Encapsulation Procedure for the SuperCDMS Gamma Calibration Sources

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Reviewed by: TBD
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SuperCDMS SNOLAB requires the use of up to six ^{133}Ba gamma sources for calibration studies. The source capsules will each have activity of several uCi and will be deployed using an automated source deployment system. Figure 1 shows a concept of the source deployment system along with the SuperCDMS cryostat, both of which will reside along with the SuperCDMS experiment at SNOLAB, in Sudbury, Canada. This document is being prepared in order to record the procedures for encapsulating the gamma sources, and for the purpose of evaluation of the encapsulation procedure by the ES&H groups of the host lab for SuperCDMS (SNOLAB), the lab that is building the calibration system (Fermilab) and the lab responsible for SuperCDMS project management (SLAC).

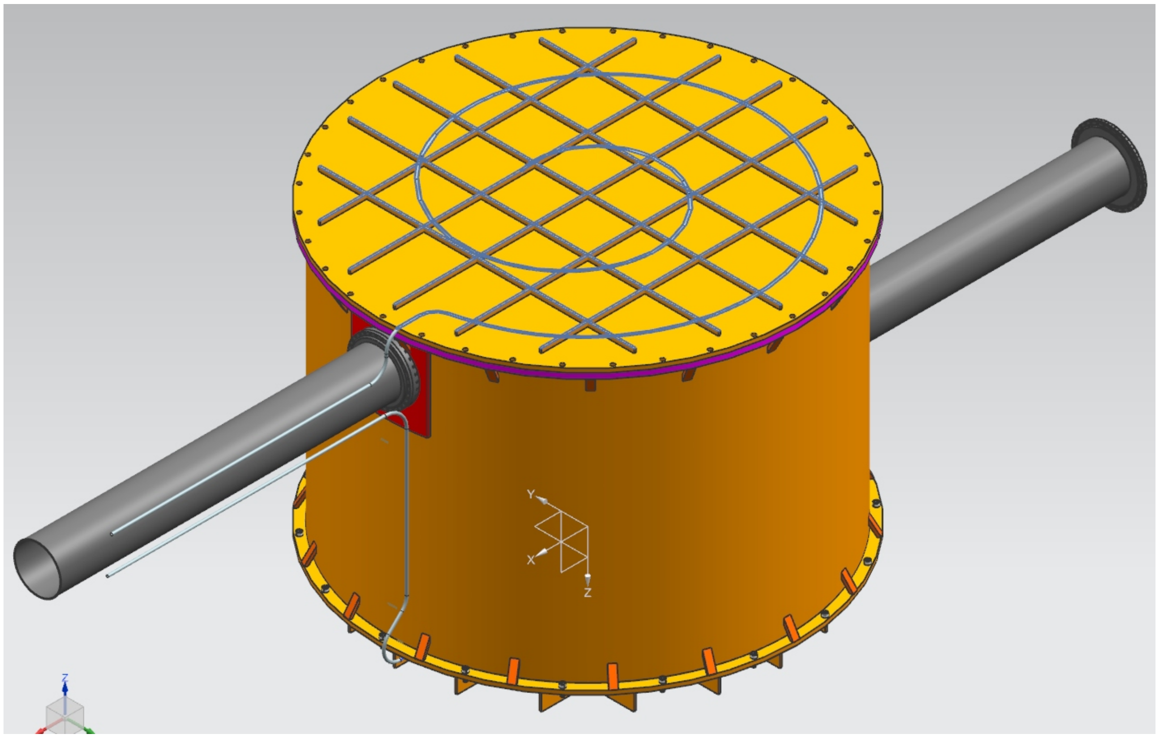

Figure 1: The drawing above shows the concept for the source delivery system. The system will consist of a guide system (shown as the thin gray tube that spirals above and below the cryostat) and a chain or cable that the sources are attached to. The cable will be mechanically driven through the guide system. In this example, guide tubes penetrate the passive shielding (not shown in diagram) along both the Electronics-stem and Fridge-stem. The tubes spiral around the top and bottom of the cryostat to allow for sources to be moved throughout the x-y plane.

To preserve the cleanliness of SNOLAB, which is an ultra-radiopure laboratory dedicated to housing low-background experiments, SNOLAB requires that any users who bring radioactive sources into the lab, must apply two distinct encapsulation layers regardless of the source activity level. This requirement exists *in addition to any encapsulation that is provided by the manufacturer, regardless of the manufacturer's encapsulation design*. The encapsulation must be reasonably demonstrated to be impermeable to gas and liquids. It must also be robust enough to withstand any mechanical forces that will be applied to it under normal operation. The exterior of the source must be demonstrated not to be contaminated following application of each encapsulation layer. Further details of the encapsulation requirements are listed in Appendix B. Because the Fermilab SuperCDMS group will design and build the source deployment system, it is this group's responsibility to ensure that the SNOLAB source requirements are met.

As shown in Figure 1, the sources will be inserted into small guide tubes that will be threaded through a small penetration in the passive shielding system of the SuperCDMS experiment. The calibration tubes will have an inner diameter of 0.25", so the source capsules, with their extra two layers of encapsulation, must be smaller than this. We intend to purchase 0.7 mm cation resin beads that contain the active source material. The beads are supplied by the vendor Eckert & Ziegler Isotope Products Inc. The beads will be shipped encased in an acrylic holder and are coated in a paraffin film in order to contain the source activity (a few more details appear in Appendix C). Our intent is to insert one to three of these beads into a small stainless tube, which will form the first encapsulation layer. The tube will then be sealed as described in the procedure below. The source capsule will then be sealed in a second stainless tube in the same manner and then attached to the source guide wire as described below. In between each of the encapsulation steps, the source capsule will be wipe tested for radioactive contamination on its surface.

It should be noted that we are also planning to deploy two ^{252}Cf neutron sources at SNOLAB, so we must also provide encapsulation for these sources. We are planning to use a similar welded tube design, with the main difference being that the ^{252}Cf sources will be purchased from Eckert & Ziegler with a double-stainless encapsulation already applied to the source. These sources are approximately 0.25" in diameter and we will then apply two additional stainless encapsulations at Fermilab to meet SNOLAB requirements. A separate document describing this procedure in detail will be provided once we have finished testing some prototype encapsulations that are of appropriate size for the anticipated ^{252}Cf source.

5.1 Source Encapsulation

To meet the requirements to be gas and liquid tight, both the inner and outer encapsulations will consist of .008" wall stainless steel 304 tubing crimped and welded on both ends. The leak tightness of this welding method was demonstrated and is described in Appendix A. The dimensions of the tubes and the encapsulation concept are shown in Figure 2. Two distinct layers of encapsulation are proposed.

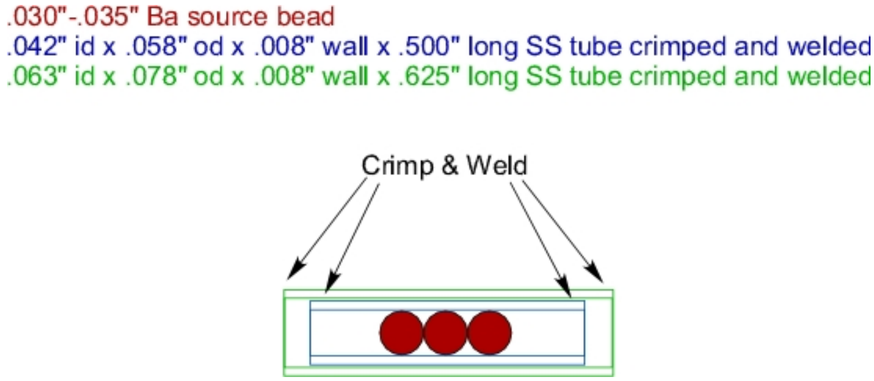

Figure 2: The drawing above shows the proposed dimensions for the stainless steel encapsulation tubes. The red circles represent source beads. The ends of the tubes will be crimped and then welded.

5.1.1 Attachment of source capsule to guide wire

The sources will be deployed on a stainless steel cable, which will be mechanically driven through another Teflon tube, which serves as the source guide tube. To attach the sources to the chain, the source package will be inserted into a third stainless tube that will then be crimped onto the cable as shown in Figure 3. The entire stainless steel encapsulation tube will be covered with a Teflon sleeve to alleviate abrasion and sticking of the sources.

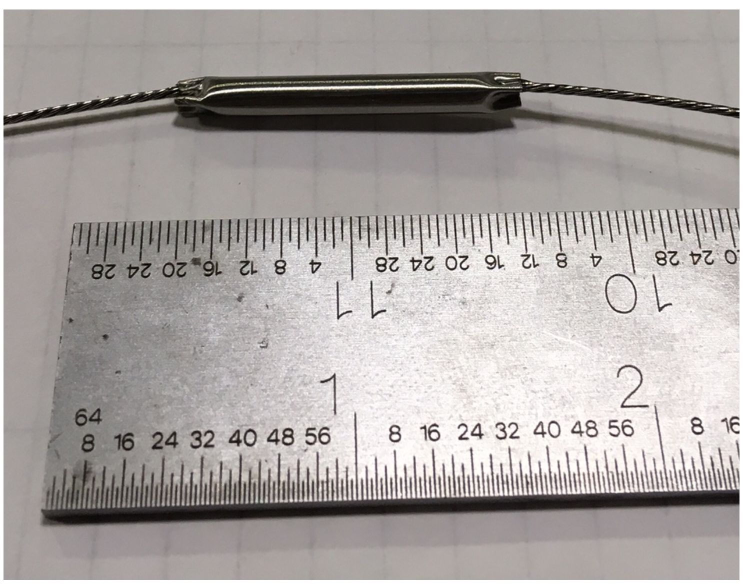

Figure 3: Closeup of example source package. The outer stainless tube will contain the sealed, double-encapsulated sources and is crimped onto a stainless wire. The wire and outer tube package will in-turn be coverd with a Teflon tube to minimize friction as the source is pushed along the Teflon guide tubes.

5.2 Encapsulation Procedure

The following proposed procedure includes steps to wipe and count the exterior of the encapsulations after welding. All tubing is 304 stainless steel in the annealed state. The crimping on the ends of the tubes is accomplished using a 4 point crimping tool and crimps are .030" in length.

1. Cut inner tube to .500" in length

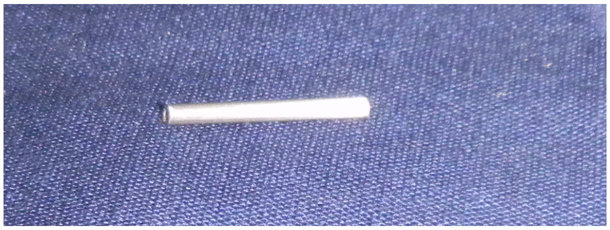

Figure 4: Cut tubing

2. Crimp one end .030" length from the end.

Figure 5: Crimping of tube (left) and detail of tube after crimping (right).

3. Place tube in copper welding fixture and weld the crimped end shut. This step will be performed in the main welding shop in the Fermilab Village.

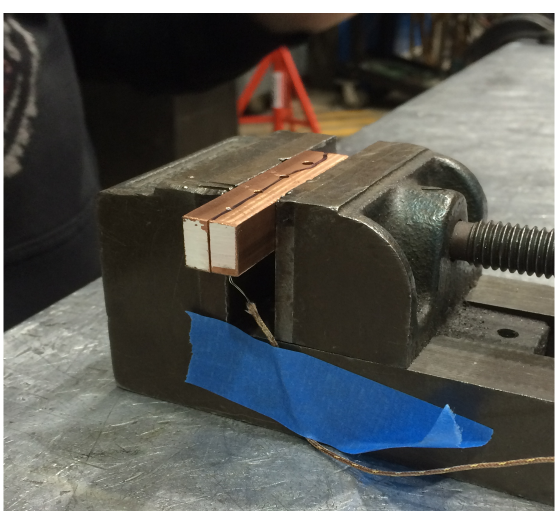

Figure 6: Preparing to weld the tube.

4. Visually inspect the welded end with a minimum of 20x magnification.

Figure 7: Detail of welded tube end.

5. Check the weld using a helium mass spectrometer leak detector with a minimum sensitivity of 10^{-9} mbar-liter/s.

Figure 8: Helium leak checking.

6. Insert source bead(s) into the inner tube, making sure it rests at the welded end of the tube. This step, along with step 7 will be performed in lab G at Fermilab. We will wipe and count any tools that came into contact with the source beads in the process of depositing them inside the encapsulation tube. - ***This process is to be developed with input from FNAL ESH&Q Division***
7. Crimp the open end per step 2
8. Weld the crimped end per step 3. This step will be performed in the main weld shop in the Fermilab village.
9. Visually inspect the welded ends with a minimum of 20x magnification per step 4 (Note there is no leak check in this step. Reliability of this second weld is addressed in Appendix A).

10. Wipe and count inner tube assembly for any radioactive leakage - ***This process is to be developed with input from FNAL ESH&Q Division***
11. Cut second tube to .625"
12. Crimp one end end per Step 2
13. Insert the inner tube assembly into the second tube.
14. Crimp the second tube per step 2
15. Weld the crimped end of the "second tube".
16. Visually inspect the welded ends with a minimum of 20x magnification.
17. Wipe and count outer tube assembly for any radioactive leakage. - ***This process is to be developed with input from FNAL ESH&Q Division***

Appendix A: Demonstration of reliable, leak tight encapsulation and measurement of temperature exposure of source bead

The tubing chosen for the source encapsulation was stainless steel, 304 series in the hard temper. A standard tungsten inert gas (TIG) welding machine was used for the welding. To make the welding of the ends easier and to prevent the hot welding plasma from entering the end of the tube, a 4 point crimping tool was used to close the ends of the tubes.

Initially, 17 unannealed 0.500" tubes were crimped and welded on one end as described in the above procedure. Due to cracking in the crimped area, almost 50% failed during leak checking. To make the end crimps more reliable, the SS tubing was annealed before crimping. This resulted in much more reliable, repeatable, and leak tight welding. 17 annealed tubes were crimped with the .030" crimp length and then welded on both ends. They were cut in half and both ends were checked for leaks with a 100% leak check success rate.

After the welding process was developed, thermal mapping tests were performed to prove that the source beads would not be overheated during the welding process and to determine how short the tubes could be. We were informed by the intended supplier of the source beads that the beads have good thermal stability up to 150^0C, so we intend to keep the beads below this critical temperature.

The procedure for measuring the temperature is described as follows. A piece of the inner tubing was crimped on one end as described earlier. A thermocouple was inserted into the tube with the sensing tip touching the crimp as shown in Figure 9.

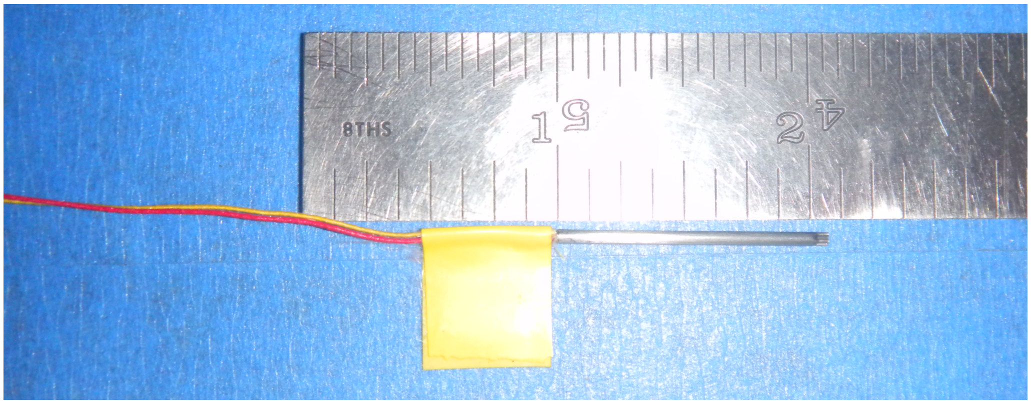

Figure 9: Detail of thermocouple inserted in tube end.

The thermocouple was then retracted by 1/8" as shown in Figure 10.

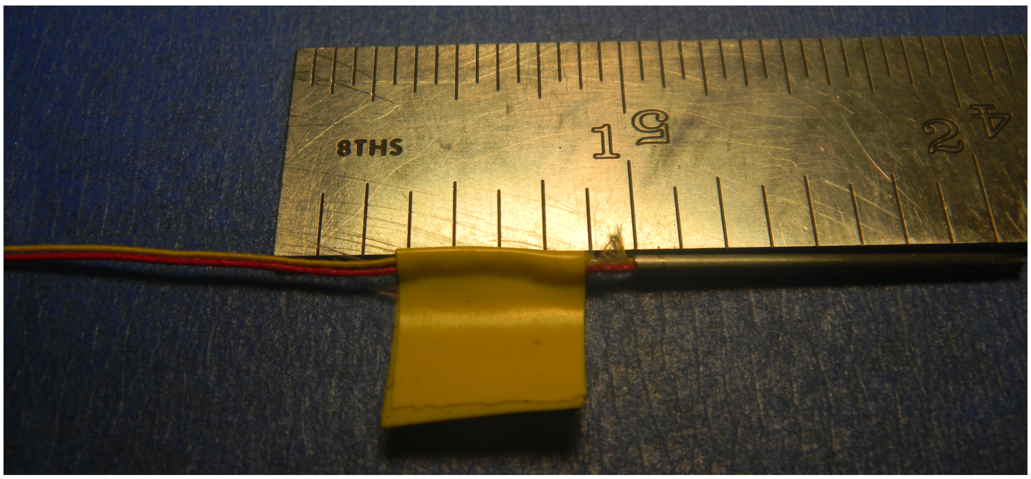

Figure 10: Detail of thermocouple at 1/8" from tube end.

The thermocouple readout was monitored by a computer and the readings were recorded every 0.1 seconds.

Figure 11: Temperature reading setup.

The tube was then clamped into the copper heat sink for welding.

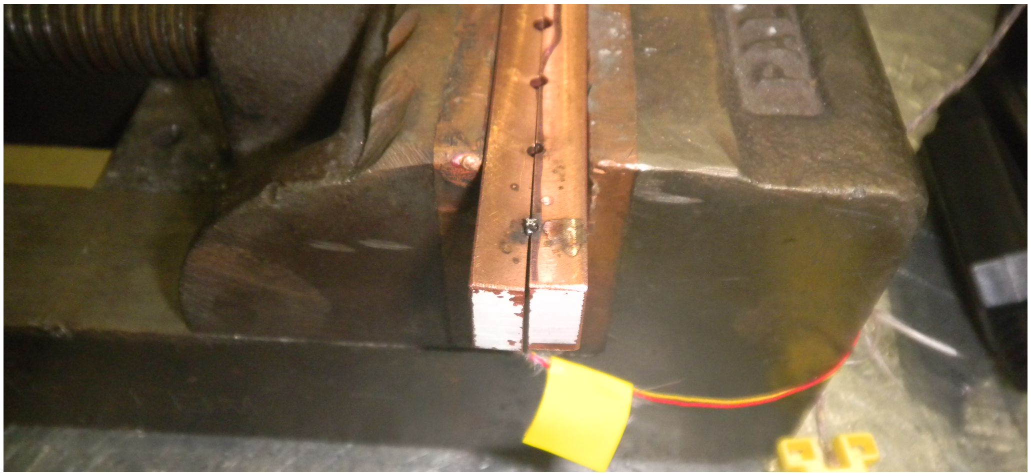

Figure 12: welding with thermocouple in place.

This process was then repeated with a second tube with the thermocouple sensing tip retracted ¼". The temperature plots are shown in Figure 13 below. The maximum temperature recorded at the closest of the two measured distances was below 45^0C. While the instantaneous maximum temperature may have reached slightly higher temperatures, we believe the 0.1 second sampling speed and relatively low maximum temperature measured with the probe at 1/8" are sufficient to demonstrate that the bead will not be overheated during the welding process. Based on the size of the beads and the crimps, the minimum distance that a bead will be located with respect to a welding joint during the welding process is 0.35". This is greater than the distances measured here so we should expect the maximum temperature experienced by the beads to be below ~33^0C. The welds were accomplished with 17 volts and 7 amps of power for 2 seconds for an input of 239 Joules.

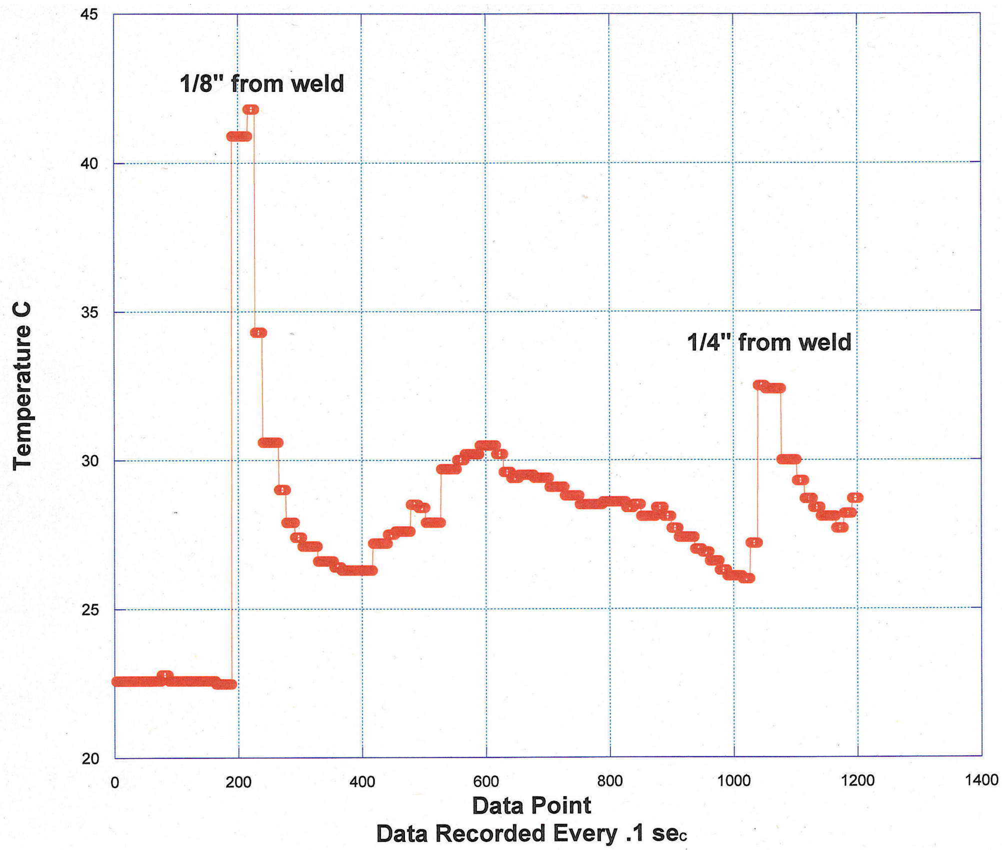

Figure 13: The plot above shows the temperature versus time with the thermocouple at two distances from the end of the tube. The x-axis is the sample number, which corresponds to every 0.1 seconds. The maximum observed temperature is ~42^{0}C, which is well below the 150^{0}C maximum temperature that the source beads can withstand.

Appendix B: SNOLAB Policy on Source Encapsulation

Attached is the SNOLAB policy on source encapsulation

SNOLAB	**SNOLAB RADIOLOGICAL SOURCE ENCAPSULATION POLICY**	
Document Number: SL-SCI-REP-10-002-P		**Revision Number: 00**
Document Owner: Radiation Safety Officer		
Reviewer:		
Name: Bruce Cleveland	**Signature: <signature on file>**	**Date: 2015-02-22**
Authorizer:		
Name: Nigel Smith	**Signature: <signature on file>**	**Date: 2015-03-16**

1.0 PURPOSE

The purpose of the SNOLAB Radiological Source Encapsulation Policy is to provide guidance to SNOLAB Users on the encapsulation of radiological sources which are used at SNOLAB. The term radiological source is used to describe any substance, natural or artificial, that emits significant radiation.

2.0 SCOPE

While occasionally the radiological sources used at SNOLAB are sufficiently active to require registration by CNSC, in many instances the radiological materials used at SNOLAB have sufficiently low activities that they are exempt from the CNSC registration requirements. None the less, these radiological sources are sufficiently active that mishandling them could significantly compromise the SNOLAB scientific program. Therefore to ensure the robustness of radiological sources at SNOLAB they must be encapsulated appropriately.

3.0 DEFINITIONS

RADIOLOGICAL SOURCE: Any substance, natural or artificial, that emits significant radiation.

SIGNIFICANT RADIATION: The amount of radiation which can adversely affect he low-background nature of SNOLAB by increasing measured radiation levels above the ambient background levels emitted from natural sources such as concrete or rock.

CNSC: Canadian Nuclear Safety Commission

RADIATION SOURCE or RADIOACTIVE SOURCE: A registered quantity of radioactive material that requires administrative controls to ensure human health and safety.

ENCAPSULATION: Unless otherwise stated, encapsulation refers to a gas, liquid and particulate-tight enclosure into which a source is placed after receipt from the manufacturer. Some vendors provide what they refer to as encapsulated or even doubly encapsulated sources consisting of sealed containers such as welded stainless steel conforming to a known standard. Because of the stringent requirements to prevent contamination at SNOLAB and the lack of knowledge of the quality control steps used by the vendor, such commercially prepared encapsulations are usually not considered relevant. Commercially prepared thin window sources such as ^{241}Am sources with a vapour deposited gold window a few microns thick are **always** considered to be unencapsulated due to the fragile nature of the window.

CONSEQUENTIAL LEVELS OF CONTAMINATION: A level of contamination if introduced into an experiment may result in backgrounds that could compromise its science goals. The sensitivity to backgrounds depends on the experiment. For example some experiments are sensitive to minute (and unmeasurable) fission sources. The level of contamination must be taken in the context of ambient backgrounds already existing in the laboratory. For example when considering a contamination of ^{238}U, the natural abundance of ^{238}U in mine dust must be considered.

4.0 RESPONSIBILITIES

SOURCE COMMITTEE: The Source Committee will review all radiological sources to ensure that adequate encapsulations are used with respect to the actual expected use of the source.

PROPONENT OR REQUESTOR OF SOURCE: The proponent or requestor of the radiological source will follow the SNOLAB Radiation Protection Program and the Radiological Source Approval Process and Use of Radiological Sources Procedures in all aspects. The proponent will complete the Source Descriptor document and any other procedures as required by the Source Committee. The proponent will perform the encapsulation of the source and perform all required assays and tests of the source encapsulation as required.

5.0 REQUIREMENTS

5.1 Source Encapsulation

The default requirement for source encapsulation will be a **minimum** of two distinct layers: The inner encapsulation and the outer encapsulation. These encapsulations are to be applied to the source after receipt from the source vendor – regardless of the source enclosure provided by the vendor. The outer encapsulation must be mechanically robust and able to withstand, at a minimum, events such as drops and impacts. If the intended use of the Source could lead to mechanical loads, the encapsulation must also be able to withstand both the anticipated normal loads and also any reasonably plausible upset condition loads. A fault analysis is required to demonstrate that the outer encapsulation will not fail in plausible scenarios. The inner encapsulation does not necessarily have to be as mechanically robust as the outer encapsulation but must remain intact during the assembly process. Each encapsulation must be gas and liquid tight and prevent the transfer of particulates.

5.1.1 Special Considerations

1. Upset Loads: For example, if a Source is to be deployed on a wire in a guide tube, considerations must include: friction against surfaces abrading the encapsulation leading either to dislodging adhered contamination or possibly breaching the encapsulation; the Source getting stuck and experiencing much higher than intended loads.

2. Sealing of encapsulation: Each encapsulation must either be demonstrated to be gas, liquid and particulate tight or if the nature of the encapsulation prevents a verification, there must be high confidence that the seal will be made properly.

5.2 Encapsulation Procedure and Records

The process of placing the source within each subsequent encapsulation must be done in such a fashion as to ensure that the probability of transfer of any radiological contaminant to the exterior of the encapsulation is vanishingly small. The procedure for encapsulation must be documented and records must be kept demonstrating that each step of the procedure has been successfully completed.

An assay of radiological contaminants transferred to the exterior of the encapsulation must be made. If the assay is sufficiently sensitive to measure consequential levels of contaminants then the measured levels of any radionuclide must be below the acceptable quantity. If the assay is insufficient to measure consequential levels, then the assay must show no measurable quantities of contaminants of any radionuclide. The results of the assays must be evaluated before proceeding to subsequent steps of the encapsulation procedure. If levels above the acceptable quantity are found (or in cases where the acceptable quantity is below the level of sensitivity of the assay, any measurable quantity is found) the cleaning steps of the procedure and the assay must be repeated. Records must be kept of the assay results.

5.2.1 Procedural Verification

Documented Procedure: In the event that there is a mishap in carrying out the procedure, the usual course of events would be to restart the procedure from a "stable" point or possibly from the very beginning. For instance, if a source is touched by bare hands after cleaning it is likely that the cleaning step must be repeated.

5.3 Special Encapsulation Cases

In the event that double encapsulation of the Source is not possible, the Source Committee will consider cases put forward by the proponents to have only a single encapsulation provided there is a sufficiently strong argument for why there is no significant risk of contamination from the Source. Such an argument might include procedures for verifying the absence of contamination or procedures for encapsulation where the probability of transfer of radiological materials to the exterior of the encapsulation is vanishingly small. In the event that only a single custom encapsulation is approved, it shall be mechanically robust. A possible example of a situation where a request for a single encapsulation might be considered is when the desired calibrating radiation from the source would be significantly compromised if multiple encapsulations were to be used.

5.3.1 Single Encapsulation Guidelines

1. While the threshold for accepting a singly encapsulated source is necessarily high, it will not deliberately be set impossibly so. For example since it is usually impossible to demonstrate a complete absence of consequential contamination from the exterior of a source, a requirement for the proponents of the source to "demonstrate that there is no consequential contamination" is not acceptable.

2. In the event that a singly encapsulated source is accepted, geographical limits on its placement in the laboratory might be set. E.g. It might only be allowed in the vicinity of the experiment for which it is used.

5.4 Encapsulation Exceptions

Under some circumstances Sources with NO encapsulation will be considered. The requirement for encapsulation might be waived if the Source consists of a short lived radionuclide such as a ^{24}Na source consisting of activated NaCl dissolved in water. With a half-life of 15 hours, such a Source would be expected to decay to inconsequential levels in a matter of days. However, there would still be strong requirements to ensure that such a Source did not inadvertently contain longer lived radionuclides that could lead to contamination.

6.0 RECORDS

6.1 Report on the Source summarizing the Committee's findings from the review of the source, verifying that the source encapsulation is acceptable.

7.0 SUPPORTING DOCUMENTS

- Radiological Source Committee Terms of Reference
- Radiological Source Descriptor Template

8.0 REFERENCES

N/A

9.0 REVISION HISTORY

ORIGINATING DATE: 2014-05-05			
REV NO.	**EFFECTIVE DATE (YYYY-MM-DD)**	**AUTHOR**	**SUMMARY OF CHANGE**
00	2015-03-16	Ian Lawson	Initial version drafted from a memo issued by F. Duncan.

Appendix C: Correspondence from Eckert & Ziegler and source quote

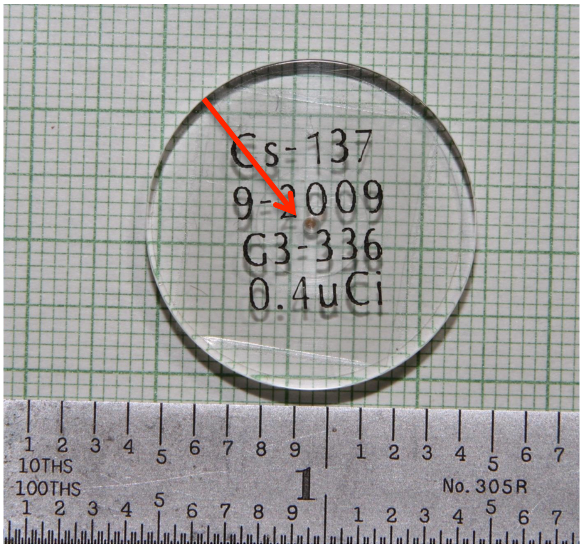

Figure 14: Example source bead (purchased by EXO collaboration from Eckert and Ziegler), not the same isotope or activity level we propose here, but same design.

The following is an email from sales rep Eric Brown containing details of the source coating.

On Nov 18, 2015, at 10:34 AM, Eric Brown <Eric.Brown@ezag.com> wrote:

Lauren,

After further investigation I found that the sources used by the EXO group were made with a piece of parafilm covering the bead so that it could easily be removed from the disk (usually the bead is permanently set in the disk with epoxy). I have asked our lab if they can repeat this with Ba-133 and will let you know soon.

Best Regards,
Eric

Eric Brown
Technical Sales Specialist
Eckert & Ziegler Reference & Calibration
1380 Seaboard Industrial Blvd.
Atlanta, Georgia 30318
USA --
Phone: +1-404-425-5068
Fax: +1-404-352-2837

Email: Eric.Brown@ezag.com
Web: http://www.ezag.com/home/products/isotope-products/isotrak-calibration-sources.html

Quote 00007274-1

Eckert & Ziegler

14 Apr 2016

Eckert & Ziegler Isotope Products, Inc.
24937 Avenue Tibbitts
Valencia, CA 91355

Attn

Fermi Lab
Receiving Warehouse 2
Kirk RD & Wilson Street
Batavia, IL 60510
United States
Contact ...: Lauren Hsu
Phone ....: 630-840-4638
Fax ....:
Email .....: llhsu@fnal.gov

Quoted By

EZ Contact ......: Eric Brown
Phone ....: 404-425-5068
Fax ....: 404-352-2837
E-mail address ..: eric.brown@ezag.com

Customer account	Slspsn	Payment ID	Customer reference
FERLAB01	566	Net 30 Days	

PPD/COL	Ship Via	Lead Time
Prepay and Add FOB:O	Fed-X-2	6 weeks

Line	Item number	Description	Qty.	Unit	Unit price	Extended Price
1.0	RFQ1744-133-1U	Ba-133, 37kBq (1.0 µCi) +/-15% 0.7 mm resin bead, Nominal	8	Ea	1,230.00	9,840.00

This is a custom product designed to customer supplied specifications. The custom product will be made as best effort and cannot be returned if the custom product does not meet the customer's intended application.

The activated 0.7 mm cation resin bead will be temporarily housed in a clear acrylic disc.

Actual bead diameter: 0.030in - 0.035in

Shipping & Handling	Sales tax	Quote Total
TBD	0.00	9,840.00 USD

This quote may not reflect miscellaneous charges, freight, or sales tax unless otherwise indicated above.
This quote is valid for 90 days.
Returns Policy: Due to the nature of our products, all sales are final and no items can be returned for credit unless demonstrated that the product does not meet specifications. Such a claim must be made within 30 days of receipt of order and the source returned to Eckert & Ziegler Isotope Products, Inc., within 60 days after receipt of shipment.