Gamma-ray Large Area Space Telescope (GLAST)

Large Area Telescope (LAT)

Integration & Test Subsystem

Van de Graaff Accelerator Safety/Operations Handbook
### Change History Log

<table>
<thead>
<tr>
<th>Revision</th>
<th>Effective Date</th>
<th>Description of Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>-01</td>
<td>3/14/03</td>
<td>Initial release. Preliminary draft.</td>
</tr>
</tbody>
</table>
Contents

1. People to Contact.................................................................................................................................4

2. Purpose...............................................................................................................................................4

3. Definitions...........................................................................................................................................5

   3.1. Acronyms........................................................................................................................................5

   3.2. Definitions.......................................................................................................................................5

4. Applicable Documents..........................................................................................................................5

5. Van de Graaff Accelerator Description................................................................................................5

6. Pre-Installation Configuration and Radiation Survey..........................................................................11

7. Final Installation Configuration and Radiation Survey.........................................................................11

8. Operation Procedure............................................................................................................................14

9. Summary of Pre-Installation Radiation Measurements by Operation Health Physics.............................17
1. **People to Contact**

For questions concerning the GLAST Van de Graaff Accelerator please contact:

Gary Godfrey x2919  
Larry Wai (Bldg 33 Manager) x3145  
Occupational Health Physics (OHP) x4299  

Current List of trained and approved Van de Graaff Operators  
Gary Godfrey (650) 926-2919  
Eduardo do Couto e Silva (650) 926-2698  
Larry Wai (650) 926-3145  

2. **Purpose**

The purpose of this document is to describe the Van de Graaff, describe how radiation safety during its use will be achieved, and provide an operations procedure for the machine.

The purpose of the Van de Graaff is to provide 17.6 MeV gamma rays for calibrating the EM, CU, and LAT. The requirements for this flow down from the LAT Performance Specification – Level II(b) Specification Document (LAT-SP-00010-02). The Beam Test program is designed to ensure that the performance of the LAT meets the requirements of LAT-SP-00010-02. The performance requirements, for which the Van de Graaff use is relevant, have been summarized in Table 1. It is estimated that the Van de Graaff will have an integrated run time of <100 hours on each of the EM, CU, and LAT.

Table 1. Summary of Science Instrument Performance Verification (a subset of Table 1 of LAT-SS-00010-02). A column has been added to the table indicating which beam tests are relevant to verifying the requirement. The verification methods are T=Test, A=Analysis.

<table>
<thead>
<tr>
<th>Req’t #</th>
<th>Req’t Title</th>
<th>I Parameter</th>
<th>Verification Method</th>
<th>Beam Tests relevant to the Verification</th>
</tr>
</thead>
</table>
| 5.2.1   | EnergyRange/Effective Area | At Normal Incidence:  
> 300 cm² @ 20 MeV  
>3000 cm² @ 100 MeV  
>6400 cm² @ 300 GeV | T and A | 1) Van de Graaff 17.6 MeV γ  
2) Tagged photons 100 to 1500 MeV, norm incidence  
3) Brem beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions.  
4) Cosmic rays in airplane |
| 5.2.2   | Energy Resolution | On axis:  
≤ 50 % 20–100 MeV  
≤ 10 % 10 GeV  
≤ 20% 10-300 GeV  
≤ 6% >10 GeV. | T and A | 1) Van de Graaff 17.6 MeV γ  
2) Tagged photons 100 to 1500 MeV, norm incidence  
3) Positrons 1,2,5,10,28, 45 GeV, variety of angles and transverse positions |
3. Definitions

3.1. Acronyms

CU Calibration Unit (4 towers)
DAQ Data Acquisition system
EM Engineering Model tower.
GERT General Employee Radiation Training at SLAC
GLAST Gamma-ray Large Area Space Telescope
EGSE Ground Support Electronics
I&T Integrate and Test
LAT Large Area Telescope.
RCA Radiation Control Area
SLAC Stanford Linear Accelerator Center in Menlo Park, California
SPAR Single Photon Angular Resolution
SSD Silicon Strip Detector
TBD To Be Determined
TBR To Be Reviewed
VG Van de Graaff accelerator

3.2. Definitions

Tracker Silicon strip tracker within each tower of the LAT

4. Applicable Documents

[1] LAT-SS-00010 LAT Performance Specification – Level II(b)

5. Van de Graaff Accelerator Description

The Van de Graaff is a small electrostatic accelerator (Model LC-400) made by the High Voltage Engineering Corporation and purchased from them in ~1975 by Stanford. It is intended for use in a college undergraduate laboratory. It was used with the Crystal Ball at SLAC in the late 1970’s and at DESY in the early 1980’s. Figure 1 shows an outside view of the machine. Figure 2 shows a view of the machine with the pressure vessel removed. Figure 3 shows a view of the machine with the HV terminal dome removed. The machine is configured to accelerate protons that are obtained from an internal steel bottle of H₂. The H₂ is ionized by an RF field in a glass source bottle to make
protons. The H₂ source is inside the positive high voltage terminal of the machine so that the protons are then accelerated through an evacuated (~1 x 10⁻⁵ torr) glass column away from the high voltage terminal to the Li target which is inside the end of the beampipe at ground potential.

The high voltage terminal is charged by a belt that is driven at a constant speed by a 1.5 hp motor. Positive charge is deposited on the belt by a screen fed by an adjustable DC power supply at the ground end of the belt. The belt carries the positive charge to the high voltage terminal where it is removed by another screen. Charge is being continually bled from the high voltage terminal by 9.5 GΩ of resistance to ground (fifteen 625 MΩ resistors grading the potential between 15 electrodes along the glass accelerating column). Charge may also be removed from the terminal by moving a set of grounded corona points moved closer to or farther from the terminal, and charge is also removed by the current flowing in the accelerator beam.

The terminal high voltage is known by measuring the current flowing through the 9.5 GΩ of column resistance (“Column” current on the control panel). The terminal HV is adjusted by changing the 0 to +15 KV DC belt charging voltage (“Belt Charge” knob on the control panel), by moving the corona points to adjust the amount of current they bleed off (manual insertion of the rod at the source end of the accelerator and the “Corona” current on the control panel meter), and by changing the beam current. An adjustable 0 to +1700 VDC wrt the HV terminal (“Beam” Decr/Incr switch) is applied to the source probe to push H⁺ out of the source plasma. An adjustable 0 to -12.5 KV wrt the HV terminal (“Focus” Decr/Incr switch) is applied to an electrode immediately downstream of the source to focus the beam on the target. The flow of H₂ gas (from a ~100 psi bottle) entering the high vacuum of the source is regulated by a “leak” that is opened by electrically heating (“Gas” Decr/Incr switch) the outer body of the leak. All three switches (Beam, Focus, Gas) run motors that turn lucite rods that turn variacs inside the HV terminal. It takes 140 sec for a variac to go from one end of its range to the other. No wires run to the HV terminal. All voltages needed at the HV terminal end are obtained from a 115 VAC 400 Hz generator run by the charging belt.

The entire high voltage terminal, accelerating column, belt, and motor are enclosed within a grounded steel pressure vessel which is pressurized with 12 psig of SF₆ to minimize high voltage breakdown. The highest sustainable terminal voltage before breakdown is ~700 KV. The evacuated beam pipe, which leaves the pressure vessel, is made of stainless steel and is terminated by a stainless steel blanket with the Li target insulted from the blanks inside face. The Li target is connected through a microammeter to ground to measure the beam current striking the target (“Beam” current on the control panel meter). The various accelerator controls and readouts are summarized in Table 2. Figure 4 shows the Control Panel and vacuum gauges.

Table 2. Summary of the various Van de Graaff controls and readouts

<table>
<thead>
<tr>
<th>CONTROL</th>
<th>Location</th>
<th>Typical for operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Valve Into VG</td>
<td>Bldg 33 wall above VG</td>
<td>On</td>
</tr>
<tr>
<td>Water Valve Out of VG</td>
<td>Bldg 33 wall above VG</td>
<td>On</td>
</tr>
<tr>
<td>Water Valve into VG interior loop</td>
<td>Lower left front of VG</td>
<td>On</td>
</tr>
<tr>
<td>Mech Pump pwr switch</td>
<td>Lower right front side of VG</td>
<td>On (up)</td>
</tr>
</tbody>
</table>
The 17.6 MeV photon is produced via the reaction

$$P + ^7Li \rightarrow Be^{8(1+)*} \rightarrow Be^8 + \gamma$$

A 440 KeV kinetic energy proton is required to excite the 17.640 MeV resonance (which has a width of $\Gamma=10.7$ KeV). In order to penetrate surface contamination on the target, a beam of 550 KeV will be used to get a good production rate. The range of a 550 KeV proton in steel is $\sim$3 um. Thus the protons never leave the $\sim10^4 \text{ um}$ thick pressure vessel or $\sim10^3 \text{ um}$ thick beampipe and target holder. The Lithium target is 1.5 mm thick and $\sim$1.5 inches in diameter. The target is insulated from the stainless steel end cup, and a wire connects the Lithium to a BNC feedthrough so the target current can be measured. Downstream of the Lithium the stainless steel is 0.050 in thick, and this is covered by an additional 1/16 in of Lead glued to the outside.

The protons will loose energy in the target by ionizing target atoms, thus causing characteristic xrays from the target. Since the target Z=3 (Li) is much lower than the structure enclosing the target Z=26 (steel), lithium’s 55 eV $K_\alpha$ xrays will be completely attenuated. However, some protons may strike what appears to be silver electrodes along the accelerating column, thus generating characteristic xrays of 22-25 KeV which would emerge as a collimated beam through the thin .050” stainless steel window of the target. A 1/16” thick piece of lead has been glued to the downstream end of the target to absorb these or other low energy photons.

Measurements with a BGO calorimeter show 1060 Hz of photons ($E_{\text{photon}}>7$ MeV) are isotropically emitted into $4\pi$ solid angle for a beam energy of 550 KeV (55 uA) and a target current of 80 uA. This rate is equivalent to the rate from a .04 uCurie source. The energy spectrum of these photons has been measured by the Crystal Ball and is shown in Figure 5.
Electrons which come from residual gas molecules or the walls of the accelerating column will be accelerated back up the column. This electron current should be substantially less than the proton current (~50 uA max) flowing the other way. When the electrons strike the HV terminal, xrays up to 550 KeV will be generated. The pressure vessel ~1 cm steel and its wrapping of ¼” Pb will partially shield these xrays. The residual amount of radiation at maximum high voltage and beam current will be measured in the Pre-Installation Radiation Survey. It is expected that this radiation will be primarily around the source end of the accelerator.

Figure 1. This is an outside picture of the accelerator.
Figure 2. This is a picture of the accelerator with the SF6 pressure vessel removed.

Figure 3. This is a picture of the accelerator with the HV terminal dome removed.
Figure 4. This is a picture of the accelerator Control Panel and vacuum gauges.

Figure 5. The points are data from the Crystal Ball for the gammas from the reaction $p+Li^7$. The solid curve is the sum of a Breit-Wigner (Eresonance=12 MeV, FWHM $\Gamma$=5 MeV) and a Gaussian (Eresonance=17.6 MeV, $\sigma$=1.3 MeV). The two curves have equal area and add up to the total number of counts in the data.
6. **Pre-Installation Configuration and Radiation Survey**

1) The Van de Graaff is set up away from the clean room on the floor of Bldg 33 with a barrier (yellow/magenta rope) around the Van de Graaff as shown in Figure 6. The barrier shall be at least 5 feet from the source end and sides of the Van de Graaff. Radiation warning signs shall be hung from the barrier on both sides of the Van de Graaff.

2) A rotating red warning light shall be mounted on top of the Van de Graaff. It will serve as a warning that radiation may be present. The light shall be connected in parallel with the AC power to the Van de Graaff belt motor.

3) Follow all procedures governing the operation of the Van de Graaff. Only certified Van de Graaff operators are allowed to run the Van de Graaff.

4) Operate the Van de Graaff at its maximum voltage (before HV breakdown) and beam current accelerating protons.

5) Perform the radiation survey. Measurements should be performed using only calibrated radiation dose rate meters. The survey consists of contact measurements, measurements at 30 cm distance, and a boundary survey.

6) Report the survey results to Operational Health Physics (x 2388) and store the completed survey in the “Van de Graaff Operations Logbook”.

7. **Final Installation Configuration and Radiation Survey**

1) Install the Van de Graaff beside the clean room and set up rope barriers around the Van de Graaff as shown in Figure 7. The lead shielding on the Van de Graaff will be demonstrated by a radiation survey to be sufficient such that the dose at the rope boundary is <.05 mR/hour. Radiation warning signs shall be hung from the boundary ropes indicating that within is an RCA area. A GERT badge will be necessary for entry inside the ropes.

2) A rotating red warning light shall be mounted on top of the Van de Graaff. It will serve as a warning that radiation and high voltage may be present. The light shall be connected in parallel with the AC power to the Van de Graaff belt motor. The red light must be visible to people working in the clean room. If the light is not visible through the adjacent clean room window, a mirror will be installed by the window to reflect the light in.
3) Radiation warning signs (RCA) shall be hung on all doors of the clean room. A GERT badge will be necessary to enter the clean room when the Van de Graaff is turned ON. When the Van de Graaff is turned OFF, the RCA signs on the doors may be turned over, so that no GERT is required for entry.

4) OHP will install TLD dosimeters in strategic locations for monitoring the Van de Graaff and clean room areas.

5) Shielding and area control of the final installation must be inspected by OHP and RP prior to operation of the Van de Graaff for the first time in its installed location.

6) A radiation survey will be done by OHP at the first turn on. The accelerator will be set to its maximum voltage and current for this survey. Additional shielding will have to be installed if any dose rates are greater than the maximum allowable values given Table 3, and the survey redone.

7) Regular periodic surveys will be conducted by OHP per the Radiological Control Manual.

8) Van de Graaff operators must have completed Radiation Worker I training and Course #270 (Radiation Generating Device Operator training). Only certified Van de Graaff operators are allowed to run the Van de Graaff.

Table 3. Maximum allowable dose rates at various locations.

<table>
<thead>
<tr>
<th>Survey Location</th>
<th>Maximum Allowed Dose Rate [mR/hr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank contact on ends or sides (GERT area)</td>
<td>100</td>
</tr>
<tr>
<td>30 cm from ends or sides of tank (GERT area)</td>
<td>2</td>
</tr>
<tr>
<td>Within cleanroom after installation (GERT area)</td>
<td>2</td>
</tr>
<tr>
<td>Target contact (GERT area)</td>
<td>2</td>
</tr>
<tr>
<td>Outside VG Boundary and outside cleanroom</td>
<td>.05</td>
</tr>
</tbody>
</table>
Figure 6. Pre-installation test configuration

Figure 7. Installation configuration.
8. **Operation Procedure**

Operating the Van de Graaff consists of the following steps:

A) Before turning on the belt do the following checklist:

1) Flip the signs on the three clean room doors to indicate “Radiation Controlled Area”. Advise any people in the clean room that they have to be GERT and that the Van de Graaff is turning on.

2) Verify that the rope barriers are in place around the Van de Graaff with “Radiation Controlled Area” signs hung on the ropes on both sides of the machine.

3) Verify that the **Corona Rod** (white rod with big green knob at the source end of the accelerator) is pushed in to ~2 inches on the scale.

4) Verify the SF₆ pressure is 12 psig (= .95 bar) on the gauge on top of the Van de Graaff tank.

5) Turn on the **in and out water valves** (1/4” tubing valves with blue lever handles above your head on the exterior wall) (make the handles parallel to the pipes).

6) Turn on the **interior water loop valve** by making the blue lever handle near the bottom front of the Van de Graaff parallel to the pipe.

7) Rotate the **Main Power Switch** (big yellow rotary switch on the upper right front side of the Van de Graaff) to on.

8) Turn on the vacuum mechanical “**roughing pump**” switch and wait until the pressure is <100 milli torr. This switch is on the bottom right front side of the Van de Graaff.

9) When the pressure is <100 milli torr turn on the “**diffusion pump**” power by flipping up a second switch on the bottom right front side of the Van de Graaff. Wait until the pressure is \( \leq 2 \times 10^{-5} \) torr before continuing to turn on the machine.

10) Turn on the “**control panel**” power by flipping up a pair of adjacent switches on the bottom right front side of the Van de Graaff.

11) Turn on the “**belt motor enable**” power by flipping up the three ganged switches on the bottom right front side of the Van de Graaff. This also turns on the red warning light which indicates you are ready to go!

B) The machine is ready to turn on and tune, so do it.
1) Be sure the “Belt Charge” knob on the control panel is set to zero (full CCW).

2) Push the On button on the control panel. You should hear the belt motor start running. The controlled leak is now heating up and letting hydrogen flow into the source. You may see the pressure start to rise. After a 30 sec time delay, the source HV will automatically turn on, ionize the gas in the source bottle, and be able to supply protons for the beam.

3) Adjust the pressure to be $1-2 \times 10^{-5}$ torr by pushing the Gas switch to the right (=H$_2$ more on) or left (=H$_2$ more off). The variac being controlled should be in approximately the correct position so holding the switch on or off for ~5 sec should make a difference. Full scale movement of the motor driven variac takes 140 sec.

4) Set the meter switch to read “Column” current, and gradually turn up the Belt Charge knob until you see 55 uA (~550 KeV) of column current. If you hear the machine breaking down (…pop…pop…) or the meter is flicking down to zero, back off the column current and wait a bit to “condition” the machine.

5) Set the meter switch to read “Beam” current. This is the current actually hitting the target. Adjust the beam current to be ~50 uA by pushing Beam switch right or left. Maximize the Beam current by pushing the “Focus” switch right or left. This focuses the beam on the target.

6) By setting the meter switch to read “Corona” current, verify that the Corona current is approximately equal to the Column current. This is the most stable operating condition.

7) Now begin a juggling act with the Belt Charge knob, Gas pressure switch, and Beam current switch to keep the Beam current and Column current steady at the desired values.

8) When things are somewhat stable, fill in one line in the Van de Graaff operation log. This includes some control panel numbers and some radiation measurements made at the Van de Graaff boundaries and in the clean room by the target. The radiation measurements are made with the yellow hand held survey meter.

9) Stay near the control panel and juggle the knobs for the duration of the run.

C) Turning Off the machine

1) Turn the Belt charge knob to zero (full CCW).

2) Push the Off button on the control panel.

3) The machine may be turned on again by starting with step B-1 again above.

D) Shutting down the machine completely after turning it off.
1) Turn off the belt motor enable switch (triple switch at lower right side of machine). Turn off the control panel power switch (at lower right side of the machine). Leave on the main power (rotary yellow switch), the roughing pump switch, and the diffusion pump switch. These switches are also at the right side of the machine. Leave on the water. This is necessary to cool the diffusion pump. A thermal cut out on the lower back side of the diffusion pump (push with a pencil to reset) will turn off the diffusion pump if it gets to hot.

2) Close the Van de Graaff interior water loop valve by making the blue lever handle near the bottom front of the Van de Graaff perpendicular to the pipe. There is pressure switch on this loop, so this guarantees that someone who doesn’t know what they are doing can’t turn on the belt motor.

3) Fill in one line in the Van de Graaff operation log.

4) Flip over the three signs on the clean room doors so that the clean room is no longer a Radiation Control Area.

5) Done…walk away.
9. **Summary of Pre-Installation Radiation Measurements by Operation Health Physics**

1) **Date:** Monday, Feb 10, 2003  
**People:** Jim Allan (OHP), Eddie McGee (OHP), Gary Godfrey

The Van de Graaff HV was turned up to its maximum voltage before breakdown (70-80 uA column current = 700-800 KeV) and run at the maximum stable current that could be achieved (50-60 uA of beam current into the target). The H₂ was set to give the nominal .5 -1.0 x 10⁻⁵ torr inside the beampipe. The corona current was ~60 uA.

Jim Allan and Eddie McGee surveyed the accelerator and found the hot spots shown in Table 3.

**Table 3.** Van de Graaff hot spots found in Feb 10, 2003 radiation survey. The survey meter had its window open.

<table>
<thead>
<tr>
<th>Location</th>
<th>Max rate found [mr/hr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact at corona rod penetration with lead cover removed</td>
<td>25.</td>
</tr>
<tr>
<td>Contact at rear wheel wells on the pressure vessel</td>
<td>20.</td>
</tr>
<tr>
<td>Contact with downstream target face</td>
<td>12.</td>
</tr>
<tr>
<td>~2” diam beam downstream of target by ~20 feet</td>
<td>1.</td>
</tr>
</tbody>
</table>

These hot spots have been reduced by installing the lead cover over the corona rod, putting lead shot bags in the wheel wells, and gluing a 1/16” thick piece of lead to the downstream target face.

2) **Date:** Tuesday, Feb 11, 2003  
**People:** Eddie McGee (OHP), Gary Godfrey

The Van de Graaff HV was turned up to its maximum voltage before breakdown (70-75 uA column current = 700-750 KeV) and run at the maximum stable current that could be achieved (50-60 uA of beam current into the target). The H₂ was set to give the nominal .5 -1.0 x 10⁻⁵ torr inside the beampipe. The corona current was 70-80 uA.

Eddie McGee made the measurements shown in Table 4.

**Table 4.** Van de Graaff measurements made in the Feb 11, 2003 radiation survey. The survey meter had its window open.

<table>
<thead>
<tr>
<th>Location</th>
<th>Contact [mr/hr]</th>
<th>30 cm [mr/hr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream end of lead corona rod cover (cover in place over corona rod)</td>
<td>.04</td>
<td>.02</td>
</tr>
<tr>
<td>Side of accelerator tank</td>
<td></td>
<td>.02</td>
</tr>
<tr>
<td>Downstream end of target (with 1/16” lead permanently glued in place)</td>
<td>.5</td>
<td>.04</td>
</tr>
</tbody>
</table>