

SCHOOL OF MATHEMATICS AND SCIENCE STANDARD OPERATING PROCEDURE 5104.2B

From: Director, Division of Mathematics and Science

Subj: OPERATION AND SAFETY PROCEDURES FOR THE 5SDH ACCELERATOR

Ref: (a) Instruction Manual for 5SDH Pelletron Accelerator
(b) Instruction Manual for RF Charge Exchange Ion Source
(c) Instruction Manual for SNICS II Ion Source
(d) RBS Vacuum Controller Instruction Manual
(e) NAVMED P-5055 "Radiation Health Protection Manual"
(f) NAVSEA S0420-AA-RAD-010 (RAD-010) "Radiological Affairs Support Program Manual"
(g) Naval Radioactive Materials Permit 19-00161-E1NP

Encl: (1) Facility Description
(2) Facility Radiation Safety Evaluation
(3) General Controls and Practices
(4) General Operating Instructions
(5) Emergency Procedures
(6) Authorized User Qualification Requirements
(7) Daily Usage Log Sheet
(8) Test Procedures for Safety and Interlock Systems

1. Purpose. To outline procedures for safe operation of the National Electrostatics Corporation (NEC) model 5SDH tandem electrostatic particle accelerator and its auxiliary equipment.

2. Cancellation

This document updates MATHSCIDIVINST 5104.2A and converts it to a Standard Operating Procedure to incorporate changes and new requirements from ref (f). This SOP is part of the required 5-year review by the USNA Radiation Safety Committee and re-authorization for the Physics 5SDH Accelerator Laboratory, serial number 9, located in Chauvenet Hall room CH-029.

3. Applicability

This SOP shall be used to govern operation of the particle accelerator and auxiliary equipment located in CH-029 at USNA.

4. Discussion

The USNA National Electrostatics 5SDH-1 Pelletron accelerator, serial number 9, is a positive-ion machine with 1.7 Megavolts terminal potential. It can produce protons to energies of 3.4 MeV and alpha particles to energies of 5.1 MeV. The accelerator is not an electron accelerator and its hazards are significantly different. The primary purpose of the accelerator laboratory is to give midshipmen practical experience using accelerator methods in nuclear, atomic, and solid-state physics. The major use is in conjunction with upper-division atomic and nuclear physics courses, but the laboratory is also used for Trident Scholar projects and other independent research.

5. Responsibilities

a. Laboratory Manager / USNA Licensee

USNA Licensees are faculty and staff who have submitted a radiation use license application and have been approved as a licensee by the RSC. USNA Licensees are considered the custodian and the principle user or lab/facility manager. Licensees may request additional Authorized Users to operate under their RSC approved license. The Licensee will only be permitted to operate under the conditions of operational instructions approved by the Radiation safety committee (RSC). Any modifications of operations require RSO/RSC approval prior to commencement. All non-compliance issues will be addressed directly by the Licensee/custodian of the source.

The Laboratory Manager shall:

- (1) ensure that the NEC 5SDH accelerator is operated only in accordance with this SOP.
- (2) ensure and certify that Authorized Users are familiar with this SOP, references (a) through (d), and are able to operate the accelerator safely.
- (3) conduct periodic surveillance checks to ensure that hazard areas are posted and are under continuous surveillance when the accelerator is in operation.
- (4) ensure that required Usage Log, Radiation Survey Log, and Warning and Interlock System Test Log are maintained.
- (5) investigate and report to the Radiation Health Officer via the Radiation Safety Officer any instances of lost or inadvertently exposed dosimeters or alleged or suspected incidents of overexposure.
- (6) endorse qualified users to the RSC to be approved Authorized Users.

b. Authorized Users

(1) Radioactive material specified on the USNA Naval Radioactive Material Permit (NRMP) or machine sources capable of exposing individuals with greater than 100 millirem per year or 2 millirem per hour exposure shall only be used by the USNA Licensee and those individuals under their supervision who are designated as Authorized Users.

In order to qualify as an Authorized User, the individual must meet the following conditions:

- (a) The individual shall be a DoD employee or student or shall have an official appointment to the USNA faculty/staff.
- (b) The individual shall have been designated as an authorized user on the licensee's radiation use license application, local authorization, or an amendment request.
- (c) The individual shall have attended the training program provided by the Radiation Safety Office. The training will be commensurate to the type of risk they are exposed at the workplace.
- (d) The individual shall have received on job training from the licensee covering the specific procedures and attendant hazards associated with the work to be performed in accordance with this SOP.

(e) Students taking the SP434 Nuclear Physics Course and SP480 and SP490 Research Courses are not generally classified as Authorized Users.

(2) Authorized Users may or may not be Radiation Workers depending on the hazard associated with their activity. All personnel shall strive to control their radiation exposure in accordance with the **ALARA** principle - **As Low As Reasonably Achievable**.

The approved Authorized User shall:

(a) be responsible for all aspects of accelerator operation, including the radiation safety of everyone in and around the accelerator room.

(b) ensure that they are an Authorized User, as defined in enclosure (6) of this SOP, before attempting to operate the accelerator.

(c) ensure that they are familiar with the contents of this SOP, its enclosures, and the relevant parts of the references.

(d) operate the accelerator within the guidelines of this SOP.

(e) execute the Pre-run Checklist on the Usage Log sheet before starting the accelerator charging chain.

(f) record the operating parameters and the radiation levels on the Usage Log Sheet once the accelerator is operating and, if necessary, relocate the RADIATION AREA warning signs and rope barriers at the approximate 2.0 millirem per hour boundary.

(g) keep a written log of interlock shutdowns and any indications of hazardous conditions on the Usage Log Sheet.

(h) maintain continuous surveillance of the accelerator while the charging chain is operating.

(i) remove the interlock circuit key whenever the controls are not attended.

(j) secure the interlock circuit key when accelerator operations are completed.

(k) check irradiated targets for residual activity and, if the radiation level is greater than 2.0 millirem per hour on contact, make a notation in the Usage Log, store the target in the Nuclear Physics laboratory source storage cabinet, and notify the Accelerator Laboratory Manager.

(l) report any equipment malfunctions, lost or inadvertently overexposed dosimeters, or suspected incidence of overexposure to the Accelerator Laboratory Manager.

(m) ensure that area monitoring surveys and interlock checks are conducted and recorded every 6 months and prior to commencing routine operations after equipment maintenance or modification.

(n) Operators must be Authorized Users as approved by the branch manager (Physics department chair), division manager (Dean of Mathematics and Science), USNA Radiation Safety Committee, and Radiation Safety Officer

c. All personnel entering the accelerator laboratory shall:

(1) control their radiation exposure in accordance with the **ALARA** principle – **As Low As Reasonably Achievable**

(2) operate equipment in a safe and responsible manner.

(3) take precautions to keep their own radiation exposure to a minimum.

(4) wear their own radiation dosimeter, if required.

(5) follow all directions of the Authorized User.

(6) follow all provisions of this SOP.

(7) report any equipment malfunctions, lost or inadvertently overexposed dosimeters, or suspected incidence of overexposure to the Authorized User or Laboratory Manager.

d. The Radiation Health Officer shall:

(1) establish standards of radiological health requirements.

(2) specify and provide personnel monitoring or dosimetry devices.

(3) maintain records of personnel exposure.

(4) certify that operators have satisfactorily completed the required Radiation Physical examination before issuing TLDs.

(5) investigate alleged or suspected incidents of overexposure and prepare the necessary reports required by the Bureau of Medicine and Surgery and the Navy Radiological Affairs Support Office, Yorktown, Virginia.

e. The Radiation Safety Officer shall:

(1) have authority to terminate immediately any accelerator operation that they find to be unsafe or not in accordance with this or other applicable SOPs.

(2) ensure that area monitoring surveys are conducted and recorded every 6 months and prior to commencing routine operations after equipment maintenance or modification.

(3) confirm that initial radiation safety training of Authorized Users as required by ref (f) complete.

(4) provide support as necessary to ensure compliance with higher authorities.

(5) provide immediate assistance should any radiological safety incident occur.

f. The RSC shall:

(1) approve users submitted by the lab manager as Authorized Users. This may be performed during quarterly meetings or on an ad hoc basis.

6. Review

This SOP will be in effect for the duration that the National Electrostatics Corporation 5SDH Pelletron Accelerator is installed and permitted at the U.S. Naval Academy. The SOP will be reviewed on an annual basis by the Lab Manager and the RSO to ensure that the procedures are current and in full compliance with ref (f).

7. Approvals

This SOP and all references contained therein have been reviewed and approved by the U.S. Naval Academy Radiation Safety Committee. Operation or maintenance of the 5SDH Accelerator in any manner or in reference to any procedure not described herein must first be approved by the RSO. Approval of such requested operation, procedure, or both will be temporary and will not constitute general approval by the RSO of the requested operation or procedure.

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B. A. SHUPP
CAPT, USN

Distribution:
MATHSCIDIV A
Physics Department
Radiation Safety Officer

FACILITY DESCRIPTION

The primary purpose of the accelerator laboratory is to give midshipmen practical experience using accelerator methods in nuclear, atomic, and solid-state physics. The major use is in conjunction with upper-division atomic and nuclear physics courses, but the laboratory is also used for Trident Scholar projects and other independent research.

The accelerator, its operating controls, experimental areas, and data acquisition and analysis computers are all located in CH-029 as illustrated in figure 1. This is a basement room, surrounded by two exterior walls, the Chauvenet loading dock, and the Nuclear Physics instrumentation laboratory CH-028. Above the accelerator room are classrooms and a corridor; below it is the earth.

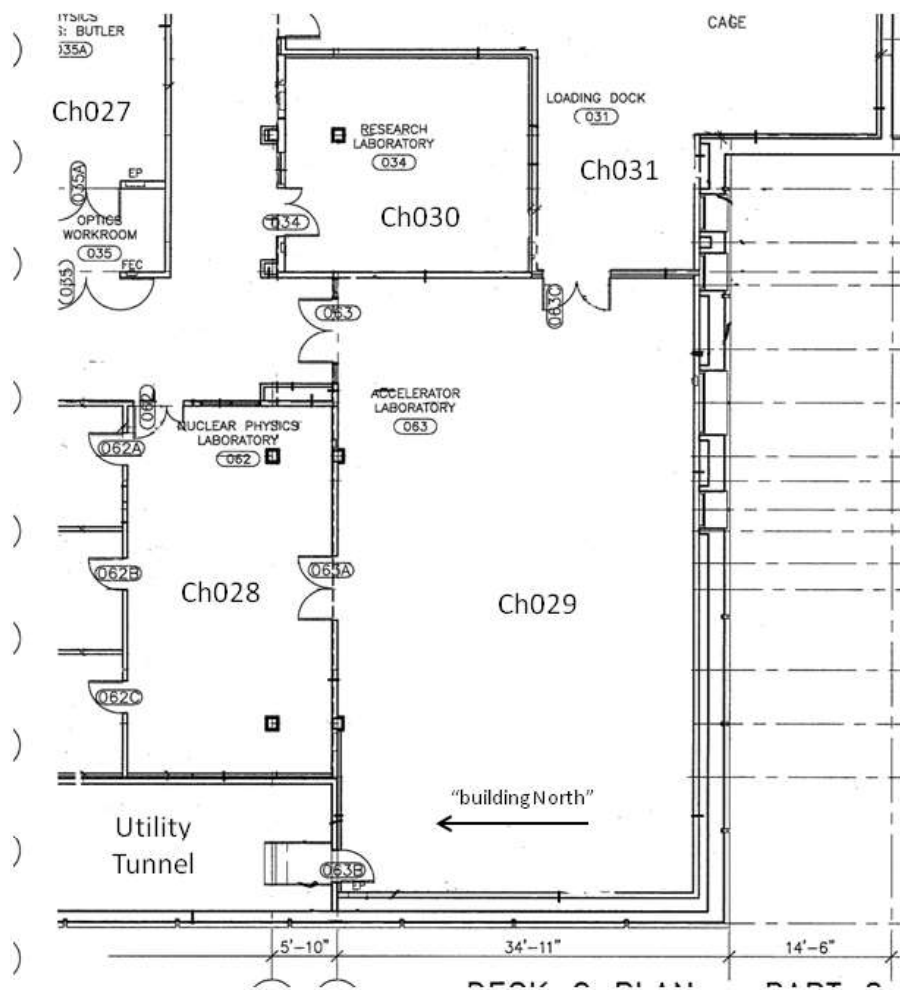


Figure 1. The Pelletron 5SDH accelerator (positive ion) is located in CH-029, a 30 ft x 60 ft room in the southwest corner of the Chauvenet Hall lab deck. The relative orientation of the diagram is specified.

The positioning of the accelerator is shown in figure 2. An overview photograph of the console, accelerator, injector, and ion sources is shown in figure 3.

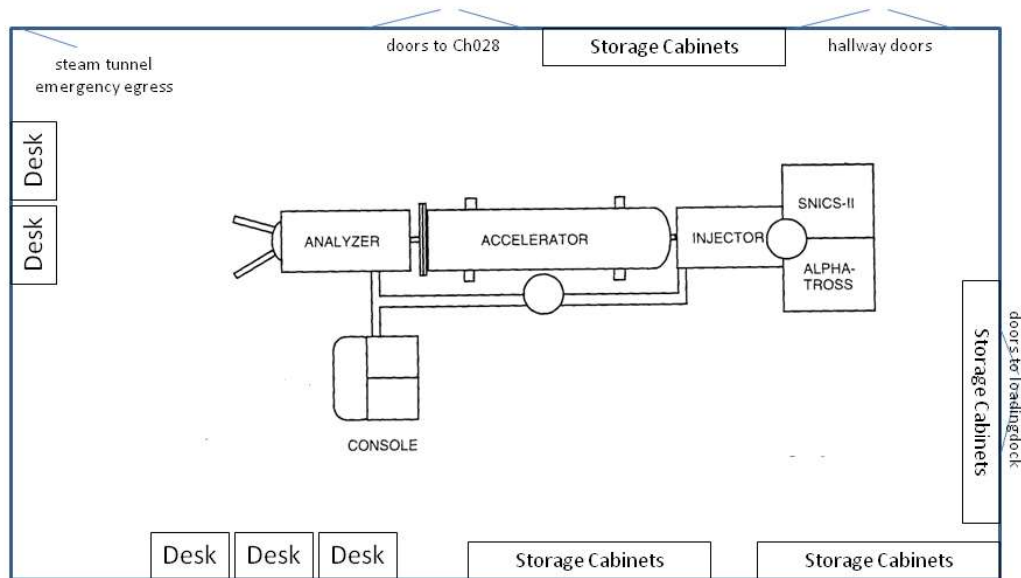


Figure 2. Location of Pelletron accelerator equipment in CH-029.



Figure 3. General view of the accelerator looking from control console toward the ion sources. The edge of the analyzing magnet is visible on the left, the accelerator pressure tank in the middle and the ion sources in the far distance.

The regions beyond the south and west walls are concrete building structures. The north side adjoins the nuclear physics laboratory CH-028. The east wall adjoins the loading dock and an unrelated laboratory room CH-030. The interior walls are made of standard “2x4” gypsum construction. Above the accelerator lab is the terrace around Chauvenet Hall.

Entrance to the accelerator room, CH-029, can be had via the hallway doors, the shared double door with room CH-028, or the emergency egress from the main utility tunnels in the corner of the room. There is a large equipment door connecting the room with the building’s internal loading dock, but this door is kept locked and is barricaded by storage cabinets. Hallway doors are kept locked when the room is unattended.

The room has one standard floor drain into the sanitary sewer system located midway along the accelerator pressure vessel itself.

The room has 8 standard building HVAC vents overhead, rated at 425 cubic feet per minute per vent. Volatile radioactive materials are not used in CH-029.

Doors are posted with emergency contact information. There is no radiological hazard when the accelerator is off. Lighted signs at the doors to the hallway, room CH-028, and steam tunnel indicate the currently measured radiation field in the room.

Ion Sources and Injector Area

The accelerator is equipped with two ion sources: a sputter-type source used to produce beams of most elements and a radio-frequency (RF) charge-exchange source used to produce helium beams, as shown in Figure 4.



Figure 4. Ion sources - Shown are the SNICS sputter source (right) and Alphatross rf-source (left).

In the SNICS-II™ sputter source, a solid cathode containing atoms of the desired beam species is bombarded by low-energy cesium ions, which causes negatively-charged beam ions to be sputtered from the cathode. These ions are mass-selected, accelerated, and focused by the injector’s optical elements.

In the Alphatross™ charge-exchange source, low pressure helium gas is ionized using RF energy in a quartz bottle surrounded by a magnetic field. Positive He ions are extracted from the bottle, acquire a negative charge by passing them through a rubidium vapor, are mass-selected in the inflection magnet, accelerated, and focused by the injector’s optical elements.

5SDH Pelletron Accelerator Structure

The National Electrostatics Corporation Model 5SDH Accelerator, serial number 9, is a tandem electrostatic particle accelerator with a maximum terminal potential of 1.7 million volts (MV). The accelerating structure is contained within a pressure vessel filled up to ~85 psig, maximum, with SF₆. An outside view of the pressure tank is shown in Figure 5 and the inside in Figure 6.



Figure 5. The 5SDH-1 Pelletron accelerator pressure tank. The pressure vessel is filled with SF₆ insulating gas. The high voltage terminal is inside the center-middle of the tank. The highest radiation fields in the laboratory occur at the surface of the middle part of the tank



Figure 6. An inside view of the 5SDH-1 Pelletron accelerating structure. The high voltage terminal is the center shiny cylindrical object. To either side are equipotential rings used to provide a uniform acceleration of the incoming and outgoing ion beam.

The accelerating structure is a tandem Van de Graaff design. The high-voltage terminal is located in the center of the pressure vessel. A “Pellettron chain” carries charge to the high-voltage terminal. Negative ions from the ion sources are accelerated to the high-voltage terminal, their electrons stripped off, and are then accelerated out of the structure.

The accelerator can produce direct beams of many different ion species to kinetic energies given by $E = (n+1) eV$, where V is the terminal potential (0.1 to 1.7 MV) and n is the final charge state of the ion. For example, proton ($n = 1$) beams can be accelerated to energies between 0.2 and 3.4 MeV and helium ($n = 1$ or $n = 2$) beams to energies between 0.2 and 5.1 MeV.

The electrical current of the momentum-analyzed, accelerated beams is less than 1 microampere.

Radiation fields in this size and type of positive-ion accelerator are generally not created by the beam, but rather by the presence of high voltage. Free electrons are attracted to the high positive voltage and crash into materials surrounding the high-voltage electrodes, creating bremsstrahlung photons.

The highest photon dose rates occur at the high-voltage terminal of the accelerator (in the center of the accelerator itself in Figure 6), due to the presence of the high-voltage terminal. The accelerator pressure tank is wrapped with a half inch of lead to attenuate these photons. The radiation field at the surface of the tank is typically less than 0.2 millirem per hour, and therefore, the room remains well below general public limits.

Experimental Areas

The three beamlines are shown in figure 7. Only one beamline can be used at a time.

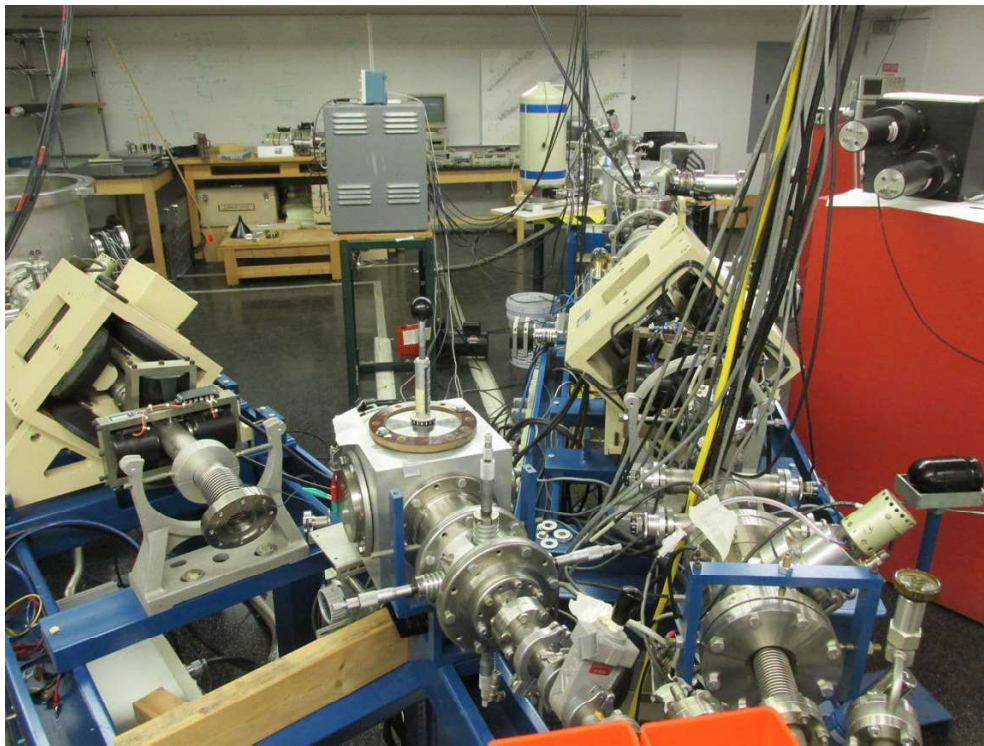


Figure 7. View of the three beamlines from the top of the analyzing magnet.

The "15-degree Left" short beamline contains a 10-inch cubical chamber with a manual target positioner. This chamber is used for ion implantation and materials modification studies with heavy ion beams (Figure 8).

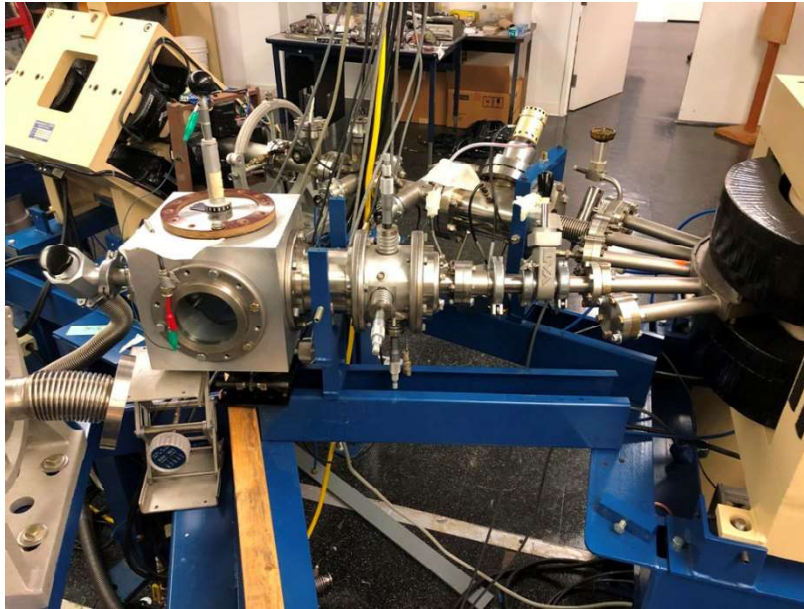


Figure 8. Photograph of the "15°-Left beamline" and scattering chamber used for ion implantation and material damage and modification studies.

The "30-degree Left" beamline contains a 25-inch diameter scattering chamber with a manual target positioner, solid-state charged-particle detectors, and a gamma-ray detector. The maximum proton beam current typically achieved into this chamber is 500 nA. Currents near 100nA are more typical.

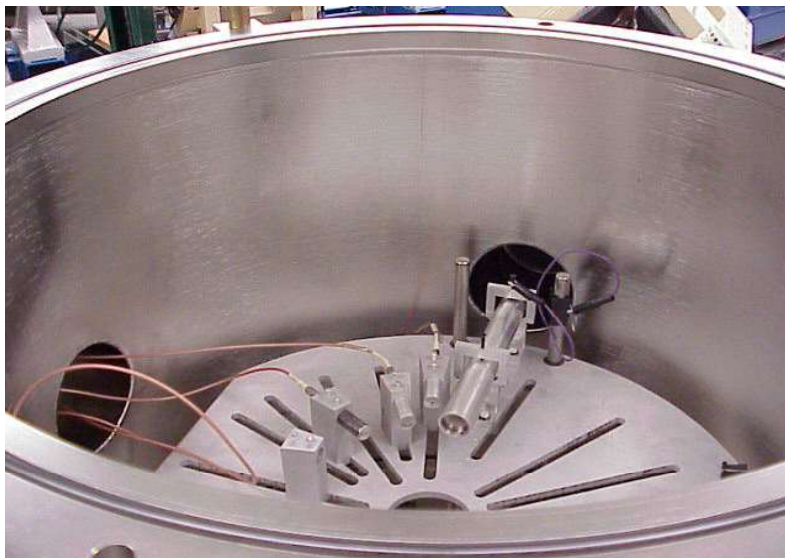


Figure 9. View inside the multipurpose scattering chamber on the "30-degree Left" beamline. The chamber is configured for detection of scattered protons in this photograph.

The "15-degree Right" beamline contains an 18-inch diameter National Electrostatics Corporation RBS scattering chamber with a computer-controlled sample positioner, a load-lock, two solid-state particle detectors, an X-ray detector, and a gamma-ray detector (Figure 10 and 11).

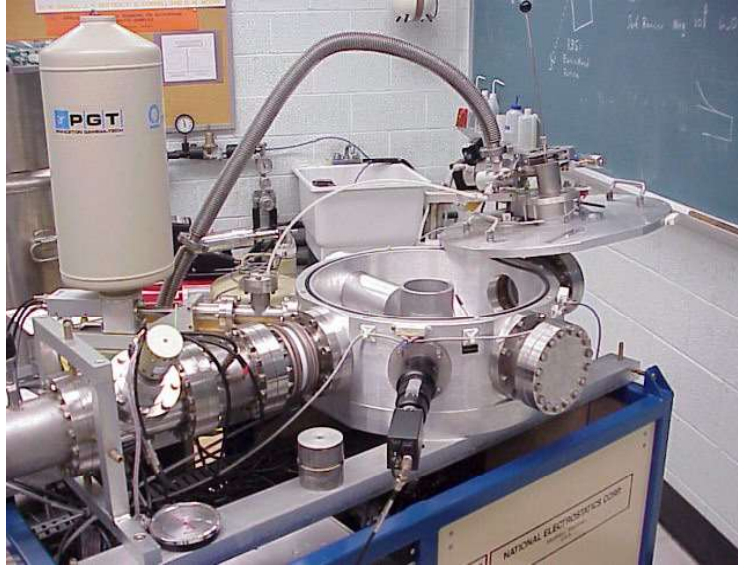


Figure 10. Scattering chamber at the end of the "15-degree Right" beamline.



Figure 11. View inside the RBS scattering chamber on the "15-degree Right" beamline. Proton beam enters from the right side of the photo through the collimator. The chamber is configured for detection of characteristic X-rays, γ -rays, and optical photons in this photograph.

The 15-degree Right beamline also can be used for external beam PIXE (Figure 12). In this mode of operation, a low-intensity (1 – 10 nanoampere) particle beam is brought out of the beamline vacuum through a thin plastic foil to bombard samples in the scattering chamber, which is filled with air or helium.

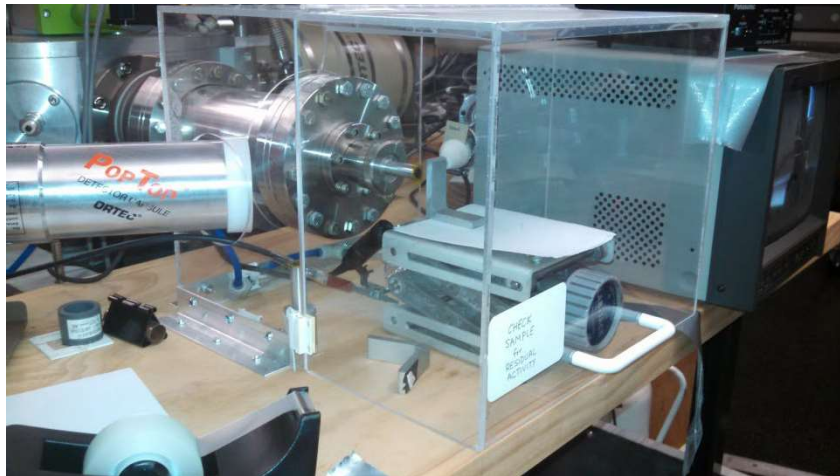


Figure 12. View of the external beam area on the “15-degree Right” beamline. Proton beam emerges through the Kapton foil to strike the sample under study ~1-2 cm away. A plastic enclosure with beam stop interlock prevents access to the region while beam is in the area. The chamber is configured for detection of characteristic X-rays and γ -rays in this photograph.

To prevent exposure of personnel to the particle beam, interlocks keep the beam from entering the external scattering chamber unless the enclosure is secure.

FACILITY RADIATION SAFETY EVALUATION

Hazard Discussion

A reasonably compact discussion of the hazards in accelerator laboratories can be found in;

“Special Purpose Particle Accelerators SHIB 07-31-2009”,
US Department of Labor Occupation Safety and Health Administration
Available from: <https://www.osha.gov/sites/default/files/publications/shib073109.pdf>

An extensive discussion of the hazards of accelerators can be found in the following reference. The reference covers all types of accelerators and is 500+ pages long.

Radiation Protection for Particle Accelerator
Facilities, National Council on Radiation
Protection and Measurements, NCRP Report
No. 144 (Bethesda, MD, 2003, 2005)
Available at: <http://www.ncrponline.org> .

The following two references are designed for construction and commissioning of the large national accelerator facilities but can provide some useful points to consider.

“Safety of Accelerators Implementation Guide for DOE O 420.2D, Safety of
Accelerator Facilities”, dtd 9 September 2022, U.S. Department of Energy,
Available at <http://www.directives.doe.gov/news/new-doe-o-420-2d-safety-of-accelerators>

“DOE Order 420.2D, Safety of Accelerator Facilities”
dtd 9 September 2022, U.S. Department of Energy,
Available at <http://www.directives.doe.gov/directives-documents/400-series/0420.2-Border-d>

The USNA Pelletron accelerator is operated less than 200 hours per year. Radiation fields in this size and type of positive-ion accelerator are generally not created by the beam, but rather by the presence of high voltage. Free electrons are attracted to the high positive voltage and crash into materials surrounding the high-voltage electrodes, producing bremsstrahlung photons.

The highest photon dose rates occur at the high-voltage terminal of the accelerator (in the center of the accelerator itself in Figure 6), due of the presence of the high-voltage terminal. The accelerator pressure tank is wrapped with a half inch of lead to attenuate these photons. The radiation field at the surface of the tank is typically less than 0.2 millirem per hour and therefore the room remains well below general public limits. The highest field measured in the previous 20 years is 3 millirem per hour at the surface of the tank. Should a field greater than 2 millirem per hour exist at the surface of the tank, a barrier of radiation rope and Radiation Area signs is constructed to exclude the area around the high-voltage terminal. The radiation field is continuously monitored a distance of 30 cm from the surface, and should a field of 2 millirem per hour be reached, an interlock system trips off the power to the machine. The accelerator console and work desks are several meters away from the high-voltage terminal to assure doses are ALARA.

Gamma rays generated by the beam particles striking samples or beamline parts; through proton-, alpha-, and heavy ion- induced reactions, are too weak to be recorded with the IM-231 Ion Chamber RADIAC (minimum measurable field ~0.1 millirem per hour) and rarely measurable with the PDQ-1 Geiger Counter (minimum measurable field 0.02 millirem per hour).

Because neutrons are notoriously hard to shield, the accelerator is not used for making neutron beams nor producing neutrons as a primary reaction product; nevertheless, the room is surveyed for neutrons with a PDR-70S RADIAC each operation. As a reference, Q-values for (p,n) and (α,n) reactions on common elements with thresholds below 3.4 MeV for protons and for 5.4 MeV for alphas are given in tables 1 and 2.

Table 1. Targets with (p,n) Thresholds Below 3.4 MeV and Coloumb Barriers Below 5 MeV.

Target	Natural Isotopic Abundance (%)	Q-Value (MeV)	Threshold (MeV)	Coulomb Barrier Height (MeV)
³ H	<i>trace</i>	-0.764	1.019	0.41
⁷ Li	92.5	-1.644	1.880	1.0
⁹ Be	100	-1.850	2.057	1.3
¹⁰ Be	<i>trace</i>	-0.226	0.249	1.3
¹¹ B	80.1	-2.765	3.018	1.6
¹³ C	1.1	-3.003	3.236	1.8
¹⁴ C	<i>trace</i>	-0.626	0.671	1.8
¹⁸ O	0.201	-2.438	2.574	2.2
³⁶ S	0.02	-1.925	1.979	3.7
³⁷ Cl	24.23	-1.596	1.640	3.9
⁴⁰ Ar	99.60	-2.287	2.345	4.1
⁴¹ K	6.73	-1.204	1.233	4.3
⁴³ Ca	0.135	-3.003	3.074	4.4
⁴⁶ Ca	0.004	-2.160	2.208	4.4
⁴⁵ Sc	100	-2.844	2.908	4.6
⁴⁹ Ti	5.5	-1.384	1.413	4.7
⁵⁰ Ti	5.4	-2.988	3.048	4.7
⁵¹ V	99.75	-1.535	1.565	4.9

Target or samples with tritium, lithium, beryllium, or boron as a major constituent are prohibited for use with protons. Trace abundances are allowed, but the target area must be surveyed for neutrons.

Table 2. Targets with (α,n) Thresholds Below 5.4 MeV and Coloumb Barriers Below 8 MeV.

Target	Natural Isotopic Abundance (%)	Q-Value (MeV)	Threshold (MeV)	Coulomb Barrier Height (MeV)
⁷ Li	92.5	-2.789	4.380	2.8
⁹ Be	100.	5.701	open	3.6
¹⁰ B	19.9	1.059	open	4.4
¹¹ B	80.1	0.158	open	4.3
¹³ C	1.1	2.215	open	4.9
¹⁴ C	<i>trace</i>	-1.819	2.339	5.0
¹⁸ O	0.201	-0.697	0.852	6.1
¹⁹ F	100.	-1.951	2.362	6.7
²¹ Ne	0.27	2.555	open	7.3
²² Ne	9.25	-0.478	0.565	7.2

Target or samples with beryllium or boron as a major constituent are prohibited for use with alphas. Trace abundances are allowed, but the target area must be surveyed for neutrons.

Dose Estimates

Table 3. Dose estimates.

Location	Representative Radiation Field (millirem per hour)	Maximum Occupancy (hours per week)	Annual Dose (millirem)
Inflection Magnet	<0.01	0.25	<0.13
Surface of the pressure tank at the high voltage terminal	0.1	1	5.2
Analyzing Magnet	<0.01	1	0.52
Operating Console	<0.01	4	<2.1
Target Area	<0.01	4	<2.1
Hallway outside door to CH-029	<0.01	0.25	<0.13
Double doors between rooms CH-029 & CH-028	<0.01	1	<0.52

To ensure the safety of the operator, experimenters, and the general public, access to the accelerator room is controlled, radiation levels in accessible areas of the room are maintained below 2.0 millirem per hour by operational controls and an active warning and interlock system. Personal radiation dosimetry is required for the operator and all frequent users in the room whenever the accelerator is in operation.

Radioactive Waste Management

Because of the beam projectiles and energies available at the laboratory, producing radioactive materials is very unlikely. Nevertheless, new target materials will be surveyed when removed from the scattering chamber. Should any target materials be found activated, the decay-in-storage method will be utilized if appropriate.

Airborne Radioactivity

Due to the beam projectiles and energies available at the laboratory, airborne radioactivity does not occur.

Additional Requirements from ref (f) Chapter 12

The Ref (f) provides guidance for *negative* electron accelerator laboratories. The USNA National Electrostatics 5SDH-1 Pelletron accelerator is a *positive* ion machine with 1.7 Million Volts terminal potential. It can produce protons to energies of 3.4 MeV and alpha particles to energies of 5.1 MeV. The Pelletron accelerator is **NOT** an electron accelerator and the hazards are significantly different.

The Pelletron accelerator is categorized as “Other Research Accelerator” per Ref (f) Section 12.2. The information below is prepared to meet the requirements of Ref (f) Section 12.2, and manages the 5SDH-1 Pelletron accelerator in a similar philosophy to Ref (f) Section 12.1, “Electron Accelerators” subject to the following exemptions and discussion. The exemptions and discussion below track Section 12.1 item-by-item.

General Discussion (12.1.1)

1. Electron accelerators easily become hazardous devices because bremsstrahlung radiation is produced anytime the electron beam strikes any material and slows down. In addition, soft X-ray radiation is produced in the vicinity of the accelerating structure because of the high electric fields present. Beamline components and the experimental target at electron accelerators can conceivably produce neutrons and become activated if the electron beam energy is greater than 8 MeV.

Bremsstrahlung radiation from proton and heavier beam particles is not a concern for Van de Graaff / Pelletron positive-ion accelerators because the beam particles are 1837 times more massive than the electron and do not slow down as quickly when they strike materials. The production cross section for bremsstrahlung photons by protons is a factor of $(1837)^2$, approximately 3×10^6 times less than that of electrons. Positive-ion accelerators generate soft X-ray in the vicinity of the high-voltage accelerating structure. The experimental target can conceivably produce neutrons if the proton beam energy is greater than 2 MeV and the beam strikes lithium, beryllium, or boron. Little activation is generally observed.

Daily usage logs back to the year 1991 were examined. Radiation fields are generally not measureable with standard Navy-issue RADIACS. The strongest photon field is measured in the vicinity of the high-voltage terminal, and it is extremely rare for it to even approach General Public limits.

2. No changes requested.

Radiation Safety Requirements (12.1.2)

1. No changes requested.

2. No changes requested.

3. No changes requested.

Training (12.1.3)

1. No changes requested.
2. No changes requested.
3. No changes requested. The general Annual Radiation worker refresher training in RADIAC use will serve as the documentation source.

Area Control Requirements (12.1.4)

1. No changes requested.
2. EXEMPTION REQUESTED. The USNA requests an exemption to the requirement for a wall or fence barrier. Because of the documented infrequency of Radiation Areas (greater than 2 millirem per hour RASO definition), any temporary Radiation Area will be controlled by rope barriers and appropriate signage. The accelerator operator is responsible for maintaining compliance with the barrier.

Accelerator Controls and Interlock System Requirements (12.1.5)

1. No changes requested.
2. No changes requested.
3. EXEMPTION REQUESTED. The definition of “exposure room” in Ref (f) is taken to be a “High Radiation Area”. The USNA requests exemption to this requirement since it is not applicable because high radiation areas do not occur due to the nature of the Pelletron accelerator.
4. No changes requested.
5. No change requested.
6. EXEMPTION REQUESTED. The complete Pelletron laboratory is located in a single room of size 24' x 60', and there are no subdivisions of the room. The operator can see the whole room from the control console area. There is no location where people are not visible. The interlock-fault control box which generates the accelerator shutdown occurs at the accelerator console. The USNA request exemptions to have one manual reset at the control panel since the control panel and operating equipment are in the same room.
7. No changes required.
8. No changes required.
9. No changes requested. The USNA Pelletron is in a single room of size 24'x60'. The operator can see the whole room from the control console area. There is no location where people are not visible. This room is interpreted as being 'at the same site'. Therefore, the manual reset is at the control console.

Warning Devices and Area Radiation Monitor Requirements (12.1.6)

1. No changes requested. No high radiation areas occur.
2. No changes requested. No high radiation areas occur.
3. No changes requested. The USNA assumes small red LEDs and small indicator bulbs on various electronic boxes are not constrained by the statement.
4. No changes requested. No high radiation areas occur.
5. No changes requested. No high radiation areas occur.
6. No changes requested. The RMS-II system will be recalibrated every 3 years.

Operational Requirements (12.1.7)

1. No changes requested.
2. No changes requested.
3. No changes requested.
4. EXEMPTION REQUESTED. Interlocks on the Pelletron accelerator trip the accelerator drive chain when radiation levels exceed 2 millirem per hour. The USNA requests exemption from this statement in relationship to the radiation field measurement portion of our interlock system due to the greater than 34-year documented history of radiation fields in the laboratory. Any other interlock systems will be checked prior to use and results documented in the daily usage log.
5. No changes requested. The circuit description is published at "A Warning Sign and Safety Interlock System for an NEC 5SDH Accelerator," J.R. Huddle, J.R. Vanhoy, and F.D. Correll, Nucl. Instrum. and Meth. B56/57, 1173 (1991). [https://doi.org/10.1016/0168-583X\(91\)95124-V](https://doi.org/10.1016/0168-583X(91)95124-V).
6. No changes requested.
7. No changes requested.
8. No changes requested.

Radiation Survey Instrument Requirements (12.1.8)

1. No changes requested.
2. EXEMPTION REQUESTED. An ion chamber shall be used to survey areas to meet legal requirements. However, approved ion chambers (IM-231PD) are not sufficiently sensitive to serve as a diagnostic tool for accelerators of this design, as the lowest division of the meter is 0.2 millirem per hour. Geiger-Mueller-based detectors do not suffer significant pileup effects at these low fields. The more sensitive PDQ-1, with a lower range of 0.01 millirem per hour is therefore useful for diagnosing machine problems.

3. No changes requested. The mechanism of neutron production on a positive- ion machine is different from that on an electron accelerator. A RASO-approved neutron survey instrument, such as the PDR-70S, will be kept on hand.

4. EXEMPTION REQUESTED. Survey instruments will be calibrated according to the NRSC guidelines.

5. No changes requested.

Personnel Dosimetry (12.1.9)

1. No changes requested.

Facility Radiation Survey Requirements (12.1.10)

1. EXEMPTION REQUESTED. The qualified expert will have experience on non-electron accelerators. The USNA requests an exemption to providing the curricula vitae to NAVSEADET RASO for the “qualified expert”.

2. No changes requested.

3. No changes requested. The requirement does not impact the Pelletron.

4. No changes requested.

5. EXEMPTION REQUESTED. The intent of this statement is to verify that no electron beam remains in the ‘exposure room’. The USNA Pelletron does not generate electron beams. Neutron activation is not likely with the USNA Pelletron. The USNA requests exemption from performing radiation surveys to verify the accelerator is secured.

6. No changes requested.

Special Considerations for Electron Accelerators with Energies Exceeding 10 MeV (12.1.11)

1. No change requested.

2. No change requested.

3. No change requested. Neutron energy correction factors normally applied by the BUMED TLD-processing facility (Bethesda) will be used.

4. No changes requested. The requirement to check new targets and components is included in this SOP.

5. No changes requested. Note that the USNA Pelletron does not create airborne radioactivity. Exhaust ventilation is not required.

Logs and Records (12.1.12)

1. No changes requested.

2. No changes requested.

GENERAL CONTROLS AND PRACTICES

Physical Controls for CH-029

Security

- (1) The accelerator room is a Controlled Area and shall be locked when unattended. Access shall be strictly controlled for security and safety reasons.
- (2) The accelerator charging chain motor shall only be enabled by a keyed switch.
- (3) The key shall be removed from the switch and secured when the accelerator is not operating.

Warning Devices.

- (1) Lighted warning signs.

(a) The accelerator room and its entrances shall be equipped with lighted warning signs that operate automatically when the accelerator controls are set to produce radiation.

(b) When the charging chain is turned off, so that no radiation can be produced, a green lamp labeled with the word "SAFE" shall be lit. The green lamp shall extinguish and a yellow lamp labeled with the word "CAUTION" shall be lit when the accelerator charging chain is running. The yellow lamp shall extinguish and a flashing red lamp labeled "DANGER" shall be lit when radiation in the accelerator room exceeds 2.0 millirem per hour as indicated by the terminal gamma radiation monitor.

(c) The warning signs shall be of a redundant design, with two lamps of each color on each sign.

(d) The warning signs shall be part of a warning and interlock system that requires that the signs be operational in order to energize the accelerator charging chain.

(e) An explanation of the warning sign shall be posted at the warning signs.

- (2) Other signs and barriers.

(a) The accelerator control console shall a sign posted bearing the conventional yellow and magenta radiation symbol and the words: **"CAUTION: RADIATION. THIS EQUIPMENT PRODUCES RADIATION WHEN ENERGIZED. TO BE OPERATED ONLY BY QUALIFIED PERSONNEL"**.

(b) Movable signs and rope barriers shall be available to mark off Restricted Areas where the local radiation level may exceed 2.0 millirem per hour. In accordance with ref (f), this region is posted as a Radiation Area. The signs shall bear the conventional yellow and magenta radiation symbol and the words: "CAUTION: RADIATION AREA".

Operational Controls for the Accelerator

General

- (1) The accelerator shall always be operated in a manner that first assures the safety of personnel and second assures protection of the equipment.
- (2) The accelerator shall be operated only when an Authorized User is present in CH-028 or CH-029.
- (3) The charging chain shall be turned off and the key removed from the switch whenever the accelerator controls are not attended.

Restrictions on Operating Parameters

- (1) Energy, beam current, and other parameters shall be adjusted to keep the radiation level at all accessible locations in the accelerator room below 2.0 millirem per hour at all times.
- (2) The warning and interlock system, which ensures that the radiation level at accessible areas of the room does not exceed 2.0 millirem per hour, shall be kept in operating condition and shall not be tampered with or bypassed in an effort to permit operation at higher radiation levels.
- (3) Deuterons and Helium-3 ions shall not be accelerated.
- (4) To minimize the possibility of neutron production, targets or samples whose major constituents include ${}^7\text{Li}$, ${}^9\text{Be}$, or ${}^{11}\text{B}$ are prohibited. Special care shall be exercised to monitor the neutron production and keep neutron radiation levels at the target below 2.0 millirem per hour.

Operating Procedures

Operation of the accelerator requires extensive knowledge of several different systems. No concise list of operating procedures should be expected to cover all situations that may arise.

- (1) Enclosure (4) contains an abbreviated set of operating instructions for routine operations.
- (2) A copy of enclosure (4) shall be posted at the accelerator console.
- (3) References (a) through (d), the Instruction Manuals for the 5SDH Pelletron Accelerator, its ion sources and the RBS vacuum controller shall be kept in the accelerator room and should be consulted for more complete instructions or for unusual situations.

Shutdown Procedures

There are two methods for shutting down the accelerator and its auxiliary equipment. Which method is used depends upon whether the shutdown is routine or whether a rapid shutdown is required due to an emergency or hazard.

- (1) The shutdown procedures are described in enclosures (4) & (5).
- (2) A copy of enclosures (4) & (5) shall be posted at the accelerator console.

Radiation Monitoring

Personal Radiation Monitoring Equipment

- (1) Each Authorized User and frequent user of the accelerator laboratory shall be issued a thermoluminescent dosimeter (TLD) of approved design by the Radiation Health Office. They shall wear their own TLD whenever the accelerator is in operation.
- (2) Occasional users, such as regular visitors or midshipmen who use the accelerator for fewer than 8 hours per week, are classified as Non-Radiation Workers. Occasional users need not be issued dosimeters, provided that they remain outside any part of the accelerator room where the radiation level exceeds 2.0 millirem per hour (a Restricted Area / Radiation Area). The operator will establish a 2.0 millirem per hour boundary, mark the boundary with signs and ropes and ensure that any users without dosimeters remain outside that boundary.
- (3) Visitors or personnel who are in the laboratory rarely do not need training other than a simple hazard control brief.

Area Radiation Monitoring Equipment

- (1) Survey Meters (RADIAC).

(a) The NEC 5SDH Accelerator shall be surveyed with an Ion Chamber Survey Meter (for X- and gamma- radiation) and a BF₃ Proportional Counter Survey Meter (for neutron radiation). Only RASO approved meters shall be used to measure radiation levels needed to satisfy legal and health related documentation requirements.

(b) All meters shall be used in accordance with approved procedures.

- (2) Permanent Area Radiation Monitors.

(a) The Accelerator Laboratory (CH-029) shall be equipped with continuously-operating, permanently-mounted gamma-ray detectors to monitor radiation sources.

(b) Gamma-ray monitors shall be located near the terminal of the 5SDH accelerator and near the control console.

(c) The permanent radiation monitoring equipment shall be part of a warning and interlock system.

(d) The permanently installed RMS radiation monitoring system shall be maintained in calibration by the OEM (Thermoelectron) recommended calibration laboratory. The presently recommended calibration facility is:

Thermo Fisher Scientific
Thermo-Eberline LLC
1 Thermo Fisher Way
Oakwood Village, OH 44146-6536
Ph: 800 - 274 - 4212

Calibration and Test

(1) Survey Meters (RADIAC).

(a) Prior to use, verify RADIAC survey meter is within calibration periodicity.

(b) Prior to use, each RADIAC survey meter shall undergo a response check as detailed in the operations manual. Meters with weak batteries or whose operability is in doubt for any reason shall not be used.

(2) Permanent Area Radiation Monitors.

(a) Operation and calibration of the gamma monitors shall be maintained in accordance with ref (f) Section 12.1.6.6 at intervals not to exceed every 3 years.

Radiation Warning and Interlock System.

Purpose.

(1) To alert personnel in the accelerator room, the neighboring Nuclear Physics Laboratory (CH-028) and the adjoining corridor to any radiation hazards present by means of lighted warning signs.

(2) To provide quantitative information to the accelerator operator continuously concerning the level of radiation present.

(3) To remove power to the accelerator charging chain motor in the event of a potentially unsafe condition, thereby removing accelerating voltage and all accelerator-produced radiation.

Circuit Diagrams.

(1) Up-to-date circuit diagrams of the system shall be maintained in CH-029.

(2) A description of the interlock system has been published as: "A Warning Sign and Safety Interlock System for an NEC 5SDH Accelerator," J.R. Huddle, J.R. Vanhoy, and F.D. Correll, Nucl. Instrum. and Meth. B56/57, 1173 (1991).

Operation of the Warning System.

(1) The warning system incorporates inputs from the chain motor power relay and from the permanent radiation area monitors. The outputs determine the display on the lighted warning signs.

(2) Chain motor power relay: Energizing the chain motor causes a relay to close, shorting an input to the warning sign controller and causing the yellow lamps labeled "CAUTION" on the warning signs to be illuminated.

(3) 5SDH Terminal Gamma Monitor: Radiation levels above 2.0 millirem per hour close the ALERT relay, shorting an input to the warning sign controller and causing the red lamps labeled "DANGER" on the warning signs to be illuminated.

(4) Console Gamma Monitor: Radiation levels above 2.0 millirem per hour close the ALERT relay, shorting an input to the warning sign controller and causing the red lamps labeled "DANGER" on the warning signs to be illuminated.

(5) Relays must be reset by pressing a button on the appropriate radiation monitor electronics chassis. The relays will not automatically reset when the radiation levels drop below threshold level.

Operation of the Interlock System.

(1) The interlock system incorporates inputs from the permanent radiation area monitors and from the lighted warning signs mounted above the doors. The output is a voltage level that determines whether or not the accelerator chain motor can be energized.

(2) Warning Signs: Turning off the warning sign controller or unplugging the sign causes a voltage level to be removed from one input of the interlock circuit. The result is that the chain motor is de-energized.

(3) 5SDH Terminal Gamma Monitor: Radiation levels above 2.0 millirem per hour open the HIGH relay, removing a voltage level from one input of the interlock circuit. The result is that the chain motor is de-energized.

(4) Console Gamma Monitor: Radiation levels above 2.0 millirem per hour open the HIGH relay, removing a voltage level from one input of the interlock circuit. The result is that the chain motor is de-energized.

(5) If a warning sign failure or high radiation level causes the interlock circuit to de-energize the chain motor, the condition must be corrected at the appropriate sensor and a reset button on the interlock chassis must be pressed in order to enable the chain motor. The chain motor will not automatically restart.

Testing of the Warning and Interlock Systems.

(1) The warning and interlock systems shall be tested at least every six months while in operation or whenever maintenance has been performed.

(2) Enclosure (8) describes the test procedure to be used.

Records

Usage Log.

- (1) Each use of the accelerator shall be documented by the Operator in the Usage Log maintained for that purpose at the accelerator control console. Data recorded shall include: the name of the Operator and the date, the time of day that the charging chains were started and stopped, the beam particle and energy, the principal target constituents and the ion source, accelerator and focusing/analyzing system operating parameters. In addition, comments concerning machine operation, interlock shutdowns and potentially hazardous conditions should be included.
- (2) A "quick scan" radiation survey shall be conducted by the Operator at least once each day that the accelerator is used and the results shall be documented in the Usage Log maintained for that purpose at the accelerator control console. Data recorded shall include: the RADIAC meters used, their calibration due dates and the radiation levels for gamma rays and neutrons at the ion source, the terminal, the analyzing magnet, the console and the target.
- (3) Also use usage logs to document RADIAC survey meter response checks and that radiation protection surveys and interlock checks were verified within periodicity.
- (4) Enclosure (7) shall be used as the format for the Usage Log.

Radiation Survey Log.

- (1) A complete radiation protection survey with the accelerator running under typical conditions shall be conducted every six months or whenever maintenance has been performed which might result in an increase in radiation levels. Data recorded shall include: the name of the Surveyor and the date and time the survey is conducted, the purpose of the survey, the RADIAC meters used and their calibration due dates, the beam particle and energy, the type of target and the radiation levels for gamma rays and neutrons at: (1) the ion source, (2) the inflection magnet, (3) the low-energy end of the accelerator, (4) halfway between the low-energy end and the terminal, (5) the terminal, (6) halfway between the terminal and the high-energy end, (7) the high energy end, (8) the analyzing magnet, (9) the console, (10) the energy-control slits, (11) the beamline Faraday cup and (12) the target. Measurements shall be made with the RADIAC meter probe held at a distance of 30 cm from the location in the beamline from which the radiation could be expected to originate. Measurements on the accelerator pressure vessel itself shall be made at the four azimuthal surface locations (above, below, to the right and to the left) for each position along the accelerator's length. The results shall be documented in the Radiation Survey Log maintained for that purpose at the accelerator control console.
- (2) This radiation survey satisfies the requirement for 6-month radiation protection surveys and 6-month interlock checks.
- (3) Enclosure (8) shall be used as the format for the Radiation Survey Log.

Area Radiation Monitors Test Log.

- (1) Results of the periodic operation checks performed on the permanent area radiation monitors shall be documented in an Area Radiation Monitors Test Log maintained for that purpose at the accelerator control console. Data recorded shall include: the name of the person performing the test and the date the test is conducted, the designation of the area monitor being tested, the RADIAC meter used and its

calibration date, the readings of the RADIAC meter and the area monitor and the judgment of the tester concerning the calibration of the area monitor.

(2) Enclosure (8) shall be used as the format for the Area Radiation Monitors Test Log.

Maintenance and Repair

The accelerator high voltage system itself requires essentially no maintenance. Accelerator repairs are performed by trained USNA technical staff. Staff and Trainers were trained on the job at National Electrostatics Corporation (models S-series and U-series Pelletrons), Triangle Universities Nuclear Laboratory (HVEC models DH, KN, FN), University of Kentucky (HVEC model CN), Florida State University (HVEC model FN), and University of Pennsylvania (HVEC models AN, EN, FN). Other possible training sites are Ohio University: Edwards Accelerator Lab, Notre Dame University, the University of Washington at Seattle, or the University of Michigan Ion Beam Laboratory.

GENERAL OPERATING INSTRUCTIONS

The USNA 5SDH-1 Pelletron Accelerator Laboratory is comprised of many subsystems of ions sources, magnets, lenses, vacuum systems, and valves in addition to the accelerator structure itself. These operate as independent subsystems although they influence the performance of each other.

The operating instructions below provide general overview of the procedures for starting and stopping the accelerator, but do not serve as a substitute for understanding the equipment. Only Authorized Users shall operate the accelerator unassisted.

1. INITIAL SYSTEM CHECKS

- a. Survey previous operation records. Previous values may be preferred over the general values suggested herein.
- b. The SF₆ Tank Pressure should be in the range 60 - 80 psig.
- c. Verify Stripper Gas line pressure is approximately 150 psig.
- d. If using the Alphatross ion source, verify the desired source gas is selected, the vacuum in the ion source bottle is appropriate, and the pressure in supply bottle > 50 psig.
- e. If using the SNICS ion source, verify the proper electrical connections are made to the ion source.
- f. Verify all vacuum systems are functioning properly. The LE and HE beamline vacuums should on the 10⁻⁷ Torr scale or better and Chamber vacuum on the low 10⁻⁶ Torr scale or better.
- g. Verify the cooling water for the inflection and analyzing magnets is on and flow sufficient.
- h. Verify the inflection magnet is set for the ion source to be utilized and at an appropriate current.
- i. Verify personnel wearing TLDs as required, portable radiation monitors available, warning and interlock system functioning.
- j. Verify that semiannual radiation protection surveys and semiannual interlock checks are within periodicity.
- k. Verify that RADIACS have current calibrations and are properly functioning.
- l. Perform pre-startup checklist on Enclosure (6).

2. STARTING THE SNICS-II SPUTTER ION SOURCE

- a. Survey previous sets of operating parameters. Previous values are preferred over the general values suggested herein.
- b. Verify appropriate source cathode is in place.
- c. Verify source beamline valve is open.

- d. Verify source bias cable is connected to SNICS source.
- e. Verify ion source cover is in place.
- f. Verify injector faraday cup is inserted.
- g. Verify the coolant level is adequate in the cooling pump reservoir.
- h. Turn SNICS Source Power switch on.
- i. Turn Cooling Pump switch on.
- j. Turn on the injector controller at the console and set the bias voltage, x-steerer, y-steerer, and Einzel lens to appropriate settings based upon the usage logs. Default values are bias ~15kV, x-steerer 0, y-steerer 0, and Einzel 15 kV.
- k. Start by setting the Ionizer Power Supply to 5 A. Set Cathode Power Supply to 2.0 kV. Verify that the cathode current is zero.
 - l. Check for ionizer outgassing on the low energy vacuum gauge.
 - m. Raise ionizer current slowly, in steps of about 5 A, up to 20 A, and then to 22 A if needed. DO NOT EXCEED 25 A, or the ionizer life will be severely shortened.
 - n. Raise Cathode power supply voltage to 6 - 10 kV (depending upon cathode material) to maximize beam current.
 - o. Verify that the cathode current remains near zero. If the current is greater than several microAmps, the cathode should be cleaned.
 - p. If adequate beam current is not obtained, set the Cesium Oven Power to ~30% power. Allow 30 minutes for temperature to equilibrate. Operating oven temperature should stay below 150°C. Reverify that the cathode current remains near zero.
 - q. Maximize beam on Injector Cup by small adjustments of the bias voltage. The Einzel lens, X Steerer and Y Steerer may also be adjusted, but these have limited impact on the injector cup current and settings at this point will not be appropriate for transmission through the stripper canal and machine.

3. STARTING THE ALPHATROSS RF ION SOURCE

- a. Check previous operating parameters. Previous values may be preferred over the general values suggested herein.
- b. Verify appropriate gas bottle is connected and valve is open.
- c. Verify source beamline valve is open.
- d. Verify source bias cable is connected to RF source.
- e. Verify ion source cover is in place.

- f. Insert Injector Faraday Cup.
- g. Turn RF Source Power switch on.
- h. Turn Freon Cooling switch on.
- i. Set Magnet Cooling water flow to approximately 30 gallons per hour (GPH).
- j. Set Source Cooling Air flow to 50 standard cubic feet per hour.
- k. Set Source Magnet power supply to 2.0 Amps.

l. After one minute, slowly open (CCW) Source Gas Metering Valve approximately two turns until source strikes. LE vacuum may need to reach 5×10^{-5} Torr before source strikes. Reduce gas flow (turn valve CW) once source strikes. Typical operating pressures are 50 - 100 millitorr on gas feed thermocouple gauge, which corresponds to $2 - 4 \times 10^{-6}$ Torr on the LE vacuum gauge.

- m. Set Probe Voltage to 6 kV for ^4He .
- n. Set Rubidium Oven Power to 70% power. Allow 30 minutes for temperature to equilibrate. Normal operating oven temperatures are 190°- 230°C. Chamber temperature should remain approximately 55°C.
- o. Set inflector magnet polarity to position labeled ALPHATROSS. Set current to 4 A for ^4He .
- p. Turn up Injector Bias Voltage to 15 kV for ^4He .
- q. Set X Steerer to zero, if better values are not available.
- r. Set Einzel Lens to 15 kV for ^4He , if better values are not available.
- s. Set Y Steerer to center 0, if better values are not available.
- t. Maximize beam on Injector Cup by small adjustments of the bias voltage. The Einzel lens, X Steerer and Y Steerer may also be adjusted, but these have limited impact on the injector cup current and settings at this point will not be appropriate for transmission through the stripper canal and machine.

4. STARTING THE PELLETRON

- a. Check previous operating parameters. Previous values may be preferred over the general values suggested herein.
- b. Check position of Corona Probe (and shorting rod if necessary).
- c. Obtain key and enable chain motor power. Check interlock system.
- d. Turn charging chain motor on by pressing Start button at motor contactor.

- e. Set Terminal Voltage dial for desired terminal potential. Note that each full turn corresponds to 500 keV.
- f. Before turning on TPS, set corona feedback control mode switch to slit mode, up-charging voltage to just above zero kV, Control Gain to ~ 0 and CPO Gain to 5.
- g. Turn on TPS and watch meters for proper behavior.
- h. Begin raising Charging Voltage slowly. Watch the RMS radiation monitors. The terminal RMS monitor should respond as the voltage is increased. As the terminal potential gets higher, small deflections should be observed on the console RMS monitor. Keep radiation levels to below 2.0 mR/hr to avoid tripping interlock.
- i. Adjust Charging Voltage and corona needle position until desired terminal potential is reached, with corona grid voltage near -5 V. Watch radiation monitors. and keep radiation levels below 2.0 mR/hr to avoid tripping interlocks.
- j. The feedback control mode should be switched up to GVM mode as the desired terminal voltage is approached.
- k. Set Corona bias voltage to an appropriate value from the Daily Log Book. NEC guidance suggests that this will correspond to a Bias Current to twice injector cup current (in μA).
- l. Confirm that LE and HE column currents are identical.
- m. Set stripper Gas to 6×10^{-6} Torr. (Typically, two turns CCW.) DO NOT EXCEED 1.0×10^{-5} Torr on HE vacuum gauge.
- n. Confirm from the meters that the Pelletron system is well balanced. Verify from RMS system that radiation levels are not anomalously higher than normal. (Terminal field should less than a few tenths of millirem per hour. Console field should be approximately 0.01 millirem per hour).

5. RUNNING BEAM

- a. Beam On Straight-Through Port of Analyzing Magnet
 - (1) Maximize beam using LE optical elements.
 - (2) Adjust HE Quadrupole doublet as needed.
 - (3) Note that because the magnet cup is unsuppressed and both charged ions and neutral ions are present in the beam, the current reading at the magnet cup will not be a direct measurement of the beam current. Larger absolute values of the current do indicate more beam.
- b. Beam On Energy Control Slits and Faraday Cup.
 - (1) Verify proper analyzing magnet polarity for desired beamline.

- (2) Verify Analyzing Magnet power supply coarse current control is turned down.
- (3) Turn Analyzing Magnet power supply on.
- (4) Verify connections to proper LE beam optics (quadrupole and steering magnets) for desired beamline.
- (5) Turn Beam Profile Monitor On.
- (6) Increase Analyzing Magnet current slowly until desired beam species is seen on the beamline Faraday cup and centered on slits and BPM.
- (7) If using slit feedback mode for the days measurements, set Control Mode to Slit and adjust Control Gain to minimize slit current oscillation.
- (8) Maximize beam in Faraday Cup by adjusting HE quadrupole and LE beam optics.

6. BEAM ON TARGET

- a. Verify proper beamline vacuum; then open beamline gate valve.
- b. Withdraw Faraday cup to permit beam to strike target.
- c. Adjust LE, HE, and beamline optical elements and other accelerator parameters to obtain desired performance.
- d. Use RADIAC meters to check radiation levels around target.

7. NORMAL SHUTDOWN INSTRUCTIONS

To be performed under routine circumstances. This procedure ensures that power supplies and controls are turned down in a sequence that fully protects the equipment.

- a. Insert all Faraday Cups.
- b. Put TPS in slit mode.
- c. Turn Pelletron Charging Voltage down to zero and immediately turn Chain Drive Motor off.
- d. Turn down slowly all power supplies with the exception of those controlling the injector deck.
- e. Close Stripper Gas valve two turns CW (max).
- f. Close vacuum valve in beamline.
- g. **IF USING SNICS-II SPUTTER ION SOURCE:** Turn Cesium Oven Power down to zero. Ionizer Power Supply to 15 A and Cathode Power Supply to 2.0 kV. Every 5 minutes or more, lower the ionizer current by 5 A more. After oven has cooled to room temperature (30 minutes or $<40^{\circ}\text{C}$), turn down the Cathode Power and Ionizer Power supplies and then turn off SNICS Source Power and Injector control box on console.

h. **IF USING ALPHATROSS RF ION SOURCE:** Turn Rubidium Oven Power down to zero and Probe Voltage to 2.0 kV. After oven has cooled to room temperature (30 minutes or greater than 40° C), turn down the Probe and Source Magnet supplies and then turn off RF Source Power and Injector control box on console.

i. Return the key to its proper storage location.

j. Check targets for residual radioactivity with RADIAC meters, as appropriate.

k. Clean up.

EMERGENCY PROCEDURES

EMERGENCY SHUTDOWN: To be performed only when there is a safety risk; such as fire, major electrical power issue, explosion, or natural disaster. If time permits, it is preferable to turn down power supplies before switching them off. Some damage, especially to the Rubidium or Cesium in the ion sources, inflection and analyzing magnets, and magnetic steerers and lenses, will occur.

1. Turn off master interlock (key) control switch. This shuts down the accelerator and removes potential radiation hazards.
2. Turn off all power supplies on control console. This removes all high voltage and high current hazards associated with the accelerator.
3. Turn off appropriate Source Power switch at the Injector.
4. Notify the RSO if the issue was anyway related to health and safety of personnel.
5. Notify the lab manager.
6. Take care of the problem.
7. Return systems in the laboratory to satisfactory condition ASAP.

AUTHORIZED USER QUALIFICATION REQUIREMENTS

To become a qualified operator, the following items must be demonstrated to the laboratory manager.

#	Description	Verification Date
1	Knowledge of the responsibilities of the Laboratory Manager, Authorized Users, and other personnel entering the accelerator laboratory as specified in the cover document of this SOP	
2	Basic understanding of proton, deuteron, and alpha particle-induced reactions at energies appropriate for the USNA Pelletron accelerator, particularly with regard to the information contained in the Q-value tables in this SOP .	
3	Able to operate the vacuum systems in the laboratory.	
4	Understanding of the voltage and current hazards in the ion sources, beam steerers, inflection magnet, analyzing magnet, and quadrupole doublet lenses.	
5	Hazards associated with the cesium and rubidium contained within the ion sources.	
6	Situations which will produce maintenance issues with the ion sources and accelerator systems.	
7	Has confirmed that they have read and understood this SOP Signed _____	
8	Able to operate the radiation safety interlock system	
9	Able to source check the RADIACS	
10	Able to operate the ion sources	
11	Able to obtain beam on the straight-through magnet cup	
12	Able to obtain beam into the chamber.	
13	Able to shutdown the accelerator.	
14	Able to survey sample following removal from scattering chamber	

Annual Review Date	Authorized User Signature

**AUTHORIZED USER QUALIFICATION REQUIREMENTS
USNA PELLETRON ACCELERATOR (CH-029)**

Name: _____

1. Initial Radiation Worker Training Complete per ref (f)

RSC Chair/Date

2. Department Chair (Branch Manager) Acknowledgment

Department Chair/Date

3. Dean School of Mathematics and Science (Division Manager) Authorization

Dean/Date

4. Radiation Safety Committee Approval (Majority Vote)

RSC Chair/Date

5. Radiation Safety Officer Approval and Review

RSO/Date

DAILY USAGE LOG
NEC MODEL 5SDH PELLETRON, S/N 9, CH-029

AUTHORIZED USER: _____ **Date:** _____ **Time:** _____

AUTHORIZED USER SIGNATURE: _____

DATE OF VALID SIX MONTH:

Radiation protection survey: _____ Interlock test: _____

RMS (Thermo Fisher Sci) recalibration due date: _____

PRE-RUN CHECKLIST

_____ Personnel in accelerator room wearing dosimeters as required

_____ Warning sign controller turned on and operating

_____ RMS II interlock system operating and will trip charging chain off.

_____ RADIAC meters are available, turned on, and response checks OK

_____ Radiation Area warning signs and rope barriers are available if needed.

CHARGING CHAIN Time On _____ Time Off _____

GENERAL

Beam Species _____ Energy _____

Beamline Used 30-deg Left _____ 15-deg Left _____ 15-deg Right _____

Target(s) _____

Tank SF₆ Pressure _____

Base Vacuum L.E. _____ H.E. _____

Operating Vacuum L.E. _____ H.E. _____

ALPHATROSS ION SOURCE

Source Bottle Gas _____ Pressure _____

Magnet Power Supply Voltage _____ Current _____

Oven Controller Chamber °C _____ Oven °C _____ % Power _____

Probe Power Supply Current _____ Voltage _____

SNICS-II ION SOURCE

Cathode Material _____

Enclosure ()

Ionizer Power Supply Voltage _____ Current _____

Oven Controller Oven °C _____ % Power _____

Cathode Power Supply Current _____ Voltage _____

INJECTOR

Deck Bias Dial _____ Voltage _____

X-Steerer+/- Dial _____ Voltage _____

Y-Steerer Dial Voltage _____

Einzel Lens Dial _____ Voltage _____

Inflection Magnet Voltage _____ Current _____

Injector Cup Current _____

ACCELERATOR CONTROLLER

Column Current L.E. _____ H.E. _____

Charging Current _____ Voltage _____

TERMINAL POTENTIAL STABILIZER

Control Gain Dial _____

CPO Gain Dial _____

Terminal Voltage Dial _____ Meter _____

Bias Current Dial _____

Slit Currents L.E. _____ H.E. _____

Grid Voltage _____

Corona Probe Current _____

FOCUSING/ANALYZING

Quadrupole Lens 1 Dial 1 _____ Dial 2 _____

Analyzing Magnet Current _____ Field _____

Magnet Cup Current _____

BEAMLINE

Slit Openings L.E. _____ H.E. _____

Faraday Cup Current _____

Quadrupole Lens 2 Dial 1 _____ Dial 2 _____

X-Steerer Voltage _____ Current _____

Y-Steerer Voltage _____ Current _____

Target Current _____

NOTES:

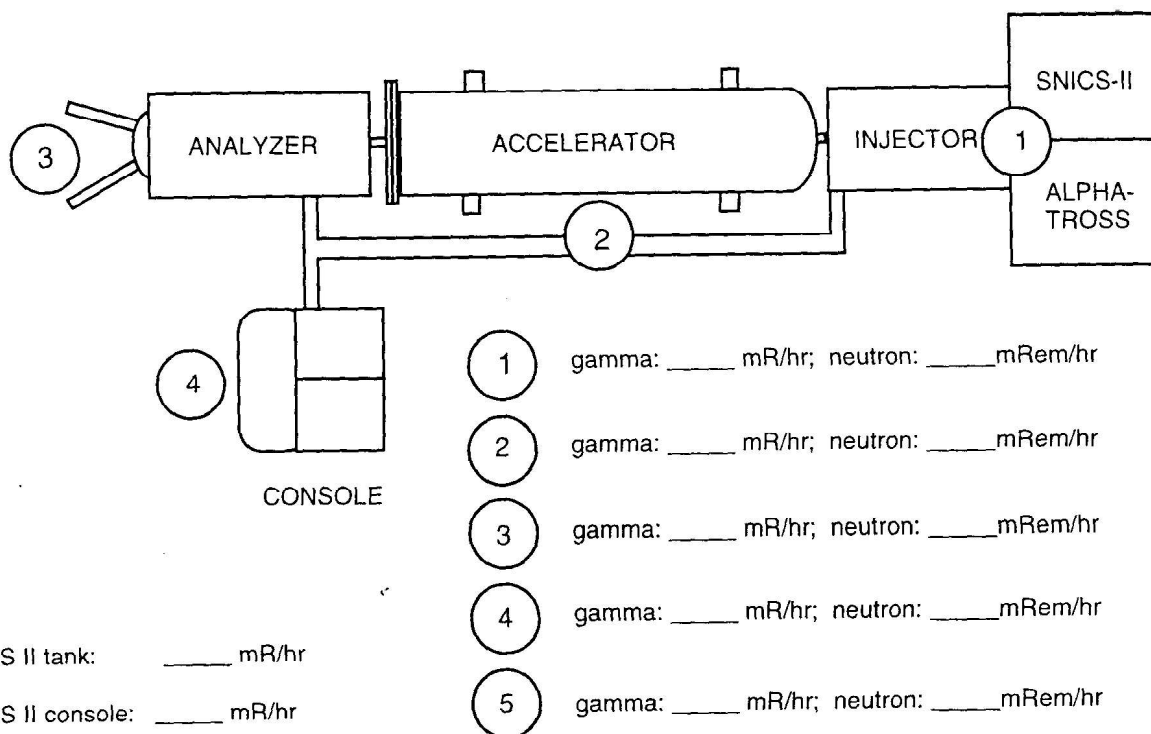
Enclosure ()

DAILY QUICK-SCAN RADIATION SURVEY

Surveyor _____	Date _____	Time _____
Ion Chamber RADIAC Model _____	S/N _____	
Cal Date _____	Cal Due _____	
Neutron RADIAC Model _____	S/N _____	
Cal Date _____	Cal Due _____	

RADIATION LEVELS

Record, directly on the diagram below, the gamma ray and neutron radiation levels for the accelerator operating parameters listed on the other side of this sheet. As a minimum, show levels at: (1) the ion source, at the inflector magnet; (2) the terminal, at the tank wall; (3) the analyzing magnet; (4) the console; and (5) the target.



RMS II tank: ____ mR/hr

RMS II console: ____ mR/hr

Reviewed by RSO: _____	Date: _____
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TEST PROCEDURES FOR SAFETY AND INTERLOCK SYSTEMS

This procedure tests the functionality of the relays and set points in the RMS interlock system. This procedure does not check the calibration of the compensated detectors. Calibration shall be maintained by the OEM (Thermoelectron) recommended calibration laboratory. The presently recommended calibration facility is:

Thermo Fisher Scientific
Thermo-Eberline LLC
1 Thermo Fisher Way
Oakwood Village, OH 44146-6536
Ph: 800 - 274 - 4212

1. PURPOSE

- a. Verify correct operation and calibration of warning and interlock system.

2. FREQUENCY

- a. Every six months.

3. REQUIRED EQUIPMENT

- a. Warning and Interlock System Test Log sheet
- b. Control key
- c. Accelerator in operation (to produce radiation field)

4. PROCEDURE

a. Preparation

(1) Verify that accelerator room doors are closed, RMS II relays are reset, master interlock chassis is reset and the warning sign controller is turned on with the function selector in the AUTO position.

(2) Insert key in master interlock system keyed switch and turn on.

(3) Set Pelletron charging control to zero. Insert injector Faraday Cup.

(4) Start Pelletron chain. Verify that yellow "CAUTION" lamp lights.

b. Check operation of the Interlock Chassis

(1) Turn master interlock system keyed switch off. Verify that Pelletron chain and yellow "CAUTION" lamp turn off.

(2) Turn key switch back on. Restart Pelletron chain.

c. Check operation of Warning Sign Controller

- (1) Turn warning sign controller power off. Verify that Pelletron chain turns off.
 - (2) Turn warning sign controller power back on. Restart Pelletron chain.
 - (3) Move function selector through the GREEN, YELLOW and RED positions. Verify that the appropriate lamps light on the signs. Return function selector to the AUTO position.
- d. Check operation of the Terminal Gamma RMS II relays
- (1) Raise the normal accelerator generated radiation field until alarm relay trips. Note meter reading and compare with required 2.0 millirem per hour. Verify that red "DANGER" lamp lights on the warning sign.
 - (2) Lower the normal accelerator generated radiation field until reading drops below the trip level. Verify that yellow reset button on RMS II chassis must be pressed before "DANGER" light goes off.
 - (3) Raise the normal accelerator generated radiation field until high relay trips. Note meter reading and compare with required 2.0 millirem per hour. Verify that Pelletron chain turns off.
 - (4) Lower the normal accelerator generated radiation field until reading drops below the trip level. Verify that red reset button on RMS II chassis must be pressed before "DANGER" light goes off. Verify that reset button on master interlock chassis must be pressed before Pelletron chain can be restarted.
- e. Check operation of the Console Gamma RMS II relays
- (1) There are two methods for generating the required greater than 2 millirem / hour radiation field.
 - i. Use radioactive sources in the vicinity of the GM tube.
 - ii. Move the GM tube as close to the terminal of the accelerator as allowed by its cables. Raise the normal accelerator generated radiation field until alarm relay trips. Note meter reading and compare with required 2.0 millirem per hour. Verify that red "DANGER" lamp lights on the warning sign.
 - (2) Lower the radiation field until reading drops below the trip level. Verify that yellow reset button on RMS II chassis must be pressed before "DANGER" light goes off.
 - (3) Raise the normal accelerator generated radiation field until high relay trips. Note meter reading and compare with required 2.0 millirem per hour. Verify that Pelletron chain turns off.
 - (4) Lower the normal accelerator generated radiation field until reading drops below the trip level. Verify that red reset button on RMS II chassis must be pressed before "DANGER" light goes off. Verify that reset button on master interlock chassis must be pressed before Pelletron chain can be restarted.
5. ACTION
- a. Record results of tests in Warning and Interlock System Test Log, noting any malfunctions.
 - b. Verify that the Thermoelectron/Fisher Scientific RMS area monitors have a current valid calibration, not to exceed 3 years as specified in ref (f) section 12.1.6.6.
 - c. Repair subsystems that do not pass tests.

WARNING AND INTERLOCK SYSTEM TEST LOG NEC MODEL 5SDH PELLETRON, S/N 9, CH-029

TESTER: _____ Date: _____ Time: _____

TESTER SIGNATURE: _____

Expiration Date of Thermoelectron RMS Area Monitor Calibrations _____

Procedure Reference Enclosure (8)	Test	Satisfactory	Unsatisfactory
4.a.(4)	Yellow "CAUTION" lamp lights when Pelletron chain starts		
4.b.(1)	Removing Key switch turns off chain and "CAUTION" lamp		
4.c.(1)	Removing Warning sign power turns off chain and "CAUTION" lamp		
4.c.(2)	Function selector lights lamps properly		
4.d.(1)	Terminal Gamma RMS II alarm relay trips at 2.0 millirem per hour		
	Red "DANGER" lamp lights		
4.d.(2)	Yellow reset button extinguishes "DANGER" lamp		
4.d.(3)	Terminal Gamma RMS II high relay trips at 2.0 millirem per hour		
	Pelletron chain turns off		
4.d.(4)	Red reset button and interlock reset button needed for chain restart		
4.e.(1)	Console Gamma RMS II alarm relay trips at 2.0 millirem per hour		
	Red "DANGER" lamp lights		
4.e.(2)	Yellow reset button extinguishes "DANGER" lamp		
4.e.(3)	Console Gamma RMS II high relay trips at 2.0 millirem per hour		
	Pelletron chain turns off		
4.e.(4)	Red reset button and interlock reset button needed for chain restart		

COMMENTS: Identify any problems.

Reviewed by RSO: _____	Date: _____
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6-MONTH RADIATION PROTECTION SURVEY LOG NEC MODEL 5SDH PELLETRON, S/N 9, CH-029

SURVEYOR: _____ Date: _____ Time: _____

SURVEYOR SIGNATURE: _____

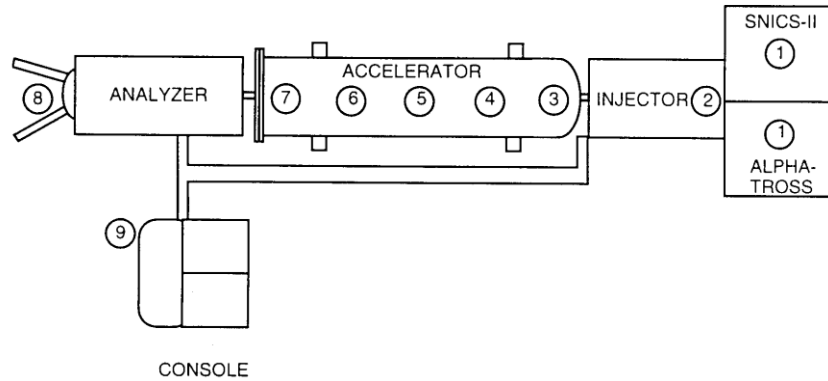
Purpose of the survey: _____

RADIAC INSTRUMENTATION

Ion Chamber RADIAC Model: _____ S/N: _____
Cal Date: _____ Cal Due: _____
Neutron RADIAC Model: _____ S/N: _____
Cal Date: _____ Cal Due: _____

RADIATION LEVELS

Record, with reference to the diagram below, the gamma ray and neutron radiation levels for the accelerator under the operating parameters.



Radiation Type	Gamma Rays (millirem per hour)				Neutrons (millirem per hour)			
Location	UP	DN	RT	LF	UP	DN	RT	LF
1. Source		XX				XX		
2. Magnet		XX				XX		
3. Accelerator								
4. Accelerator								
5. Accelerator								
6. Accelerator								
7. Accelerator								
8. Magnet		XX				XX		
9. Console		XX	XX	XX		XX	XX	XX
10. Slits		XX				XX		
11. Faraday Cup		XX				XX		
12. Target		XX				XX		

NOTE: ATTACH A COPY OF THE COMPLETED "DAILY USAGE LOG"

Reviewed by RSO: _____

Date: _____