doses to personnel. It is anticipated that the above worst case dose rates will grossly overestimate doses but are a conservative (or safe-sided) approach to ensure that work with the AmBe source is designed to ensure that the 200 μSv limit for wipe testing work performed for this report is not exceeded.

The Amersham and worst case gamma/neutron dose rates vary from each other by a factor of 10. Readings taken during phase 1 of the preliminary work will allow the actual gamma and neutron dose rates from the AmBe source to be measured and hence allow better estimates of doses to personnel to be calculated in phase 2.

The following table shows the time calculated to reach various dose constraints. These times assume whole body exposure to an unshielded AmBe source at a distance of 1 metre. Based on the worst case dose rates calculated above, it can be seen that the maximum dose of 200 μSv for the wipe testing work performed for this report can be reached in 5.4 minutes from an unshielded AmBe source. It is important therefore to employ the principles of time, distance and shielding to ensure that personnel do not exceed the 200 μSv limit.

Dose constraints	**Time based on Amersham Dose Rates**	**Time based on Worst Case Dose Rates**
Annual public dose 1 mSv	4 hours 29 minutes	27 minutes
Maximum dose of 200 μSv per person	54 minutes	5.4 minutes

4.3 Estimated Doses to Personnel For Phase 1

For phase 1, the AmBe source will remain in-situ within its transport container. Whole-body exposure from an unshielded source will not occur in phase 1 but there may be a small dose from the shielded source. The surface gamma dose rate on the AmBe container is approximately 60 μSv/h (measured at the last RSAP audit in 2010). The neutron dose rate on the surface of the container has not been measured but is expected to be low due to the neutron shielding afforded by the container.

Based on a surface gamma dose rate of 60 μSv/h, it would take 3.3 hours in direct contact with the AmBe source in its container to reach the 200 μSv dose limit. Personnel will actually spend as little time as possible near the container, only briefly when it is moved to and from the wipe testing location in the radiation laboratory. For phase 1 and 2, close contact with the container will occur for less than 5 minutes. The maximum whole body dose for 5 minutes in close contact with the container is calculated to be:

$$60\ \mu Sv/h \times 5\ min \div 60\ min = 5\ \mu Sv.$$

Once steps a. and b. of phase 1 in section 3.2.1 are completed, a better estimate of the whole body dose for the remainder of phase 1 can be calculated. In any case, electronic dosimeters will be used to monitor and record the actual doses.

During phase 1, doses would primarily be received by the hands when taking digital photos and performing wipe tests on the top side of the source.

The dose limit for the hands is 500 mSv in RPS1[5]. The following table shows the time it would take to achieve this dose.

	Time based on Amersham Dose Rates	**Time based on Worst Case Dose Rates**
500 mSv dose limit to hands	94 days	9.5 hours

It is expected that during phase 1, less than 10 minutes will be spent taking digital photos and performing a series of wipe tests. The total dose to hands for this 10 minute of exposure will be as follows:

Dose to hands based on Amersham Dose Rates	**Dose to hands based on Worst Case Dose Rates**
37 μSv	367 μSv

Even for the worst case combined (gamma and neutron) dose rate of 2204.5 μSv/h, a 10 minute exposure delivers an estimated dose to the hands of 367 μSv for phase 1 work. This dose is a very small fraction, 0.073%, of the permitted 500 mSv limit for hands.

4.4 Estimated Doses to Personnel For Phase 2

To minimise doses during phase 2, substantial shielding consisting of a wall of water and lead shielding was constructed as described in section 3.1. It was expected that this shielding would greatly attenuate the gamma and neutron dose rates. It was estimated that the whole body dose to personnel standing behind the wall of water would be between 10-20 μSv while the source was out of its container but behind the shielding. Gamma and neutron dose rate readings would be measured using the AN/VDR-2 gamma radiation meter and Meridian Model 5085 neutron meter to confirm this and electronic dosimeters would be worn by personnel to monitor their doses in real-time.

Visual inspection was performed remotely using closed-circuit TV and a digital camera was used to take photographs. The source was rotated to view all sides of the source. The CCTV camera was positioned so that both the sides and bottom end of the source were visible. Note that the top of the source was viewed and photographed during the phase 1 work.

The following are whole body dose estimates for phase 2 work:

Description of activity performed and estimated time near the AmBe source	**Doses (based on Amersham Dose Rates)**	**Worst Case Doses**
Attach source to handling rod and place on tripod 30 seconds at 1 metre	1.9 μSv	18.4 μSv
Rotate handling rod up to three times 10 seconds at 1 metre	0.6 μSv x 3 = 1.8 μSv	6.1 μSv x 3 = 18.3 μSv
Place source back in container and detach handling rod 30 seconds at 1 metre	1.9 μSv	18.4 μSv
Total dose for phase 2	**5.6 μSv**	**55.1 μSv**

It is expected that during phase 2, up to 20 minutes may be spent taking digital photos and performing a series of wipe tests and the hands may at times be high enough above the wall of water to receive some direct exposure from the AmBe neutron source. The total possible dose to the hands for 20 minutes of exposure will be as follows:

Dose to hands based on Amersham Dose Rates	Dose to hands based on Worst Case Dose Rates
74 μSv	734 μSv

As in phase 1, the estimated dose to the hands for phase 2 is a very small fraction, 0.15%, of the permitted 500 mSv limit for hands.

4.5 Summary of Estimated Doses to Personnel

The following table summarises the expected whole body doses from phase 1 and 2 work.

Description	Whole Body Doses (based on Amersham Dose Rates)	Worst Case Whole Body Doses
Phase 1 - source remains in container at all times	5 μSv	5 μSv
Phase 2 - source is removed, rotated and replaced in container	5.6 μSv	55.1 μSv
Phase 2 – when source is behind shielding wall	20 μSv	20 μSv
Total whole body dose for both phase 1 and phase 2 work	**30.6 μSv**	**80.1 μSv**

The following table summarises the expected dose to the hands from phase 1 and phase 2 work.

	Dose to hands based on Amersham Dose Rates	**Dose to hands based on Worst Case Dose Rates**
Phase 1	37 μSv	367 μSv
Phase 2	74 μSv	734 μSv
Total dose to hands for phase 1 and 2 work	111 μSv	1101 μSv

In section 4.1, the maximum whole body dose was set at 200 μSv and the maximum dose to the hands was set at 1.5 mSv. From the above two tables it can be seen that:

a. the worst case whole body dose is estimated to be 80.1 μSv which is less than half of the 200 μSv limit; and
b. the worst case dose to the hands is estimated to be 1.1 mSv which is within the 1.5 mSv limit.

Two radiation workers will share the work under phase 1 and phase 2 with the result that each worker should receive approximately half the doses estimated in the above tables.

Gamma and neutron dose rates will be monitored in real-time using survey meters and electronic dosimeters with gamma/neutron dose capability will also be used to monitor personal dose in real-time.

5. Results

5.1 Quality Control Readings

Within the radiation laboratory, the gamma radiation background level measured using the AN/VDR-2 radiation meter was typically 0.20 μSv/h and the neutron radiation background level measured using the Meridian Model 5085 neutron meter was 0.0 μSv/h.

For quality control purposes the alpha radiation instruments, i.e. the AN/PDR-77 and iSolo alpha/beta counting system were used to obtain:

a. readings for the background radiation level;
b. readings using an Am-241 alpha check source (S/N: NU496) having an activity of 618 Bq (on 12/10/2005); and/or
c. readings using a Co60 beta check source (S/N: OL627) having an activity of 654 Bq (on 7/8/2006)

Table 1 shows the background and Am-241 check source readings taken using the AN/PDR-77 with its 10 cm x 10 cm alpha probe.

Table 1. AN/PDR-77 readings

Description of check	Alpha count rate
Background radiation level check	0 cpm*
Am-241 check source (MW821) (617 Bq on 15/10/2004) Source to detector distance = 1 cm	15,000 cpm

* cpm = counts per minute

Table 2 shows the background, Am-241 check source and Co-60 check source readings taken using the iSolo alpha/beta counting system.

Table 2. iSolo readings

Description of check	Readings
Daily background check	Counting Time* = 10 minutes Alpha background = 0 cpm Beta background = 14.9 cpm
Background radiation level with no wipe sample present	Counting Time* = 5.96 minutes Alpha activity = 0.000963 Bq Beta activity = -0.11 Bq#
Background radiation level using a blank wipe sample	Counting Time* = 9 minutes Alpha activity = 0.011 Bq Beta activity = 0.0728 Bq
Am-241 alpha check source (NU496) (618 Bq on 12/10/2005)	Counting Time* = 5 minutes Alpha activity = 608.91 Bq Beta activity = 96.69 Bq
Co-60 beta check source (OL627) (654 Bq on 7/08/2006)	Counting Time* = 5 minutes Alpha activity = 0 Bq Beta activity = 360.28 Bq

*Counting time is the time the iSolo counted alpha and beta emissions on wipe samples.
#Note that the negative beta background arises due to the algorithm used by the iSolo system which automatically subtracts contributions from naturally occurring Radon/Thoron.

The daily background check in Table 2 is a preset feature that shows the alpha and beta count rate (in counts per minute) calculated over a 10 minute counting time. The values for the daily background check are within the manufacturer specifications for the iSolo. The other readings in Table 2 are counts collected for various times which are displayed as alpha and beta activities which have had the contribution from naturally-occurring Radon/Thoron radiation subtracted via a proprietary algorithm used by the iSolo alpha/beta counting system. When measuring low background levels a negative beta activity can arise due to the algorithm. It can be assumed that a negative beta activity value means zero activity for beta radiation i.e. there is no measurable beta radiation above background beta radiation levels.

The above results for the AN/PDR-77 and iSolo alpha/beta counting system show that both instruments are capable of measuring alpha contamination down to natural background levels as well as detecting and measuring emissions from the weak alpha and beta check sources that were used. The instruments should be able to measure the presence of alpha contamination on wipe samples at or above 200 Bq, which according to ARPANSA guidance[1] is the level above which a source is not considered leak tight and should be withdrawn from use.

5.2 Phase 1 Work – Source Remains in its Shielded Container

For phase 1 work (outlined in section 3.2.1), the AmBe source remained within its shielded transport container at all times. Figure 11 below shows a diagram of the AmBe source within its transport container and the locations where gamma dose rate readings were taken using the calibrated AN/VDR-2 survey meter (S/N: 031A) and neutron dose rate readings were taken using the Meridian Model 5085 neutron meter.

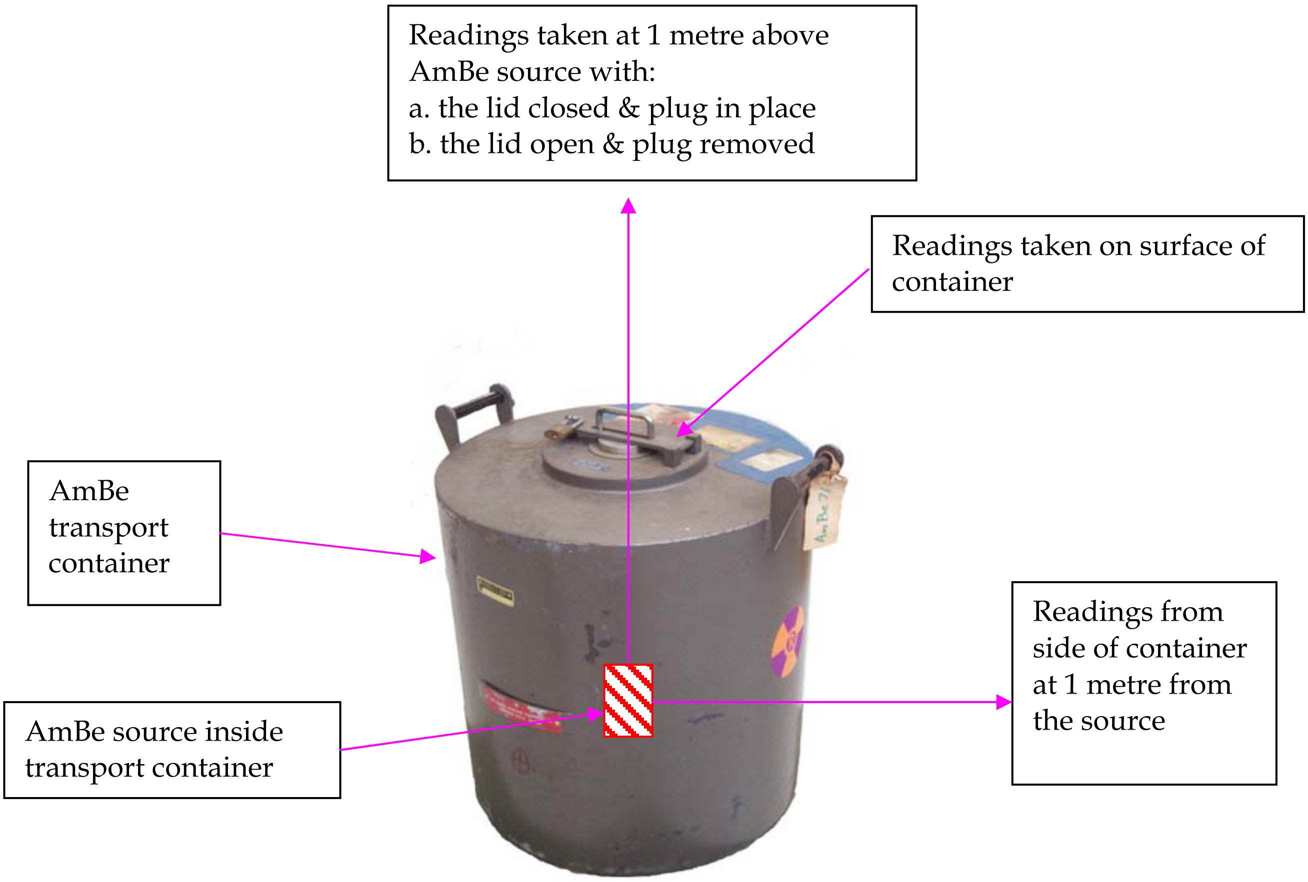

Figure 11. AmBe transport container and reading positions (not to scale)

Table 3 summarises all the gamma and neutron dose rate readings taken at various locations shown in Figure 11. Note that in the case of readings taken above the transport container, the radiation instruments were suspended above the container using a small crane.

Table 3. AmBe dose date readings

Measurement Positions	**AN/VDR-2 gamma dose rate**	**Meridian Model 5085 neutron dose rate**
Shielded readings taken from side of transport container, at 1 metre from the AmBe source	4.51 μSv/h	6.4 μSv/h
Shielded readings taken on top surface of AmBe transport container	58 μSv/h	57 μSv/h
Shielded readings above transport container at 1 metre from AmBe source – plug in place	4.7 μSv/h	8 μSv/h
Unshielded readings above transport container at 1 metre from AmBe source – plug removed	9.6 μSv/h	38 μSv/h

Table 4 compares the "unshielded" dose rates at 1 metre from the AmBe source measured during the phase 1 work with the Amersham dose rates and worst case dose rates presented in section 4.2. It is apparent that the Amersham and in particular the worst case dose rates are gross overestimates compared to the actual dose rates that were measured. This means the dose estimates for personnel calculated and presented in section 4.2 are very conservative, hence personnel will in fact receive whole body doses and dose to the hands that are significantly lower than the estimates given in sections 4.3 – 4.5. The measured readings in the last column of Table 4 can be used as a guide in safety calculations for future work with the AmBe neutron source (#71).

Table 4. Summary of Amersham, worst case and actual measured dose rates

	Amersham Dose Rates	**Worst Case Dose Rates**	**Readings measured during phase 1 work**
Gamma dose rate	~ 118.5 μSv/h at 1 m	~ 118.5 μSv/h at 1 m	~ 9.6 μSv/h at 1 m
Neutron dose rate	~ 104.3 μSv/h at 1 m	~ 2086 μSv/h at 1 m	~ 38 μSv/h at 1 m
Combined gamma & neutron dose rate	~ 222.8 μSv/h at 1 m	~ 2204.5 μSv/h at 1 m	~ 47.6 μSv/h at 1 m

Figure 12 is a photograph taken using the angled mirror (refer to Figure 8 in section 3.1) which shows a view down into the transport container "well" once the plug insert had been removed. The AmBe source can be seen at the bottom of the well. The source capsule has a threaded end that attaches to the handling rod.

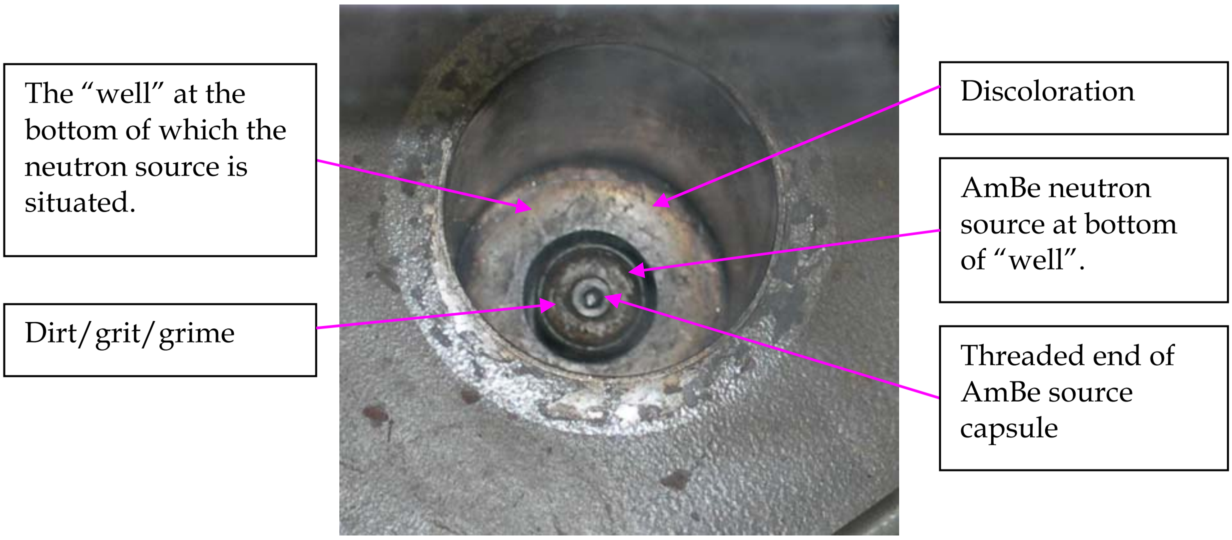

Figure 12. AmBe source within the opened transport container (photographed using angled mirror)

From the photograph as well as careful visual inspection of the source using the angled mirror, the following features were observed:

a. the presence of dirt/grit/grime;
b. scratches on and around the source due from past use; and
c. some discoloration or tarnish at the bottom of the well.

There were no obvious cracks in the source capsule, no signs of corrosion, nor any obvious leakage of material.

Two wipe samples were collected. The first by wiping the bottom of the source container plug and the second by wiping the top of the source (shown in Figure 12) and inside of the transport container using the U-shaped remote handling tool. Table 5 summarises the results from these two 2 wipe samples. Both wipe samples had on them what can be described as dirt, grit and grime that was black/grey in colour. There were no obvious rust-like stains on either of the wipe samples to indicate that corrosion had occurred.

Table 5. Summary of wipe testing results for phase one work

Sample No. & Description	**Comments**	**AN/PDR-77 with alpha probe**	**iSolo Readings**
Sample 1 – Bottom of source container plug	Removable plug that seals source within transport container was removed and its bottom end, which normally sits above the source, was wiped.	0 cpm	Counting Time*: 5.14 min Alpha: 0.00963 Bq Beta: -0.26 Bq
Sample 2 – Top of source, inside transport container	After removing plug, the top end of the exposed source and surrounds were wiped.	0 cpm	Counting Time*: 7.28 min Alpha: 0.0136 Bq Beta: -0.028 x 10^{-2} Bq

*Counting time is the time the iSolo counted alpha and beta emissions on wipe samples.

Given that both the AN/PDR-77 and iSolo readings indicated that no alpha contamination is present, phase two of the radiation work plan was undertaken. The negative beta activity is an artifact of the Radon/Thoron background subtraction algorithm used by the iSolo instrument and indicates there is no beta contamination present. Gamma dose rate readings of the samples taken with the AN/VDR-2 radiation meter were at the background level, typically 0.2 μSv/h.

5.3 Phase 2 Work – Source is Removed from its Shielded Container

Phase 2 work (outlined in section 3.2.2) involved the removal of the AmBe source to enable it to be inspected by CCTV and for wipe testing to be performed.

Figure 12 shows the rear-side of the "wall of water" shielding built using water-filled containers as described in section 3.1. The wall of water was positioned next to the metal-frame trolley which held the neutron source testing setup. Personnel were shielded from the neutron source by standing on the rear side of the "wall of water".

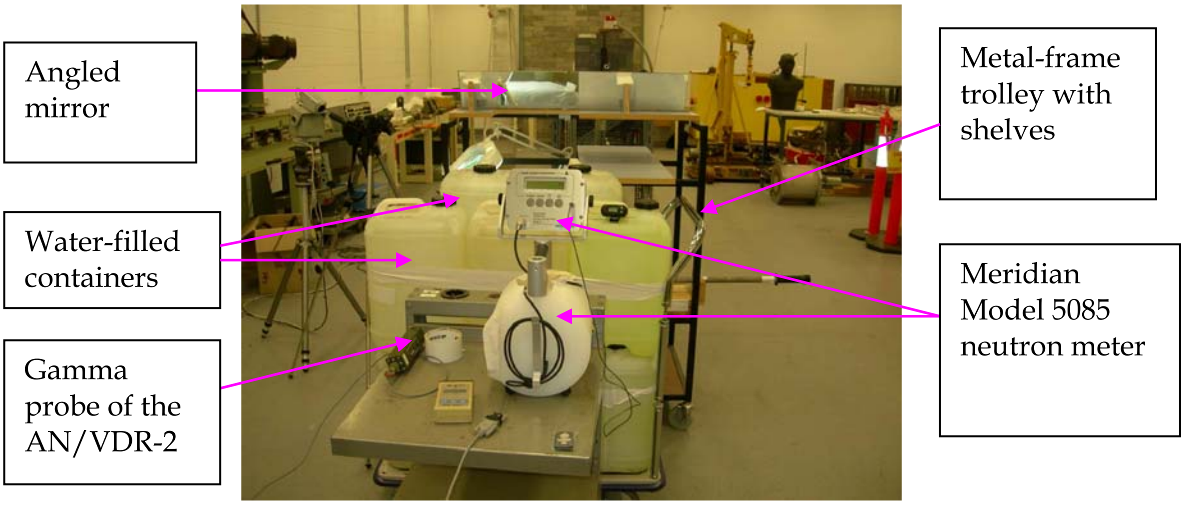

Figure 12. Rear-side of wall of water-filled containers used for neutron shielding

After removing the AmBe neutron source from its container and placing it at the neutron source testing location on the metal-frame trolley, the AN/VDR-2 survey meter and the Meridian Model 5085 neutron meter, shown on the rear side of the wall of water in Figure 12 above, were used to measure the gamma and neutron dose rate readings. These readings are listed in Table 6.

Table 6. Readings taken behind "wall of water"

Instrument	Reading
AN/VDR-2 gamma dose rate	1.1 µSv/h
Meridian Model 5085 neutron dose rate	7 µSv/h
Combined (gamma + neutron) dose rate	8.1 µSv/h

The combined (gamma + neutron) dose rate was only 8.1 µSv/h which is below the "pro rata dose rate level of 10 µSv/h". (In principal, exposure to a pro rata dose rate level of 10 µSv/h will result in an annual dose of 20 mSv assuming an occupationally-exposed radiation worker works in the presence of a 10 µSv/h radiation field for 8 hours a day, 5 days a week, 50 weeks per year totalling 8 x 5 x 50 = 2000 hours/year.)

The empty transport container was carefully moved away in a direction behind the shielding and protection provided by the "wall of water". The slot at the bottom of the well, shown in Figure 13, where the AmBe neutron source resided was wiped using a thin 1 metre long rod with a wipe attached to one end. Visual inspection revealed the following features:

a. some discoloration or tarnishing of the metal;
b. presence of dirt/grit/grime/dried grease (this is what was picked up when collecting wipe samples); and
c. circular scrape marks due to the fact that when attaching the AmBe source capsule to the handling rod the capsule undergoes some rotation while downward pressure is applied with the handling rod.

The discoloration or tarnishing noted in Figure 13 is likely to be due to the formation of an oxide layer on the surface of the metal which may assist with preserving the underlying metal.

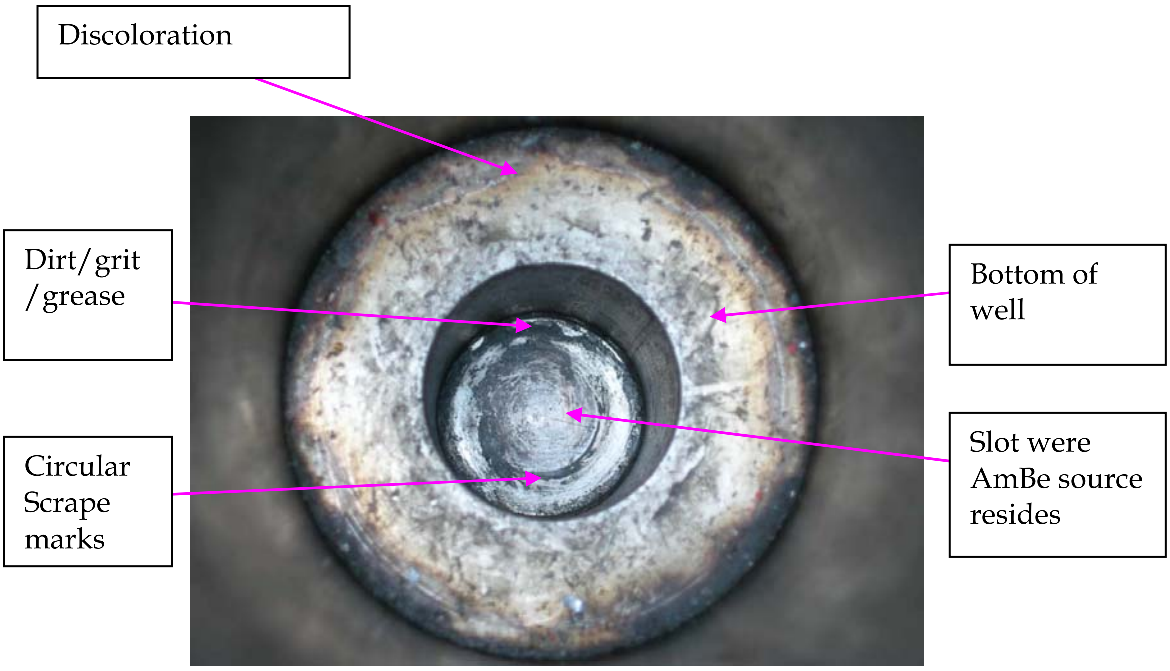

Figure 13. Bottom of well where AmBe source resides within transport container

CCTV was used to visually inspect the AmBe source capsule from the safety of the adjacent control room. The initial source orientation was the 0° position shown in Figure 14. The source was rotated by 180°, shown in Figure 15, and visually inspected again. Figure 13 shows a close up of the markings on the bottom of the capsule which are as follows:

AMN5000 1977

The year 1977, is most likely the year of manufacture of the source. This is supported by the fact that available records indicate this source was acquired by DSTO during Feb 1978. From the Amersham catalogue[2] of 1977/8, it is known that AmBe source capsules with an activity of 5 Ci had a product code "AMN.23". Amersham used the descriptor prefix "AMN" to indicate the product codes for its entire AmBe neutron source range. The origin or meaning of AMN5000 on the DSTO AmBe source is not known. In figures 11-13, there is a groove cut into the bottom end of the source capsule, along the entire diameter of the source. In the Amersham catalogue of 1977/8, the "AMN.23" AmBe sources were normally supplied with only a small 2mm slot at the centre. It is possible that the AMN5000 is a unique product code for the customised source capsule acquired by DSTO. Another possibility is it may refer to the 5000 mCi (i.e. 5 Ci) activity of the source.

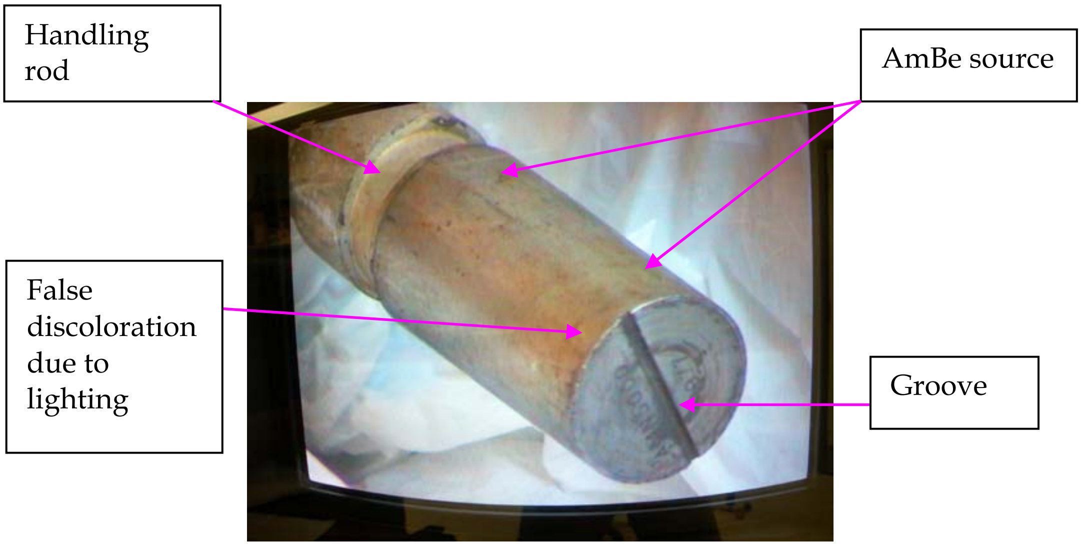

Figure 14. AmBe source (0 ° position)

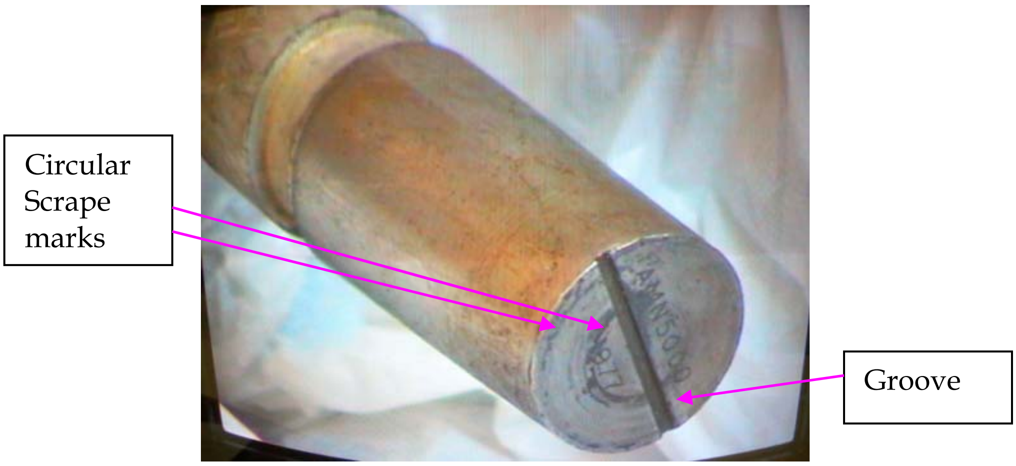

Figure 15. AmBe source (180 ° position)

Figure 16. Markings on bottom of AmBe source

The source capsule showed signs of wear and tear from past use. Circular scrape marks could be seen on the bottom end of the capsule. The capsule had some discoloration, though the yellow-like colour observed in figures 14-16 was exaggerated and was due to the quality of the ambient lighting and use of a fluorescent lamp and the fact that the images were viewed on a CCTV screen. The bottom end of the source capsule in the above figures gives an indication of its true colour. This true colour was visually observed when using the angled mirror shown in Figure 17.

There were no obvious signs of corrosion, cracks or fissures from the visual inspection performed using CCTV. No obvious leakage of material was observed during the inspection process. Overall, the source capsule appeared to be in reasonable condition for continued use.

Figure 17 shows the use of a wipe attached to a U-shaped remote handling tool to wipe the surface of the AmBe source. The wiping process was performed by standing behind the safety of the "wall of water" and using the angled mirror to safely view the AmBe neutron source.

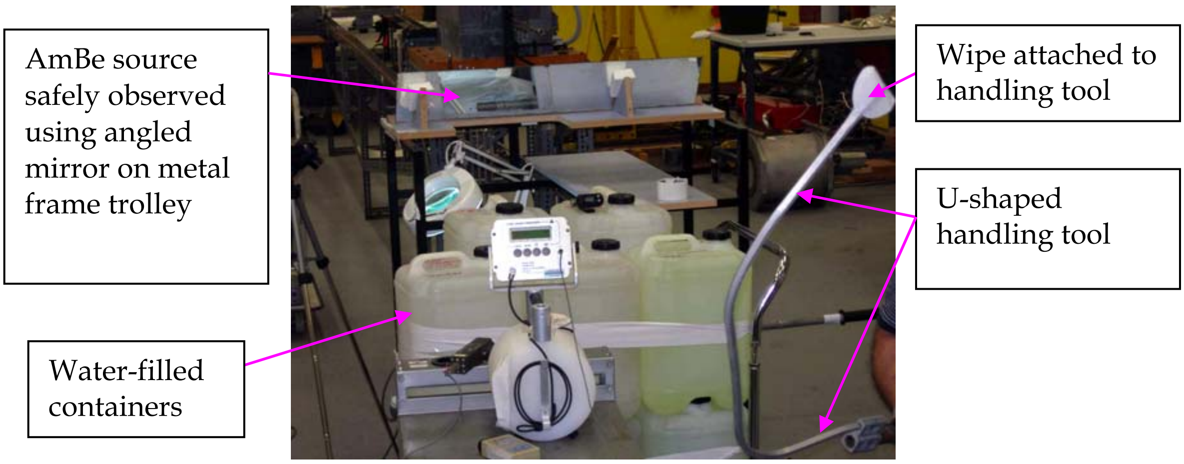

Figure 17. Wiping the AmBe neutron source using wipe attached to U-shaped remote handling tool

Table 7 shows the results of wipe testing results for phase two of the radiation work program after removing the AmBe source from its transport container and placing it at the neutron source testing position. Both the AN/PDR-77 and iSolo readings indicate that no alpha contamination was present. The alpha readings were of the order of background when compared to the Solo background readings and checks that were given in Table 2 of section 5.1. Note that gamma readings of the samples taken with the AN/VDR-2 were at the background level, typically 0.2 μSv/h.

Similar to the previous wipe samples, the three wipe samples described in Table 7 had on them what can be described as dirt, grit and grime that was black/grey in colour. There was no rust-like stain on any of the wipe samples to indicate that corrosion had occurred.

The wipe test samples were sent to ARS for further verification (see Appendix A).

Table 7. Summary of wipe testing results for phase two work

Sample No. and Description	**Comments**	**AN/PDR-77 with alpha probe**	**iSolo Readings**
Sample 3 – Bottom of well in source container.	After removing the AmBe source from the container, the bottom of the well where source sat was wiped.	0 cpm	Counting Time*: 6.14 min Alpha: 0.025 Bq Beta: 0.61 Bq
Sample 4 – Wipe test of AmBe source (0 deg)	The bottom end and side of the AmBe source were wiped using a remote handling tool.	0 cpm	Counting Time*: 4.53 min Alpha: 0.0109 Bq Beta: 0.91 Bq
Sample 5 – Wipe test of AmBe source (180 deg)	The AmBe source was rotated 180 deg and then it was wiped again using a remote handling.	0 cpm	Counting Time*: 5.96 min Alpha: 0.00831 Bq Beta: 0.56 Bq

*Counting time is the time the iSolo counted alpha and beta emissions on wipe samples.

5.4 Doses to Personnel

Table 8 shows the gamma and neutron doses and total dose received by the personnel conducting the preliminary checks on the AmBe source described in this report using the listed electronic dosimeters. The actual doses received (8 μSv and 10 μSv) were significantly lower than the worst case estimate of 80 μSv per person. This was due to the fact that there was some doubt regarding the accuracy of the neutron dose rate given in the Amersham Catalogue 1977/8 for AmBe sources. As a precaution, the worst case dose was calculated by applying the highest neutron radiation weighting factor of 20 to the Amersham neutron dose rate.

Table 8. Actual doses to personnel

Name & Dosimeter	Gamma Dose	Neutron Dose	Total Dose
Arthur Eleftherakis DMC 2000GN S/N: 007395	1 μSv	7 μSv	8 μSv
Martin Kocan Thermo EPD-N2 S/N: 07106323	1 μSv	9 μSv	10 μSv

6. Discussion

Preliminary checks on AmBe neutron source #71 involving measuring gamma and neutron dose rates, visually inspection and obtaining wipe samples of the AmBe source were successfully completed on 20 Jan 2011. Doses to personnel did not exceed 10 μSv.

Visual inspection of the AmBe source capsule revealed there were some signs of wear and tear on the exterior of the source capsule due to past usage, but the source capsule appeared intact and in good condition. There were no observable cracks or fissures and there were no signs of any material having leaked out of the source capsule.

The AmBe neutron source and the inside of the transport container (specifically the "well" within which the source sits) were carefully wiped using a U-shaped remote handling tool. Five wipe samples were collected. DSTO testing of these wipe samples involved use of the AN/PDR-77 radiation meter with a 10 cm x 10 cm alpha probe to check for gross alpha contamination and a sensitive iSolo alpha/beta counting system was used to check for the presence of low level alpha and beta contamination. All wipe samples were also checked for gamma radiation using an AN/VDR-2 radiation meter with its gamma probe and all readings were at the background level (~ 0.2 μSv/h) measured in the laboratory. Table 9 below summarises the results of the wipe testing.

Table 9. Summary of Results of DSTO Testing on Five Wipe Samples

Instrument	Measurement results for all 5 wipe samples
AN/PDR-77 with 10 cm x 10 cm alpha probe	0 counts per minute
iSolo alpha/beta counting system	alpha level < 0.03 Bq beta level < 1 Bq
AN/VDR-2	0.2 μSv/h (background level)

ARPANSA guidance[1] specifies that a source is not considered leak tight if contamination levels in excess of 200 Bq are measured. Based on the results in Table 9 both the alpha and beta levels from all wipe samples were found to be significantly less than this level, hence it can be concluded that there was no detectable contamination present.

The wipe samples were dispatched to Australian Radiation Services (ARS) for independent testing to confirm that no alpha contamination was present. Appendix A provides a copy of the ARS Wipe Test Report which states that the Am-241 activity from the combined 5 wipe tests was below the detection limit of the ARS measurement system and concludes that there is no detectable contamination on any of the wipe samples.

The DSTO and independent ARS testing performed on the five wipe samples obtained from the AmBe neutron source and inside its transport container both conclude that there was no detectable contamination. Based on this conclusion together with the visual inspection of the source capsule, the source appears to be in good condition for continued use within a controlled laboratory environment.

Problems were encountered with lighting levels when photographing the AmBe source capsule. For any future wipe testing type work, improved lighting should be considered to ensure better quality photographs can be taken.

The equipment described in section 3.1, such as the water-filled containers, metal-frame trolley and neutron source wipe testing setup, were used to create an entirely improvised facility for allowing the AmBe source to be visually inspected and wipe testing in a safe manner and keep doses to personnel as low as reasonably achievable. With more funding a dedicated in-house facility for performing routine wipe testing could be set up or alternatively it may be more cost-effective to contract out this type of activity.

7. Recommendations

Recommendation 1. The results of this report and the independent ARS testing both indicate that the AmBe source #71 is in good condition for continued use.

Recommendation 2. A copy of this report should be included in a submission to ARPANSA requesting approval for continued use of AmBe source #71.

Recommendation 3. Consideration should be given to acquiring a new AmBe neutron source and disposing of the old source within a 5-10 year timeframe.

8. References

1. Regulatory Guide: Use of sealed sources beyond their recommended working life, Document ID: RPB-SUP-270A, ARPANSA, September 2009

2. Radiation sources industrial laboratory, The Radiochemical Centre, Amersham, 1977/8

3. ICRP Publication 26, Recommendations of the International Commission on Radiological Protection, January 1977, Pergamon Press

4. ICRP Publication 60, 1990 Recommendations of the International Commission on Radiological Protection, November 1990, Pergamon Press

5. RPS1, Recommendations for limiting exposure to ionizing radiation (1995) (Guidance note [NOHSC:3022(1995)]) and National standard for limiting occupational exposure to ionizing radiation [NOHSC:1013(1995)], Radiation Protection Series Publication No. 1, Republished March 2002

6. Table 6.7 on page 199, The Radiochemical Manual, Edited by G. Longworth, AEA Technology plc, Analytical Services Group, Harwell, 1988

7. Table 7.4 on page 155, The Health Physics Radiological Health Handbook, Compiled and edit by B. Shleien and M. S. Terpilak, Nucleon Lectern Associates, 1984

Appendix A: ARS Wipe Test Report

AUSTRALIAN RADIATION SERVICES PTY. LTD.
Keeping people safe.

PO Box 3103 Nunawading VIC 3131 Australia
22 King Street Blackburn VIC 3130 Australia
T +61 3 9877 4898 F +61 3 9877 8272
E info@radiation.net.au W www.radiation.net.au
ABN 66 006 528 267

Wipe Test Report

Client: DSTO
506 Lorimer St.
Fishermans Bend VIC 3207

Report №: 11-1159-W1

Contact: Dr. Arthur Eleftherakis

ARS Job Number:	11-1159-W1
Wipe Description:	Defensap™
Quantity submitted:	Five wipe samples (from different locations on the source and source container)
Submission Date:	28th January 2011
Test Required:	Detection of any radioactive contamination due to americium-241 on wipe.
Test Method:	The five wipe samples as received were transferred to a standard measurement container as one sample. Americium-241 radioactivity on the combined wipes was determined using high resolution gamma ray spectrometry with a count time of 3600 s.

AUSTRALIAN RADIATION SERVICES PTY. LTD.

Report prepared by:	Dr. Matthew Taylor Physicist	**Signed:**	
Reviewed by:	Dr. Malcolm Cooper Consultant Environmental Chemist	**Signed:**	M.B. Cooper
Date:	3rd February 2011		

Report №: 11-1159-W1

Test Results:

ARS ID	Relevant Source Description				Measurement Results
	Model № (Housing Serial №)	Source Serial №	Radionuclide	Activity	Am-241 activity (Bq)[1]
11-1159-01 (5 wipes combined)	AMN.24 (X.14)	AMN5000	Am-241/Be DSTO #71	5 Ci	< 0.2

Information on Test Assessment:

The americium-241 activity for the 5 combined wipes was below the detection limit of 0.2 Bq for the measurement system used and therefore it can be concluded that there is no detectable contamination on any of the wipe samples.

Page 2 of 2

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4. AUTHOR(S) Arthur Eleftherakis and Martin Kocan	5. CORPORATE AUTHOR DSTO Defence Science and Technology Organisation 506 Lorimer St Fishermans Bend Victoria 3207 Australia

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Americium-Beryllium, neutron source, wipe testing

19. ABSTRACT
This report describes preliminary checks performed on AmBe neutron source #71 consisting of wipe testing and visual inspection for the purpose of determining if the source capsule was in good condition and leak tight for continued use within the laboratory. Wipe samples obtained from the AmBe neutron source and inside its transport container were tested by DSTO and also independently by Australian Radiation Services. The results of both tests conclude there was no detectable contamination and that the AmBe neutron source was still leak tight. Visual inspection of the AmBe source capsule indicated it was still in good condition for continued use within a controlled laboratory environment.