Isotope Identification as a Part of the Decommissioning of San Diego State University's Texas Nuclear Neutron Generator

A project performed by
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1. Introduction

The Department of Physics at San Diego State University has maintained a Neutron Generator facility in room P-32C since the mid 1960's. This facility has provided students and faculty with a resource for the study of neutron interactions with matter, such as activation analysis, flux determinations, cross section determinations and shielding studies. The model 9500 was built by Texas Nuclear Research in the early 1960's, and could be used for either photon or neutron generation, depending on the source ions introduced into the accelerator's plasma bottle and the target material. A pneumatic “rabbit” sample transfer system moved irradiated samples from of the neutron generator to the detectors for gamma-ray spectroscopy analysis. This neutron generator was capable of providing a flux of 14 MeV neutrons at $10^{11}$ n/cm$^2$ -sec, using deuterons accelerated through a 150 kV potential and 2.5 mA ion beam current.

In February of 1988, the Texas Nuclear Research neutron generator was replaced by a unit manufactured by Kaman Sciences Corporation. The Texas Nuclear unit was then removed and stored for later disassembly and disposal. As a result of the unit’s age, the Texas Nuclear generator required frequent maintenance and repair. Additionally, advances in neutron generator technology of the newer Kaman unit allowed the target to be hermetically sealed, eliminating the chance for exposure to airborne tritium, contamination, and activation products to maintenance personnel.

2. Current Disposition

In the summer of 1993, the neutron generator was disassembled into three large sections consisting of the titanium-tritide target, the oil diffusion pump and the corona shield/accelerator tube assembly. The target was packaged and stored in room P-33A and the other 2 assemblies were wrapped in plastic for storage. In June
of 1995 the neutron generator was further disassembled to enable storage in 55 gallon drums and thoroughly surveyed for loose surface contamination. Openings on the disassembled hardware components were closed off using either duct tape or bolted stainless steel flanges to prevent the possible spread of contamination. Significant levels of removable surface contamination could be found on system internal and some external surfaces, up to five hundred thousand disintegrations per minute. Initial analysis of the removable contamination using aluminum absorbers and a Geiger-Mueller tube indicated beta particle or possibly photon emitters with an energy of approximately 180 keV. This apparent radiation energy conflicted with what one would be expect to find, given knowledge of the source material and the possible neutron activated products that would be present in this type of unit. All activation products of neutron generator components, as a result of the exposure to 14 MeV neutrons are short lived, and would have decayed to below detection levels in the period of time since the unit was last operated, a period of approximately six years.

3. Scope of the Project

This project consists of identifying the nuclide responsible for the apparent radiation energy. Additionally, as a service to San Diego State’s Radiation Safety Office, an estimate of the amount of activity in the unit will be made, as required for future disposal purposes as well as packaging the unit for shipment according to current state and federal regulations. The handling, disposal, and activity estimation of the tritium target, as well as disposal of the vacuum pump oil is not within the scope of this project and will be dealt with by the SDSU Radiation Safety Office at a future date.
4. **Identification of the Isotope**

**A. Target**

The only radioactive material installed into the accelerator for the production of neutrons was the tritium target. The manufacturers’ handbook states that the target for this model neutron generator would have consisted of anywhere from 1 to 20 curies of tritium absorbed on a titanium substrate (~500 µg/cm² thick, 1.25 in. diameter) evaporated onto a copper backing plate 0.010 inch thick. The target required periodic changing, based on the amount of time the generator was in operation. Unlike newer designs, the targets were not sealed, so there was a potential for exposure to workers to elemental tritium, tritium oxide, and loose surface contamination.

**B. Detection System**

A Canberra Industries® Low Energy Germanium detector (LEGe) and model 2024 spectroscopy amplifier, connected with an Oxford® PCA Multiport Tennelec Multichannel Analyzer, interfaced to a Macintosh computer, was used to identify the photon energy. The source of low energy photons for LEGe detector calibration was a 0.1 mCi $^{55}$Fe source. $^{55}$Fe decays by electron capture (2.73 yr half-life) to stable $^{55}$Mn, with the manganese emitting the characteristic “K” shell x-rays used for the calibration; 5.888 (8.2%), 5.899 (16.2%), and 6.489 (2.86%) keV. Dry filter paper, the type used for removable contamination surveys, was used to collect the unknown source material for analysis from the neutron generator’s interior surfaces.
C. Procedure

Two methods were used to determine the radiation emitters: a Low Energy Germanium Detector (LEGe) for spectroscopy, and a Geiger-Mueller tube for the Half Value Layer (HVL) calculation.

The LEGe detector was calibrated using a $^{55}$Fe low energy photon source for a count time of 10,000 seconds at a source to detector distance of 8 inches. Two peaks were used for calibration. The 5.888 keV and 5.899 keV energies were averaged and combined into one peak at 5.894 keV. The other calibration peak was at 6.489 keV. The filter paper was counted for 10,000 seconds at distances of eight inches and near contact with the window surface. The first 256 channels were offset, eliminating pulses below approximately 1.5 keV to help control Multichannel Analyzer deadtime.

The same filter paper containing the source material was used for the HVL calculation. A thin-end widow Geiger-Mueller tube inside a lead shielded counting vault was used to collect the count data for the HVL calculation. Good geometry conditions were approximated using a 1/16th inch lead sheet shelf with a 1/8th inch diameter hole in the center between the source and the detector. Aluminum foils of various mass thicknesses were used as the attenuating medium.

D. Results

HVL Method

Sheet lead with a small hole drilled in the center, mounted to a shelf, provided the good geometry approximation for the measurements. Count data of the source plus lead shield with combinations of the aluminum attenuation plates were made. The plates used were commercially manufactured for the purpose of beta range-energy determinations, and were of various mass thicknesses. Counts per unit time were recorded. The counts using the attenuation plates were normalized to
the unattenuated counts, and the mass thickness of the attenuation plates were converted to thickness in centimeters. The thickness required to reduce the number of counts by 50% (the Half Value Layer) was taken from Figure 3, a plot of attenuator thickness vs. normalized counts on a semi-log scale. Using the HVL value from the plot, the mass attenuation coefficient, \((\mu/\rho)_{eq}\), was calculated using the equation

\[
\left(\frac{\mu}{\rho}\right)_{eq} = \frac{0.6931}{\rho \text{(HVL)}} \frac{\text{cm}^2}{\text{g}}
\]

where \(\rho\) is the density of aluminum, 2.69 g/cm\(^3\), and the HVL as taken from figure 3. The average photon energy, \(h\nu_{eq}\), was interpolated using \((\mu/\rho)_{eq}\) and mass attenuation coefficient tables\(^3\) for aluminum that include coherent (Rayleigh) scattering.

\[
\left(\frac{\mu}{\rho}\right)_{eq} = \frac{0.6931}{2.69 \frac{\text{g}}{\text{cm}^3} \cdot 15.2 \times 10^{-3} \text{cm}} = 16.951 \frac{\text{cm}^2}{\text{g}}
\]

Using reference 3, 16.951 cm\(^2\)/g falls between the energies of 10 keV and 15 keV. By linear interpolation, 16.951 cm\(^2\)/g equates to a photon energy of 12.5 keV.

**LEGe Method**

Tritium emits a beta particle spectrum that has a maximum energy of 18.6 keV, with an average energy at 5.7 keV. Photopeaks from the filter paper appeared at 4.4 keV and 4.84 keV. This is consistent with photon energies that would be expected from K shell fluorescence photons from titanium caused by hard collisions with orbital electrons from the 5.7 keV tritium beta. The \(K_{\alpha1}\) and \(K_{\alpha2}\) energies\(^2\) are 4.511 and 4.505 keV respectively, and cannot be resolved with this detector and are most likely combined into one peak. The \(K_{\beta1}\) energy is 4.932 keV and was detected as 4.8 keV. Additional tritium beta induced bremsstrahlung photons occupy energy levels above and below the characteristic x-ray energy of titanium to a maximum of 18.6 keV. The spectrum obtained from the LEGe detector ends at approximately 15.5
keV. Photons at higher energies, characteristic of activation products between 50 keV and 2 MeV, were not detected using a coaxial germanium detector calibrated to $^{109}\text{Cd}$ and $^{40}\text{K}$ photon energies.

E. Discussion

The accelerator target consists of tritium absorbed onto titanium ($Z = 22$). Inelastic radiative interactions occur with tritium betas as a process of slowing down, the result being the emission of x-ray photons (bremsstrahlung). The energy given up by the beta particle as photon energy during the scattering process varies from 0 to 100% energy transfer. Bremsstrahlung photons, generated from interactions of tritium betas, creates a spectrum of photon energies, with the maximum energy at 18.6 keV, and an average photon energy of 5.7 keV would be expected.

Florescence photon generation is also a result of a mixture of tritium and titanium. Florescence photons are called “characteristic” photons because the photon energy is a characteristic unique to each element. These photons are generated as a result of hard collisions between the beta and inner shell electrons of titanium. For an inner shell electron to be ejected, the beta energy must be equal to or greater than the K or L shell binding energy for that element. For titanium, the binding energies are 4.97 keV for the K shell and 0.564 keV for the L shell, with the K shell energy being slightly less than the average tritium beta energy of 5.7 keV. The characteristic x-ray energies of titanium are energetic enough to be detected by the LEGe and Geiger-Mueller detectors.

F. Conclusion

The initial survey using Geiger-Mueller instruments detected the florescence photons from the titanium. The Low Energy Germanium detector showed the
unknown photon energies to be characteristic of the element titanium, which is consistent given knowledge of the source design. The Half Value Layer calculation (and coaxial Germanium detector measurements) shows that there is no high energy photon emitter present, and that the energy spectrum has an average value of approximately 12.5 keV. This value is roughly double the value determined by the LEGe detector due to the relative crudeness of a Geiger-Mueller tube detector, possible variations of absorber purity and mass thickness, and fluctuations in background count rate.

5. Repackaging the Drums

The neutron generator had been previously disassembled into several large components and some were sealed in a 55 gallon drum. Two large components, the vacuum pump and the oil diffusion pump, still contained quantities of oil of unknown activity. Current regulations prohibit disposal of liquids in the same drum as solid materials, so the oil had to be drained from these two pumps. The drum also contained free oil that had inadvertently drained out of the vacuum pump during previous handling, which required the transfer of the contents of this drum to another drum. Additionally, the oil diffusion pump was too large to fit inside a 55 gallon drum and had to be size reduced. An exact inventory of the contents of the drum was not available, nor was there an estimation of the total activity contained in the drum. A brief summary of the steps involved with the packaging is discussed below.

Two procedures were written; one dealing with the opening of the sealed drum and draining of the oil contained in the vacuum pump inside, the second for the size reduction and oil draining of the diffusion pump. Both procedures were reviewed and approved by the Radiation Safety Officer before work was allowed to begin. These procedures are found in appendices B and C.
As per the procedures, before work began, the area was covered with sheet plastic to contain any loose surface contamination that would be generated as a result of handling the drum contents or oil. Sealed items, such as the vacuum pump, piping and manifolds, where handled and opened inside a chemistry hood. The hood protected the workers from exposure to tritium gas and any dry particulate contamination. Periodic Geiger-Mueller detector surveys were made outside the hood to ensure that the controls used were adequate to prevent the spread of dry particulate contamination. Frequent glove changing during the job, and careful work practices, followed by post work surveys using Liquid Scintillation Counting (LSC), showed that there was no contamination spread outside the plastic area from handling oil contaminated objects. Frequent monitoring using the Overhoff tritium detector showed very little outgassing occurring from sealed objects, and no tritium gas was detected outside the hood were workers were standing. Post operational bioassays of the workers showed no uptake of tritium.

Two persons conducted the operation: one inside the surface contamination area handling the objects, taking measurements and performing the contamination surveys; the other was outside recording information and passing supplies into the area.

The original storage drum contained free oil in the bottom, inadvertently drained from the vacuum pump. Each of the objects removed from this drum were physically measured, identified, and surveyed before being transferred to the new drum, labeled as Drum 1. Drum 2 contains the disassembled oil diffusion pump. The information of the contents of both drums was initially recorded on the Drum Inventory Sheet (appendix D), then transferred to a spreadsheet (appendix F). Activity calculations were based on the LSC swipe results and physical measurements taken on each object during the transfer. Equations used to calculate the activity of each object are listed in appendix E. Drum one is estimated to contain
.479 millicuries, and drum two .0731 millicuries. A 100 µl oil sample removed from the vacuum pump is estimated to contain 1.09 millicuries.
Figure 1. A typical Iron 55 spectrum used for calibration of the MCA.

Figure 2. Source material showing the fluorescence peaks of titanium.
Figure 3. Plot for determining the Half Value Layer (HVL)
6. References

a Texas Nuclear Corporation, Austin Texas. A subsidiary of Nuclear Chicago. Texas Nuclear could not be contacted by telephone. From dates on available documentation, it is assumed that this company is out of business.

b Kaman Sciences Corporation, Garden of the Gods Road, Colorado Springs, Colorado 80907. A model A-711 was installed.

c Canberra Industries, Inc., One State Street, Meriden, Connecticut 06450. (203) 238-2351

d Tennelec/Nucleus Inc. 601 Oak Ridge Turnpike, Oak Ridge, Tennessee 37830. (615) 483-8405.

1 J. T. Prud'homme, Texas Nuclear Corporation Neutron Generators, 2nd ed. (Texas Nuclear Corporation, Austin, Texas, 1962), pp. 140-144.


Appendices

A. LEGe System Settings
B. Vacuum Pump Safety Procedure
C. Oil Diffusion Pump Safety Procedure
D. Drum Inventory Sheet
E. Equations used to Calculate Surface Areas
F. Activity Calculations of Drum Contents
Appendix A.

LEGe System Settings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Switch Setting/Position</th>
</tr>
</thead>
</table>
| 1. Canberra HV power supply  
  Model 3105 |  
  Detector Bias Voltage | 1000V DC, negative |
| 2. Canberra FAST Amplifier: |  
  Fine gain | .394 |
  Coarse Gain | 1K |
  Input Polarity | negative |
  Shaping time: |  
  GI | 0.5 μsec |
  Amp | 2 μsec |
  Restorer: |  
  Threshold | Auto |
  Mode | Sym |
  PUR | Uni/on |
| 3. Oxford PCA Multiport MCA  
  (Macintosh Platform) |  
  offset | 256 |
  conversion gain | 4096 |
  display | 8192 |
  preset | 10,000 sec Live |
Appendix B; Vacuum Pump Safety Procedure

Safety procedure for the unpacking and repackaging of SDSU’s neutron generator and sampling and draining of the vacuum pump.

SDSU RSO Review and Approval________________ Date____

Preoperational setup.

1. Assemble the items needed at the location.
   - personnel required- 2 minimum
   - poly bottle and funnel
   - swipes and vials for LSC counting
   - tritium meter/GM pancake probe
   - sheet plastic
   - tape
   - paper/pencils/
   - funnel
   - tape measure/ruler
   - box of rubber gloves
   - Tyvek disposable coveralls, shoe covers
   - tools to remove fittings, plugs
   - clean, empty 55 gal. drums
   - floor dry, kitty litter or suitable, approved alternative for stabilizing items in the drum and back filling the vacuum pump.
   - disposable scoop for the floor dry material
   - paper towels/absorbent wipes
   - rad waste can
   - electrical extension cord for the frisker
   - camera to photograph items in the drums
   - 2 pairs of leather or heavy cotton gloves
   - telephone on site or portable phone in case of emergency
   - Item Inventory Record Sheet

2. Perform pre-operational contamination surveys of the floor area, building entrance and exit, hood floor, sash, lip and surrounding counter top areas.

3. Ensure the hood is clean. Check to make sure the hood has had a current airflow check.

4. Source check the meters. Verify proper operation and calibration is current.

5. Lay sheet plastic on the floor and tape down the edges over the area where the work is to be performed. Lay plastic sheet down on the floor of the hood and up the walls of the hood.
6. Stage clean, empty 55 gallon drums near the hood so items can be removed from the old drum, placed in the hood and measured, surveyed and then placed in the clean drum.

7. Stage all neutron generator components that are going to be packaged in 55 gallon drums at the Radioactive Waste Management Facility, SDSU building #113.

8. Drape the face of the hood with sheet plastic so that it covers the top of a drum placed in front of the hood.

9. Visually inspect new drums for obvious defects, such as holes, defective welds, drum lid O ring damage, etc.

10. Some time before drum opening, submit a sample of urine for a bioassay.

A. Drum opening

A.1. Don Tyvek coveralls and rubber gloves and shoecovers.

A.2. Position the drum close to the open sash of the hood. Remove the drum ring. Lift the drum lid slightly at the edge nearest the hood. Check for tritium outgassing with the Overhoff meter. Tritium level should increase, then slowly decrease as the gas in the drum goes up into the hood and out the stack. Any handling or work with the items shall be done in the hood.

A.3. Periodically survey the floor area around the drum and hood for changing levels of surface contamination with the portable GM detector. Decon as necessary with paper towels dampened with water. Dispose of paper towels in the rad waste can.

A.4. Carefully remove each item from the drum and place it in the hood. Change gloves and take and record measurements. Survey each item for loose surface contamination internally and externally. Record the swipe number, location, physical description and dimensions or any other information that may be applicable on the Item Inventory Record Sheet. Photograph each item as necessary.

A.5. Move surveyed items, one at a time, from the hood to the clean drum. Maintain an inventory of what goes into each drum.

A.6. When all items have been surveyed, measured and placed in the new drum, add the contents of 1 bag of floor dry (or similarly approved agent), or as much as possible if one bag will not fit. This step may be modified or eliminated by the RSO staff as deemed necessary due to the possible re-opening and examination of the drum contents at a future date.
A.7. Replace and tighten the drum ring to seal the drum.

B. Vacuum Pump Oil Sampling and Draining

B.1. Verify that there is adequate airflow through the hood.

B.2. Remove all unnecessary items from the hood that may remain from the completion of prior steps of the procedure.

B.3. Visually examine the pump orientation in the drum. If the exterior surfaces have oil puddles or is sitting in an oil puddle, use an absorbent towel to minimize the chance of dripping or spills of oil as the pump is transferred to the hood. Consider placing absorbent paper on the floor outside the drum.

B.4. Don leather or cotton outer gloves over rubber gloves before lifting the vacuum pump out of the drum.

B.5. Place a layer of absorbent paper in the floor of the hood to absorb any oil or oily contamination that might come from the inside of the pump or exist on the exterior surfaces of the pump.

B.6. Remove the pump from the drum and place it in the hood. Check for any obvious oil leaks or drips.

B.7. Remove outer leather/cloth gloves and place them to the side for reuse.

B.8. Take physical measurements and swipe survey the exterior surfaces of the pump. Sniff any openings with the Overhoff tritium meter. Record the meter reading.

B.9. Ensure the hood sash is lowered to the indicated level to minimize turbulence for maximum protection should there be a puff release of tritium. Have the Overhoff meter in the hood and operating in case any monitoring of outgassing is necessary.

B.10. To drain the oil, carefully loosen the oil plug and sniff with the Overhoff meter. Record outgassing time and Overhoff meter reading. Once outgassing has stopped, remove the plug and drain the oil out of the pump into the poly bottle, using the funnel. After as much of the oil that is practical is removed, back fill the pump with floor dry. Orient the pump in several directions and refill with more floor dry. Replace and tighten the plug.

B.11. Carefully peel the tape back on one of the taped ends of the inlet and outlet pipes attached to the pump. Sniff the inside of the pipes through this hole with the Overhoff. Expect a short burst of tritium activity. Be ready to reseal the tape immediately if the tritium level does not start to decline in a short period of
time (about 30 seconds). Record length of time the Overhoff measurement is taken and the maximum meter reading.

B.12. Once the pipe stops outgassing, backfill the pipe with floor dry and retape the end.

B.13. Repeat steps B.11 and B.12 on the other taped openings.

B.14. Don leather or cotton outer gloves over rubber gloves before lifting the vacuum pump out of the hood into the new 55 gal. drum.

B.15. Dispose of any oily or contaminated absorbents or plastic into the drum with the pump, or segregate them for disposal at a later time as deemed necessary at the time by the RSO staff.

B.16. Survey the work area with the portable GM frisker. Decon as necessary.

B.17. Repeat steps A.6 and A.7 and seal the drum.

C. Post operational surveys

C.1. Perform a whole body frisk at the conclusion of drum sealing

C.2. Perform post operational contamination surveys of the floor area, building entrance and exit, hood floor, sash, lip and surrounding counter top areas.

C.3. Submit a urine sample for bioassay and have it LSC analyzed approximately 1 hour after drum closing. If there is any increase in tritium levels above the preoperational sample, consult the RSO for further instructions.
Appendix C: Diffusion Pump Safety Procedure

Safety procedure for the disassembly, oil draining and packaging of SDSU’s neutron generator oil diffusion pump.

SDSU RSO Review and Approval___________Date____

Preoperational setup.

1. Assemble the items needed at the location.
   - personnel required- 2 minimum
   - poly bottle and funnel
   - swipes and vials for LSC counting
   - tritium meter/GM pancake probe
   - sheet plastic
   - tape
   - paper/pencils/
   - funnel
   - tape measure/ruler
   - box of rubber gloves
   - Tyvek disposable coveralls, shoe covers
   - tools to remove fittings, plugs, bolts
   - clean, empty 55 gal. drums
   - floor dry, kitty litter or suitable, approved alternative for stabilizing items in the
     drum and back filling the diffusion pump.
   - disposable scoop for the floor dry material
   - paper towels/absorbent wipes
   - soap or similar approved material that will remove oil residues for decon
     purposes
   - drip pan
   - rad waste can
   - electrical extension cord for the frisker
   - 2 pairs of leather or heavy cotton gloves
   - telephone on site or portable phone in case of emergency
   - Item Inventory Record Sheet

2. Perform pre-operational contamination surveys of the floor area, building entrance and exit, hood floor, sash, lip and surrounding counter top areas.

3. Ensure the hood is clean. Check to make sure the hood has had a current airflow check.

4. Source check the meters. Verify proper operation and calibration is current.

5. Lay sheet plastic on the floor and tape down the edges over the area where the work is to be performed. Lay plastic sheet down on the floor of the hood and up
the walls of the hood. Position the drip pan and oil absorbent wipes on the plastic to receive the diffusion pump when it is removed from the drum.

6. Stage the 55 gallon drum containing the diffusion pump near the hood and drip pan.

7. Some time before drum opening, submit a sample of urine for a bioassay.

A. Diffusion pump positioning and removal from the drum

A.1. Don Tyvek coveralls and rubber gloves.

A.2. Position the drum close to the open sash of the hood. Remove the top flange of the diffusion pump and place it into the hood. Check for tritium outgassing with the Overhoff meter. Tritium level should increase, then slowly decrease as the gas in the diffusion pump goes up into the hood and out the stack.

A.3. Periodically survey the floor area around the drum and hood for changing levels of surface contamination with the portable GM detector. Decon as necessary with paper towels dampened with soap and water. Dispose of paper towels in the rad waste can.

A.4. Don leather gloves and carefully remove the diffusion pump from the drum and place it in the drip pan on the floor, taking care not to spill any oil.

A.5. Carefully disassemble the diffusion pump as necessary to enable the oil to be drained and have the unit fit inside a 55 gallon drum. Change gloves and take and record physical measurements. Survey each item for loose surface contamination internally and externally. Record the swipe number, location, physical description and dimensions or any other information that may be applicable on the Item Inventory Record Sheet.

A.6. Move disassembled and surveyed parts into the drum. Maintain an inventory of what goes into the drum.

A.7. Drain the oil from the diffusion pump into a poly bottle used for contaminated oil storage. Orient the pump in several directions as necessary to get as much oil out as possible. Sample the oil when the reservoir becomes accessible or when the oil is in the container.

A.8. Place the remaining diffusion pump assembly into the 55 gallon drum.

A.9. When has been disassembled and surveyed, measured and placed in the drum, add the contents of 1 bag of floor dry (or similarly approved agent), or as much as possible if one bag will not fit. This step may be modified or eliminated by
the RSO staff as deemed necessary due to the possible re-opening and examination of the drum contents at a future date.

A.10. Install and tighten the drum ring to seal the drum.

A.11. Swipe survey the exterior surfaces of the drum, and count them on the local LSC counter. Decon the outside of the drum as necessary with soap and water solution.

B. Post operational surveys

B.1. Perform a whole body frisk at the conclusion of drum sealing, and wash hands and arms with soap and water.

B.2. Perform post operational contamination surveys of the floor area, building entrance and exit, hood floor, sash, lip and surrounding counter top areas.

B.3. Submit a urine sample for bioassay and have it LSC analyzed approximately 1 hour after drum closing. If there is any increase in tritium levels above the preoperational sample, consult the RSO for further instructions.
### Drum Inventory Sheet

<table>
<thead>
<tr>
<th>Swipe Number</th>
<th>Location</th>
<th>Survey Result DPM/100cm^2</th>
<th>Brief Description</th>
<th>Drum Number</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
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</tr>
</tbody>
</table>
Appendix E. Equations used to Calculate Surface Areas

These equations were used as a basis to determine surface areas $A$, of objects packaged in the drums:

Hollow cylinders, such as hoses, pipes, accelerator sections and tubes:

$$A = (2 \text{ surfaces})(2\pi R(R+h))$$

Solid cylinders, such as the internal sleeve:

$$A = 2\pi R(R+h)$$

Flat, square objects, such as pans and brackets:

$$A = (2 \text{ surfaces})(bh)$$

Flat circular objects, such as flanges:

$$A = (2 \text{ surfaces})(\pi R^2)$$

Box like objects, such as the fore pump:

$$A = (2 \text{ surfaces})(2bw + 2hw + 2bh)$$

Where $R$ is the radius, $h$ is the height (or length), $b$ is the base and $w$ is the width.
## Appendix F.

### Contents of Drum 1

<table>
<thead>
<tr>
<th>Swipe Number</th>
<th>Item</th>
<th>Swipe Location</th>
<th>Estimated Area</th>
<th>DPM/cm²</th>
<th>DPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Glass accelerator section</td>
<td>Exterior</td>
<td>221</td>
<td>1426</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Previous internal survey</td>
<td>Interior</td>
<td>221</td>
<td>426</td>
<td>356660</td>
</tr>
<tr>
<td>2</td>
<td>Vacuum pump drip pan</td>
<td>Exterior</td>
<td>736</td>
<td>4749</td>
<td>256</td>
</tr>
<tr>
<td>3</td>
<td>Vacuum pump belt cover</td>
<td>Exterior</td>
<td>480</td>
<td>3097</td>
<td>120</td>
</tr>
<tr>
<td>4</td>
<td>&quot;L&quot; shaped vacuum pump manifold</td>
<td>Exterior</td>
<td>616</td>
<td>3974</td>
<td>105</td>
</tr>
<tr>
<td>5</td>
<td>Manifold internals</td>
<td>Interior</td>
<td>616</td>
<td>3974</td>
<td>124118</td>
</tr>
<tr>
<td>6</td>
<td>Steel &quot;L&quot; shaped bracket</td>
<td>Exterior</td>
<td>180</td>
<td>1161</td>
<td>21</td>
</tr>
<tr>
<td>7</td>
<td>Stainless Steel gate valve</td>
<td>Exterior</td>
<td>144</td>
<td>929</td>
<td>85</td>
</tr>
<tr>
<td>8</td>
<td>Gate valve internals</td>
<td>Interior</td>
<td>144</td>
<td>929</td>
<td>428382</td>
</tr>
<tr>
<td>9</td>
<td>Misc. rubber/plastic hoses</td>
<td>Exterior</td>
<td>1244</td>
<td>8026</td>
<td>2132</td>
</tr>
<tr>
<td></td>
<td>cables, brass hose fittings,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>screws, small parts</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Liquid oil sample (not contained in drum 1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Vacuum pump (Fore pump)</td>
<td>Exterior</td>
<td>2624</td>
<td>16930</td>
<td>82</td>
</tr>
<tr>
<td>12</td>
<td>Vacuum pump base</td>
<td>Exterior</td>
<td>480</td>
<td>3097</td>
<td>53</td>
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</table>

Total Area: 7706 inches² 48719 cm²

Total DPM: 1.06E+09

Total Tritium Activity of Surface Contamination (millicuries): 4.79E-01
### Contents of Drum 2

<table>
<thead>
<tr>
<th>Swipe Number</th>
<th>Item</th>
<th>Swipe Location</th>
<th>Estimated Area</th>
<th>DPM/cm²</th>
<th>DPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Background swipe</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Stainless Steel &quot;T&quot; section</td>
<td>Exterior</td>
<td>729</td>
<td>4704</td>
<td>22</td>
</tr>
<tr>
<td>3</td>
<td>Stainless Steel &quot;T&quot; section</td>
<td>Interior</td>
<td>729</td>
<td>4704</td>
<td>20129</td>
</tr>
<tr>
<td>4</td>
<td>Internal sleeve/Cold Trap</td>
<td>Exterior</td>
<td>427</td>
<td>2755</td>
<td>12638</td>
</tr>
<tr>
<td>5</td>
<td>Flange</td>
<td>Exterior</td>
<td>226</td>
<td>1458</td>
<td>4539</td>
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<tr>
<td>6</td>
<td>Heating element section</td>
<td>Exterior</td>
<td>1485</td>
<td>9581</td>
<td>11</td>
</tr>
<tr>
<td>7</td>
<td>Heating element section</td>
<td>Interior</td>
<td>1485</td>
<td>9581</td>
<td>2424</td>
</tr>
<tr>
<td>8</td>
<td>Length of copper pipe w/elbow</td>
<td>Exterior</td>
<td>75</td>
<td>484</td>
<td>32</td>
</tr>
<tr>
<td>9</td>
<td>Length of copper pipe w/elbow</td>
<td>Interior</td>
<td>75</td>
<td>484</td>
<td>5115</td>
</tr>
<tr>
<td>10</td>
<td>3 &quot;C&quot; clamps</td>
<td>Exterior</td>
<td>48</td>
<td>310</td>
<td>56</td>
</tr>
<tr>
<td>13</td>
<td>Aluminum Corona Shield/HV cover (crushed)</td>
<td>Exterior</td>
<td>5089</td>
<td>32834</td>
<td>2048</td>
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<tr>
<td>14</td>
<td>Aluminum flange</td>
<td>Exterior</td>
<td>190</td>
<td>1226</td>
<td>104</td>
</tr>
</tbody>
</table>

Total Area: 10558 inches², 68120 cm²

Total DPM: 2.29E+08

Total Tritium Activity of Surface Contamination (millicuries): 1.03E-01
## Oil Activity

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Location</th>
<th>Sample Volume</th>
<th>DPM/liter</th>
<th>Volume (liters)</th>
<th>Activity (millicuries)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Vacuum pump oil</td>
<td>100µl</td>
<td>803213130</td>
<td>3</td>
<td>1.09E+00</td>
</tr>
<tr>
<td>11, 12</td>
<td>Diffusion pump oil</td>
<td>100µl</td>
<td>2981900</td>
<td>1</td>
<td>1.34E-03</td>
</tr>
</tbody>
</table>

Total Activity in Poly Bottle (millicuries) __1.09E+00__