LCLS Ultrafast Science Instruments

Engineering specification Document (ESD)	Doc. No. SP-391-000-75 R0	LUSI SUB-SYSTEM CXI instrument

Engineering Specifications for the CXI Particle Injector System

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Revision	Date	Description of Changes	Approved
R0	20MAR09	Initial release	

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1. Overview

The CXI particle injector will consist of a differential pumping system that will include an aerodynamic focusing lens system capable of transferring an aerosol suspension from atmospheric pressure to the vacuum of the CXI Sample Chambers (ESD# SP-391-001-43, ESD# SP-391-000-67) and delivering the aerosol particles to the interaction region with the LCLS beam. The system will be motorized to allow steering of the particle beam.

Also included in the Particle Injector System are aerosol generation devices as well as aerosol diagnostics devices to be used on the aerosol at atmospheric pressure.

The Particle Injector System will also include diagnostics for the particle beam inside and outside the vacuum of the CXI Sample Chambers.

The differential pumping interface, the aerodynamic lens and their mounting mechanism are referred to as the particle injector. The design of particle injector can be seen on Figure 1, Figure 2 and Figure 3. Other devices, such as aerosol generators, aerosol diagnostics and in-vacuum particle beam diagnostics are part of the CXI Particle Injector System but not the particle injector itself.

This document describes the specifications of the Particle Injector System and outlines how the devices will be designed, fabricated and operated. Where applicable, this document specifically addresses how specific requirements from document PRD# SP-391-000-26, *Physics Requirements for the CXI Particle Injector System*, are to be met. In some cases, where a Physics Requirement cannot be met, the reason is given and the expected performance is compared to the requirement.

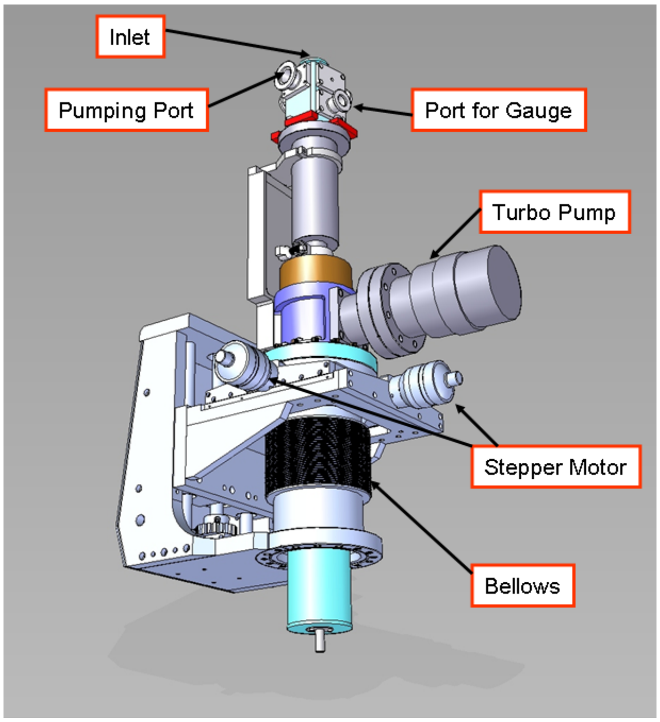

Figure 1: Mechanical design of the CXI particle injector.

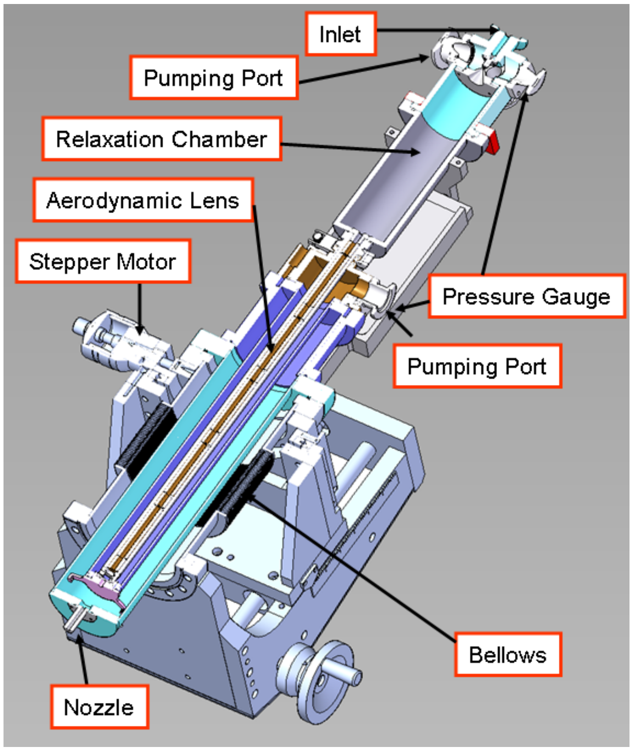

Figure 2: Cross-section of the particle injector identifying major components of the system.

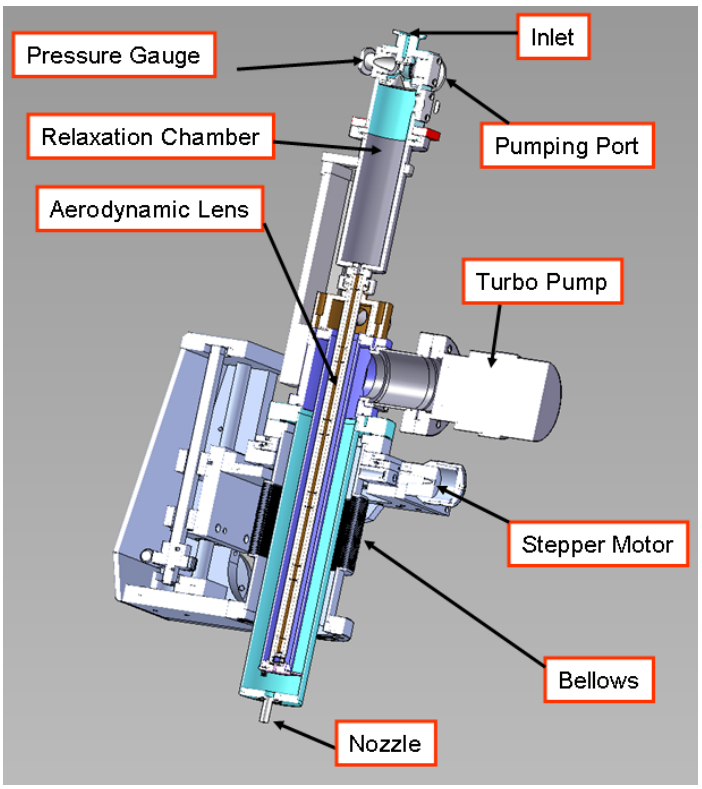

Figure 3: Cross-section of the particle injector (rotated by 90 degrees compared to Figure 2) identifying major components of the system.

The coordinate system is defined in Mechanical Design Standards Supplement DS-391-000-36.

2. Applicable documents

PRD# SP-391-000-19	Physics Requirements for the CXI Instrument
PRD# SP-391-000-20	Physics Requirements for the CXI 0.1 micron Sample Chamber
PRD# SP-391-000-26	Physics Requirements for the CXI Particle Injector System
PRD# SP-391-001-41	Physics Requirements for the CXI 1 micron Sample Chamber
ESD# SP-391-000-67	Engineering Specifications for the CXI 0.1 micron Sample Chamber
ESD# SP-391-001-43	Engineering Specifications for the CXI 1 micron Sample Chamber

3. General Requirements

3.1. Location

The CXI Particle Injector System shall be located inside the CXI hutch (hutch 5) in the far experimental hall.

3.2. Environment

The humidity and temperature are controlled in the FEH hutches, therefore no component specific temperature stabilizing system shall be provided for the instrument, unless the expected temperature stability is determined to be insufficient to meet the stability requirements.

The temperature and relative humidity in the FEH Hutch 5 will be maintained at 72°F ±1°F (22.2°C ±0.5°C) and 45% ±10%, respectively.

3.3. Maintenance, Accessibility and Operations

The particle injector shall be attached to the top of the CXI Sample Chambers placing the inlet at a height of roughly 7ft 6in. It will be assembled and disassembled on the order of once every week for the life of the device. Due to the height of the device and relatively frequent access required, a small structure allowing users to stand roughly 3 ft high shall be provided.

During operations, the aerosol generating devices must be located close to the inlet of the Particle Injector to minimize transmission losses. A platform shall be provided to locate these devices above the top of the Sample Chambers. This platform shall be easily removable, ideally on wheels so it can be moved close to the Particle Injector inlet during operations and moved away when the injector is not in use. A small step stool shall be provided for users to set up the aerosol generation and diagnostic devices located on the platform.

The particle injector shall be reasonably easily disassembled for maintenance and cleaning, due to potential clogging, which is expected to occur once a week on average and up to 5 times daily at the peak. Specifically, easy access for cleaning the skimmer at the inlet of the injector shall be provided, preferably with a valve allowing removal of the skimmer without the need to break vacuum. (See Figure 4).

Past experience with an existing similar particle injector indicates that clogging could be an issue. In order to minimize down time, some requirements exist to allow rapid replacement of some devices and for cleaning without breaking vacuum. This section outlines these requirements.

There shall be a valve at the entrance of the aerodynamic lens stack which when closed shall allow for the first differential pumping stage to be removed without breaking vacuum.

Two identical copies of the first pumping stage shall exist so that one can be used while a second one is being cleaned or unclogged.

It shall be a design goal to include a valve at the exit of the aerodynamic lens stack which when closed shall allow for the lens stack to be removed without breaking vacuum.

3.4. Lifetime

The expected service life of the device is 10 years.

4. Major System Components

The major components of the particle injector are shown on Figure 1, Figure 2 and Figure 3.

4.1. Inlet

The aerosol generated at atmospheric pressure will be delivered to the inlet of the particle injector using silicon tubing.

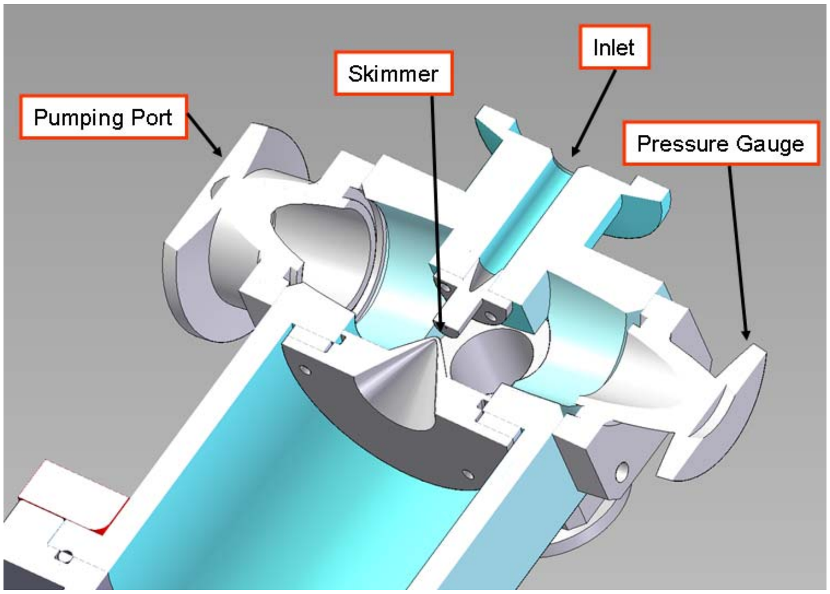

Figure 4: Cross-section of the inlet and skimmer area of the particle injector.

4.2. Differential Pumping

The system shall consist of 3 differential pumping stages. The first stage is between the inlet nozzle and the skimmer, as shown of Figure 4.

The relaxation chamber, beginning just after the skimmer and continuing all the way to the entrance of the aerodynamic lens is not pumped, as shown on Figure 5. The aerodynamic lens stack is also not directly pumped.

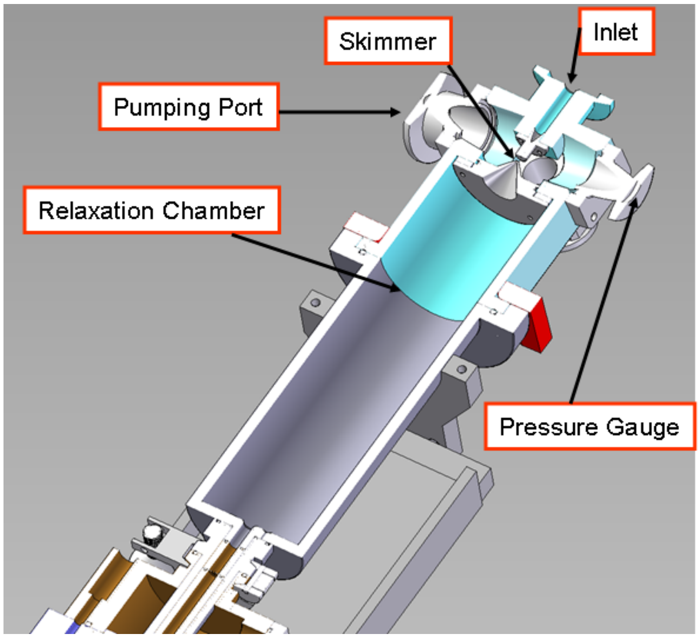

Figure 5: Cross-section of the inlet and relaxation chamber area of the particle injector.

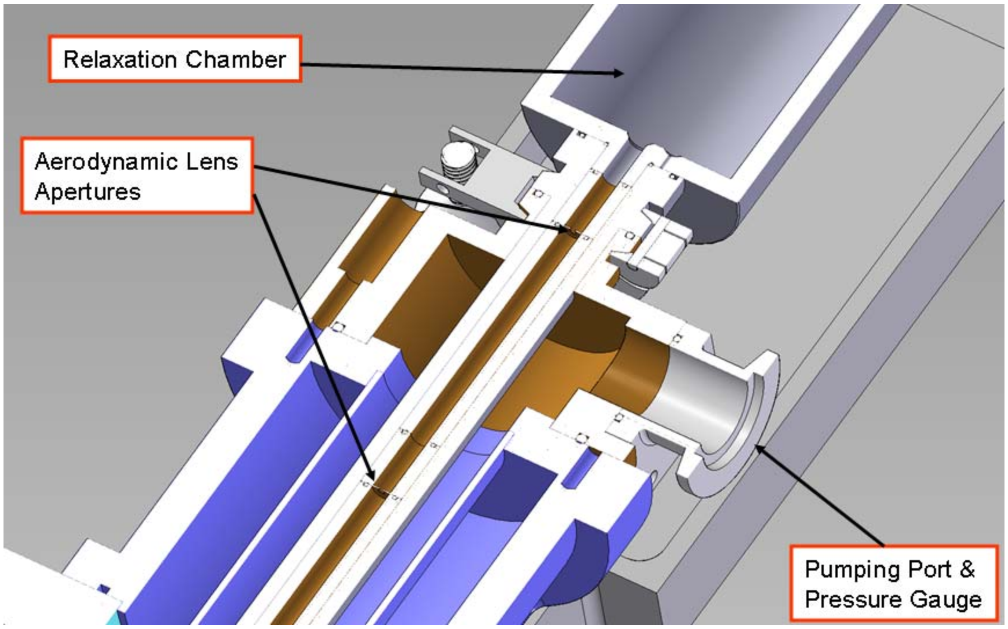

Figure 6: Cross-section of the entrance of the aerodynamic lens.

The second differential pumping stage is accessed through the KF port in Figure 6. It extends from that port to the exit nozzle of the aerodynamic lens shown in Figure 8 (the blue region).

The third differential pumping stage corresponds to the area between the aerodynamic lens stack nozzle and the differential pumping exit nozzle (Figure 8) that leads into the main vacuum chamber.

4.3. Aerodynamic Lens Stack

The aerodynamic lens stack consists of the very precisely machined cylinder with a set of concentric apertures that get progressively smaller. These apertures constrict the flow of gas through the cylinder causing any particle suspended in this gas to be focused to a certain point which depends on the particle size and the pressures in the lens stack. The lens apertures are shown on Figure 7. The aerodynamic lens stack nozzle (Figure 8) marks the end of the lens stack where the particle beam exits as a focused beam.

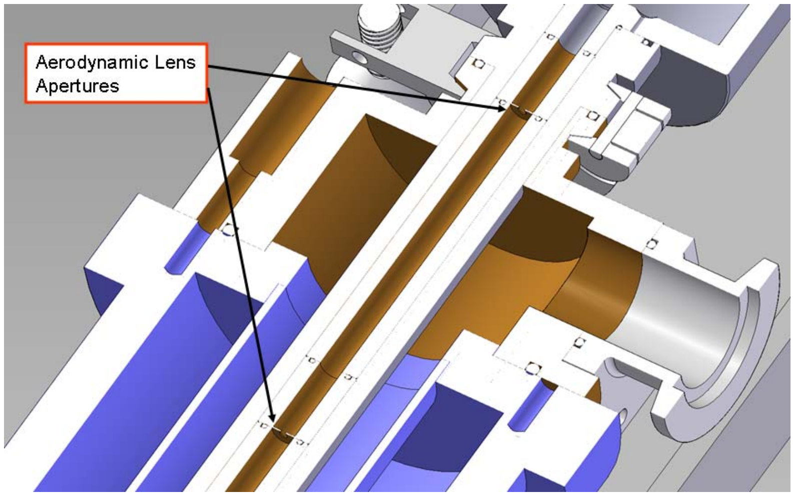

Figure 7: Cross-section of the entrance of the aerodynamic lens showing the small apertures required to achieve aerodynamic focusing.

4.4. Aerodynamic Lens Stack Stabilizer

The aerodynamic lens position is stabilized in the third differential pumping region by a stabilizer (Figure 8) that mates the aerodynamic lens stack nozzle and the inner surface of the third differential pumping region. The focused particle beam passes through the large orifice unperturbed.

4.5. End Cap

The end cap mounts to the end of the third differential pumping stage with three screws. It has a large orifice that is used to mount the exit nozzle. This piece is modular and can be replaced or redesigned to mount required diagnostics.

4.6. Exit Nozzle

The exit nozzle, shown on Figure 8, is the interface between the main vacuum chamber and the aerodynamic lens stack. Note that this piece can be any shape or size. It only acts as an aperture for pumping. the particle beam is already focused at the exit nozzle of the aerodynamic lens stack.

4.7. XYZ Positioning Stage

The XYZ positioning stage is a motorized 3-axis stage allowing the particle beam to be steered transverse to the beam and the nozzle to be placed at varying distances from the LCLS beam. This stage is shown on Figure 1. A bellows is required on this stage to allow for the reentrant function of the injector.

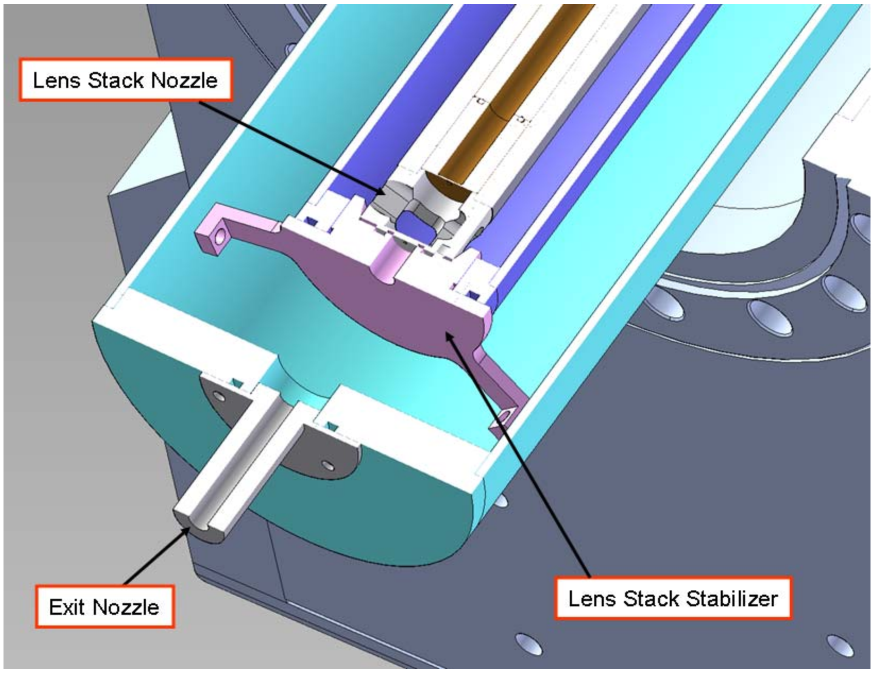

Figure 8: Cross-section of the nozzle of the particle injector, at the exit of the aerodynamic lens stack.

4.8. Aerosol Generation Devices

It will be necessary to create an aerosol suspension to be delivered to the inlet of the particle injector. These devices shall be located on a platform near the particle injector inlet. They are commercially available, although some of them will require modifications to allow for remote operations.

4.9. Aerosol Diagnostic Devices

Commercially available aerosol diagnostic devices shall be used to characterize the sample being delivered to the particle injector inlet. These devices shall be located on the same platform as the aerosol generation devices and they shall all be remotely operated.

4.10. Equipment and User Platform

This platform will support the aerosol equipment above the CXI Sample Chambers close to the particle injector inlet. The structure supporting this platform shall be moveable so it can be moved away from the Sample Chambers when the Particle Injector is not is use. The structure shall be on wheels. The structure shall also have a few steps so users can stand roughly 3 ft above the floor in order to set the Particle Injector equipment up before they start their experiment.

4.11. Charge Detectors

Devices known as Charge Detectors shall be used inside the CXI Sample Chambers to detect single charged particles as they fly through the Charge Detector. A charge detector is a device capable of measuring the image charge produced on a conductor by a charged particle flying past it. It will be used to determine the transmission of the particle injector and for alignment of the particle beam. Two Charge Detectors will be used inside the CXI Sample Chambers. The first one will be attached directly to the Particle Injector (right after the injector exit nozzle) while the second will be mounted inside the sample chamber, completely detached from the injector.

5. Performance Requirements

5.1. The particle injector shall be capable of delivering particles in the size range 10-1000nm.

Two or more aerodynamic lens stacks may be required to provide optimum focusing for a specific size range, i.e. 10-250nm vs. 250-1000nm.

5.2. The design goal of the particle injector shall be to produce a focus of 250 μm or less for all sizes in the range specified in Requirement 2.1.

This will be achieved by accurately controlling the pressure in each vacuum stage of the differential pumping interface. The pressure in the first stage shall be controlled to 0.1 Torr of better. The pressure in the second and third stages will be dictated by the pressure in the first stage. Particles of different sizes require different pressures in the system to achieve focusing.

5.3. It shall be a design goal to have greater than 50% transmission of the particles to vacuum through the differential pumping interface.

This will be achieved with accurate machining and alignment of the apertures in the lens stack and by minimizing the distance between the aerosol generator and the particle injector inlet.

6. Cyclic Requirements

6.1. The X, Y and Z motorized stages used to steer the particle beam are expected to be actuated in small (100 micron steps) on average 20 times daily for 10 years with a peak of 500 times per day for a few days every year.

6.2. The Y translation stage moving the Particle Injector exit nozzle in and out of the LCLS beam is expected to be actuated over its full stroke once per day on average for 10 years with a peak of 10 times per day.

6.3. The system shall be capable of enduring such usage for the expected lifetime of the device.

7. Mechanical Interfaces

7.1. The particle injector shall interface to the CXI Sample Chambers through a 6” non rotatable CF flange located directly above the interaction region of the chamber.

7.2. The particle injector shall connect to two roughing vacuum pumps in 2 locations.

> Long vacuum hoses shall be provided to reach the pumping ports of the particle injector, located up to 7ft 6in above the floor.

7.3. The injector inlet shall interface to the aerosol generator via a flexible silicon tube.

> The total length of this tube shall be minimized.

7.4. The electronic connections and feedthroughs of the first charge detector shall be fully included in the particle injector assembly.

> This shall be achieved by routing the wires through the third differential pumping stage, on the outside of the aerodynamic lens cylinder.

7.5. The second charge detector electronics and feedthroughs shall be fully included within the design of the sample chambers without any interferences or collisions allowed.

8. Materials

8.1. All parts and materials for the device shall be new and compatible with the performance requirements of this specification. Mil source certifications, including heat number, chemical analysis for all materials used in the manufacturing of the device shall be furnished. The device will be used in a radiation environment. Use of Teflon is specifically prohibited.

8.2. All applicable material safety data sheets (MSDS) shall be provided and stored in an accessible location.

9. Kinematics/Supports

9.1. The Particle Injector shall be supported by a 3-axis motion stage as shown on Figure 1.

10. Alignment/Fiducialization

10.1. The long axis of the particle injector shall be aligned to the Y-axis to within ±1 degree in pitch and yaw.

> The orientation of the long axis of the particle injector will be fully dictated by the interface to the 6” CF flange on top of the CXI Sample Chambers. The ±1 degree accuracy requirement of the pitch and yaw of the Particle Injector shall be achieved with machining tolerances on the Particle Injector and the Sample Chambers.

10.2. There is no requirement on the roll angle of the long axis of the Particle Injector.

11. Particle Injector Positioning Requirements

11.1. The particle beam shall travel in the –Y direction. The injection shall be from above the interaction region with the particles travelling down.

This solution is imposed by the presence of the beamline traveling top Hutch 6 on the South side of CXI beamline and the requirement for easy access to the internal components of the CXI Sample Chambers which places a large door on the North side of the Sample Chambers.

11.2. It shall be possible to position the particle beam in the X and Z directions over a range of at least 10 mm with the center of travel centered on the designed interaction region in the sample chamber to within 0.5 mm.

11.3. The particle injector shall be reentrant into the CXI Sample Chambers with the Y position motorized as described in Table 1.

The previous two requirements will be achieved with the 3-axis motion stage which will have at a minimum the motorized motions listed in Table 1.

11.4. It shall also be possible to bring the lens stack nozzle of the particle injector into the interaction region inside the Sample Chambers.

This will allow for a rough alignment of the injector with the LCLS beam. Some of the components inside the Sample Chambers will have to be moved for this to occur. The reentrant part of the injector will have to be extended from the current prototype to achieve this.

Motion	Nom. Position	Range	Resolution	Repeatability	Stability
X	0 mm	-5 mm < x < 5 mm	10 µm	10 µm	1 µm (10 µm)
Z	0 mm	-5 mm < y < 5 mm	10 µm	10 µm	1 µm (10 µm)
Y	0 mm	0 mm < x < 150 mm	10 µm	10 µm	1 µm (10 µm)

Table 1: Positioning resolution, stability and repeatability requirements for the particle injector. The stability requirement is for short term (a few minutes) and the number in parentheses is for long-term (12 hours). Both stability numbers refer to stability with respect to the focal spot of the LCLS beam inside the CXI Sample Chambers.

12. Aerosol Generator and Diagnostics Positioning Requirements

12.1. The distance between the aerosol generators, as well as the aerosol diagnostics, and the inlet of the differential pumping interface (the particle injector) shall be minimized to reduce the loss of particles in the aerosol transport tubing.

This shall be achieved with a moveable equipment platform at a height near the top of the Sample Chambers which will support all the aerosol generators and aerosol diagnostics devices. This platform shall be on wheels to allow it to be retracted away when the aerosol devices are not in use. The base of the platform shall be placed on the South side of the beamline transporting the beam to Hutch 6, holding the devices above the beamline to Hutch 6. The platform shall be stored on the South side of the Hutch when not in use.

12.2. The design goal shall be to have the aerosol generators located less than 30 cm from the inlet of the particle injector.

12.3. An enclosure covering the platform may need to be provided for safety reasons for certain types of aerosol.

This enclosure will be connected to the hutch exhaust system in order to prevent the aerosolized particles from entering the hutch environment, if required by for certain samples. A 10" diameter flexible hose is envisioned for the exhaust system and it will be connected to a hole in the side of the enclosure.

13. Aerosol Generation Requirements

13.1. The Particle Injector System shall allow for the aerosolization of a variety of samples including particles in solution and powders.

13.2. The aerosol generation system shall be compatible with organic and inorganic samples, as well as amorphous and nano-crystalline samples.

13.3. The aerosol generation system shall be compatible with particles in the size range of 10-1000nm.

Commercial devices will be used to create to aerosol. These devices will include the following

- Electrospray Aerosol Generator
- Fluidized Bed Aerosol Generator
- Constant Ouput Atomizer

13.4. It shall be possible to neutralize the aerosol particles after the creation of the aerosol. This will be achieved using an ionized bath gas produced with a radioactive source, typically Po210.

The commercial Electropray Aerosol Generator includes a mounting fixture for a commercially available Po210 source specifically made to fit in the system. Special safety requirements apply for the Po210 source and these requirements are found in Section 21.

Another commercial product, an Aerosol Neutralizer will also be provided for use with any other aerosol generator.

13.5. It shall be possible, with future upgrades, to select particles based on their chemical composition and size before they are aerosolized.

13.6. The system shall allow for the future integration of any user supplied aerosol generation device.

> The aerodynamic lens system is a passive system and will transmit to vacuum any aerosol suspension. There is nothing in the system preventing a user to supply a system which can select the particles based on chemical composition or any other parameter before the aerosol is generated. This selected aerosol can be transmitted to vacuum like any other aerosol, regardless of how it was created.

14. Aerosol Diagnostics Requirements

14.1. It shall be possible to select particles within a narrow size range from the aerosol suspension in the size range 10-1000nm.

> A commercially available Electrostatic Classifier with two Differential Mobility Analyzers will be provided to fulfill this requirement. Due to the large particle size range, two Differential Mobility Analyzers, a short and a long one, will be provided.

14.2. There shall be a diagnostic device capable of measuring the size distribution of the aerosol in the size range 10-1000nm.

> This will be achieved with the Electrostatic Classifier and the Differential Mobility Analyzers.

14.3. There shall be a diagnostic device capable of measuring the aerosol concentration at atmospheric pressure.

> This will be achieved with a commercially available Condensation Particle Counter.

14.4. It shall be possible to sample the aerosol onto a suitable substrate for offline characterization.

> This will be achieved using a commercially available Nanometer Aerosol Sampler.
>
> Users will provide their own substrates.

15. Particle Transfer to Vacuum Requirements

15.1. All aerosol transfer lines shall be kept as short as possible by positioning the aerosol generation devices and the aerosol diagnostic devices as close as possible to the particle injector inlet.

> They will all be located on top of the moveable equipment platform.

15.2. It shall be possible to remove the moisture from the aerosol suspension before it enters the differential pumping interface.

> This will be achieved using a commercially available Filtered Air Supply and a Diffusion Dryer.

16. Particle Beam Diagnostics Requirements

Charge Detectors

Charge Detectors will be used to detect single charged particles as described in Section 4.11. The following are the requirements for the Charge Detectors.

16.1. The Charge Detectors shall be capable of detecting particles with as few as 500 electron charges.

16.2. The Charge Detectors shall measure the charge of the particles with an accuracy of 100 electrons.

> The previous two requirements will be achieved with low noise electronics and properly shielded wires and cables. The design of the Charge Detector is shown on Figure 9. It includes a conductive Pick-Up Tube, supported inside a housing and well insulated.

16.3. The Charge Detectors shall measure the velocity of the particles with an accuracy of 10 m/s.

> The particle velocity is expected to be on the order of 200 m/s. The required accuracy will be achieved with fast digitization of the electronic signal from the charge detector.

16.4. The first Charge Detector and its associated in-vacuum electronics shall be attached directly to the exit nozzle of the particle injector.

16.5. The first Charge Detector and its in-vacuum electronics shall be designed in a way that allows the entire assembly to pass through the 6” CF flange for the particle injector. This will allow the entire injector and Charge Detector assembly to be removed without disassembly.

16.6. The signal cable(s) or wire(s) feedthroughs of the first Charge Detector shall be included in the particle injector assembly so that no wire or cable needs to be disconnected in order to remove the particle injector and the first Charge Detector assembly.

> This will be achieved by routing the wires between the large cylinder of the third differential pumping stage and the smaller cylinder of the aerodynamic lens. A feedthrough connector will be located near the entrance of the aerodynamic lens.

16.7. The first charge detector assembly shall be removable to enable experiments requiring close approach of the ext nozzle to the interaction region. The first charge detector may also act as the exit nozzle.

16.8. The positioning requirements for the second Charge Detector are found in the PRDs for the 1 micron and 0.1 micron sample chambers ((PRD# SP-391-001-41 and PRD# SP-391-000-20 respectively). This second Charge Detector is completely independent of the particle injector assembly.

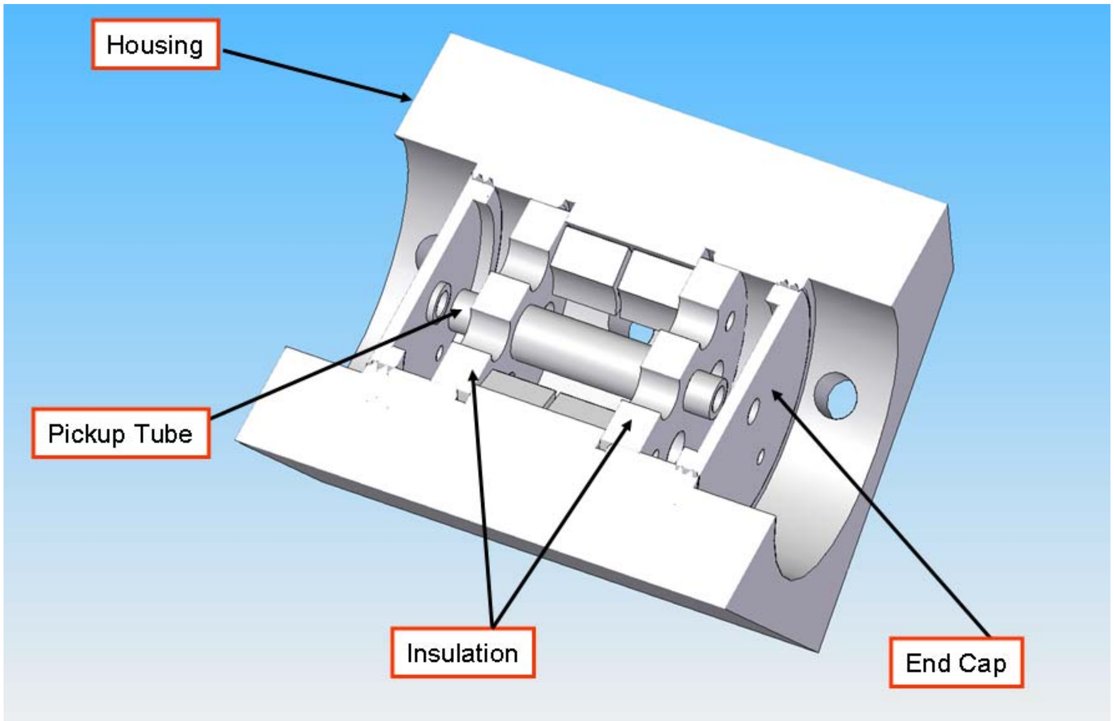

Figure 9: Cross-section of the charge detector design.

Particle Beam Viewer

A particle beam viewer shall also be implemented to characterize the beam profile and position. The following requirements apply to this particle beam viewer.

16.9. A low power unfocused laser beam with a roughly 1 cm diameter shall counter-propagate with the particle beam.

This means this laser beam shall travel in the +Y direction and be inserted into the vacuum through the bottom of the CXI Sample Chambers.

16.10. The light scattered by this laser beam shall be focused onto a CCD located outside the sample chamber.

The sample viewer described in the CXI Sample Chamber PRDs (SP 391-000-20 and SP 391-000-141) will be used for this since it is ideal for viewing the particle beam on the LCLS axis.

16.11. A second achromatic lens and CCD shall view the particle beam perpendicular to both the particle beam and the LCLS beam.

This requires a port on the Sample Chamber that would be located either in the +X or –X direction, or close to those directions. A port will be implemented on the –X side of the Sample Chamber for this purpose. This port will not be exactly in the XY plane but only a few degrees away, which will provide an acceptable view of the particle beam.

17. Vacuum Requirements

17.1. The particle beam focus described in Requirement 2.2 shall be achieved with an aerodynamic lens focusing system and a differential pumping interface, as shown on Figure 2 and Figure 3.

17.2. There shall be 3 stages in the differential pumping interface.

17.3. The first stage shall allow for a pressure range of 1 to 30 Torr.

17.4. The second stage shall allow for a pressure range of 0.001 to 1 Torr.

17.5. The third stage shall allow for a pressure range of 10^{-5} to 10^{-3} Torr.

> The three stages are described in Section 4.2. Two roughing pumps will be used evacuate the first two differential pumping stages and a small turbo pump (4.5" CF 70 l/s) shall be used to achieve the low pressure in the third differential pumping stage, as shown on Figure 3 and Figure 10. The same roughing pump used to evacuate the second differential pumping stage will be used to back the turbo pump.

17.6. There shall be the possibility of remotely adjusting the pressure in each stage to achieve focusing of particles of the desired size.

> This will be achieved using remotely controlled valves to restrict the conductance to the vacuum pumps.

17.7. All lubricants, cutting fluids, etc., used in manufacturing shall be "sulfur-free". SLAC document No. SC-700-866-47 is a compendium of SLAC approved lubricants. The use of sanding discs, abrasive paper or grinding wheels is typically prohibited. In special circumstances good vacuum practices should be followed when grinding and polishing is required. This process shall be reviewed and approved by the engineer for its vacuum compatibility.

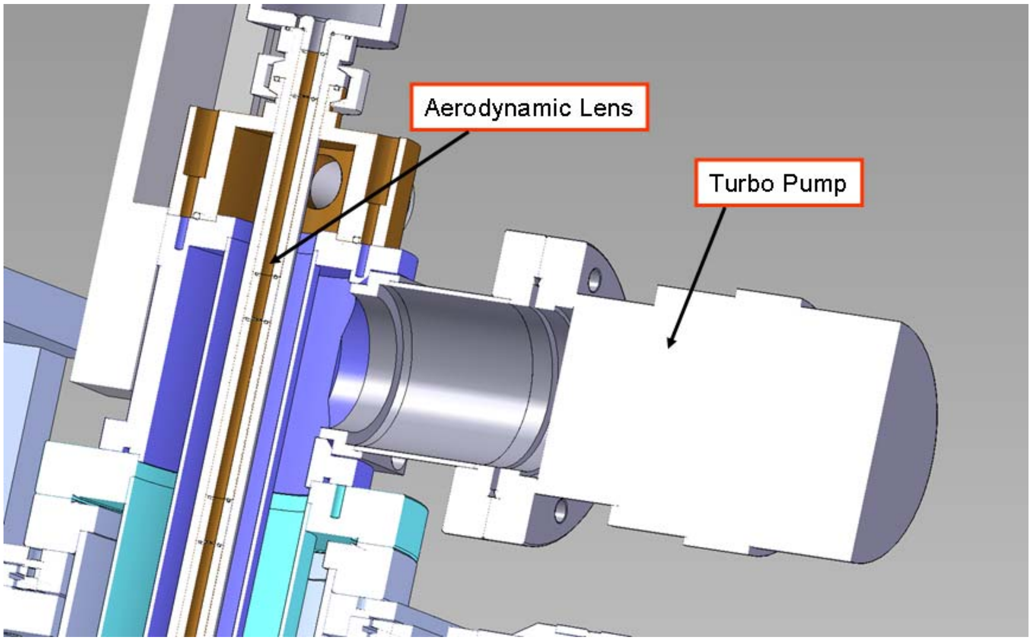

Figure 10: Cross-section of turbo pump connection to the particle injector.

17.8. All parts and subassemblies shall be cleaned for UHV. Once parts are cleaned for vacuum, handle only with clean latex or nitrile gloves in/on a clean room/surface. This includes all subassemblies. For storage or transportation, place in clean sealed vacuum grade plastic bag that has been back-filled with nitrogen.

18. Electrical Requirements

18.1. The electronic components associated with the charge detectors are very low noise devices and all rack mounted electronics for the charge detectors shall be mounted away from high noise electronics inside the racks. Preferably, they should be shielded from all possible electronic interference in the racks.

18.2. Acquisition of unique, device specific controllers, when required, will be the responsibility of CXI; all other power supplies and control cables shall be provided by the Controls/Data Acquisition Group.

18.3. The interface from the control racks to the Particle Injector System (cable trays and routing, connector supports, etc.) will be determined jointly with the Controls/Data Acquisition Group.

18.4. To comply with OSHA/DOE regulations, all electronics will have certification either through a National Recognized Testing Laboratory (NRTL) or the Authority Having Jurisdiction (AHJ) as per the SLAC Electrical Equipment Inspection Program

19. Controls Requirements

The controls and data acquisition associated with the Particle Injector System shall be consistent with the requirements outlined in the documents PRD SP-391-000-03, *Physics Requirements for the LUSI Controls and Data System* and PRD SP-391-000-06, *Physics Requirements for the LUSI Data Management. Requirements* specific to the Particle Injector System are described below.

19.1. Some commercial devices for aerosol generation and diagnostics at atmospheric pressure will be required. All of these devices shall be fully controlled remotely via the instrument control system. No manual knobs or controls are to be allowed. If the commercial devices contain manual controls, they shall be modified accordingly for remote control.

19.2. Every axis of motion of the particle injector shall be motorized and controlled remotely via the instrument control system.

19.3. The position of every actuator shall be recorded in the scientific metadata for every LCLS pulse for which scientific data is recorded.

19.4. It shall be possible to record every parameter of the aerosol generation and diagnostics devices in the scientific metadata for every LCLS pulse for which scientific data is recorded.

19.5. The users of the instrument shall select from a list of parameters which ones they wish to record in the metadata for a given run.

19.6. Every controlled parameter included in the list that can be saved shall also be displayed on the control station at the request of the users with a refresh rate of 1 Hz.

19.7. The pressure in each differential pumping stage shall be monitored and controlled remotely via the instrument control system.

19.8. The remote valve position controlling the first differential pumping stage shall be logged to enable identification of skimmer clogging.

19.9. It shall be possible to scan any parameter controlled by the instrument control system and record the signal at each point of the scan for any "detector" including but not limited to the following: charge detector rate counters (see Section 20), Ion TOF hit rate counter (see PRD SP-391-000-30) and a Faraday cup current.

19.10. Software interlocks shall be implemented to prevent the injector nozzle from moving too close to the LCLS beam when other devices inside the Sample Chambers are present. These software limits shall be variable depending on the details of the configuration inside the chambers. The limits shall be user-modifiable with password protection.

20. Data Acquisition Requirements

The particle injector itself has no data acquisition requirements. However the charge detectors do have requirements related to data acquisition.

20.1. The image charge pulse on the charge detector pickup tube shall be amplified, differentiated, digitized and recorded with a time resolution of 100 ns.

> An example of the signal expected from the charge detector is shown on Figure 11. This is the type of signal that will need to be amplified and differentiated.

20.2. There shall be a trigger level set the rising edge of the differentiated pulse to trigger the recording of the pulse.

> This threshold is shown on Figure 11.

20.3. Each pulse shall be digitized and recorded with 2000 sampling points per pulse.

> An Acquiris digitizer, approved by the LUSI Controls Group shall be used. Each pulse is expected to last roughly 100 ms, therefore the digitizer shall be capable of operating at least at 100 kHz.

20.4. The digitized waveforms shall be displayed on the instrument console at a rate of 5 Hz when desired by the users.

> If the trigger rate is higher than 5 Hz, then only a fraction of the detected pulses will be displayed.

20.5. The average waveform shall be updated at a rate of 5 Hz and reset at the discretion of the users.

> There shall be a reset button for the charge detector average waveform that when pressed by the user will clear the average waveform from memory and start displaying the average from the moment the button was pressed.

20.6. It shall be possible to record each individual pulse coming from single particles passing through the charge detector or to record an average trace over multiple particles, with this number set by the users via the instrument control system.

20.7. There shall be a charge detector rate counter which shall measure the number of detected particles (number of the times the trigger is activated) every second. This counter shall reset every second.

20.8. The charge detector rate shall be displayed on the instrument control console at a rate of 1 Hz.

> A box on the instrument control panel shall display the instantaneous count rate in particles/sec.

20.9. The charge detector rate shall be recorded in the experimental metadata if desired by the users.

20.10. The pulse height of each pulse and the time between the 2 peaks of the differentiated pulse shall be calculated for each triggered pulse.

20.11. The pulse height and time duration shall be displayed at a rate of 5 Hz, along with the displayed waveform discussed in Requirement 20.4.

20.12. The average pulse height and time duration shall be displayed at a rate of 5 Hz and reset when desired by the users.

20.13. The average pulse height and duration shall be recorded in the instrument metadata if desired by the users.

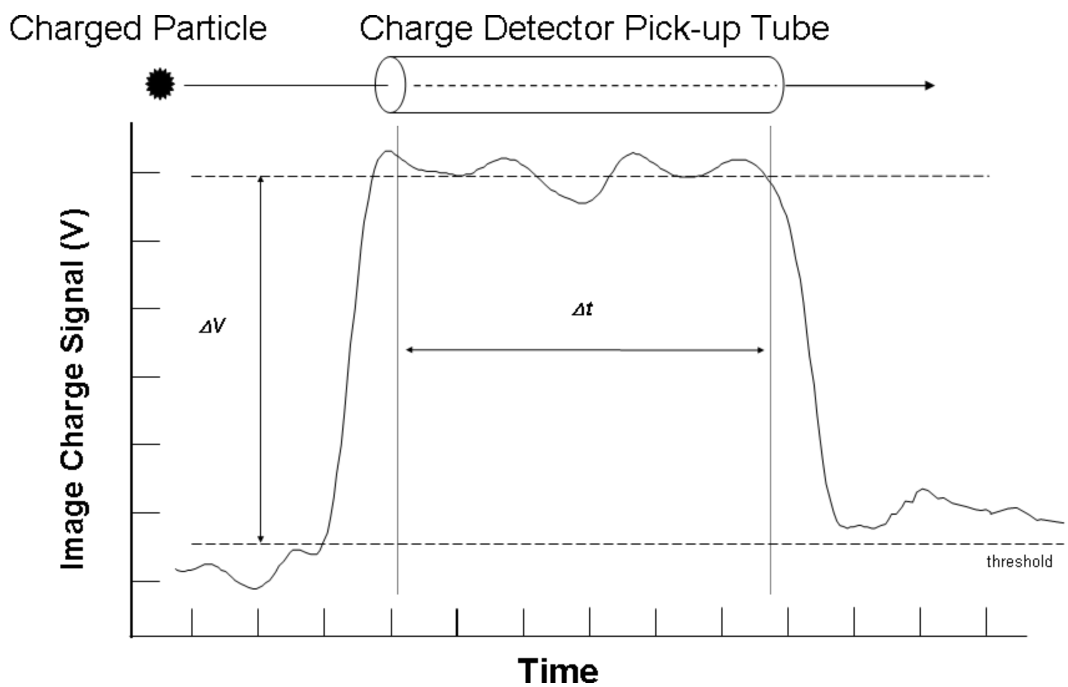

Figure 11: Example of the signal expected when a charged particle passes through the Pick-up Tube of the charge detector.

21. Environmental Safety and Health Requirements

21.1. Earthquake

SLAC National Accelerator Laboratory (SLAC) is situated in an active seismic zone. All hardware exceeding a weight of 400 Lbs. and / or mounted greater than 4 feet above the floor will be reviewed by a SLAC "citizen safety committee" for seismic loading resistance. Applicable loads and structural behavior will be evaluated for compliance to the 2007 version of the California Building Code (CBC) and SLAC ES&H Division document SLAC-I-720-0A24E-001-R002: "Seismic Design Specification for Buildings, Structures, Equipment, and Systems".

21.2. Radiation Physics

No supplemental X-ray radiation shielding will be required for the Detector Stage since it shall be located in a radiation hutch.

There will be safety issues related to the use of a Po210 source to neutralize the aerosol. This source will be fully enclosed within the aerosol generation instrument and requires a special tool for access. Hazards will exist when removing or replacing the source. All the necessary safety steps related to the use of such a radioactive source shall be followed, including but not limited to

- Wearing gloves when handling the source
- Only removing the source when necessary
- Replace the source biannually, or earlier
- Use a proper enclosed storage when the source is not in use
- Corrosive materials can degrade the integrity of the unit. Do not use chemicals that corrode 303, 304, or 316 stainless steel, copper, silver, braze or epoxy
- Only GERT trained personnel shall be allowed to handle the source

21.3. Pressure Vessel/Vacuum Vessel

The particle injector shall be designed for use in a High Vacuum environment with the appropriate safety factors.

Pressure relief safe guards will be provided, where appropriate, to ensure compliance with all applicable guidelines/regulations, i.e. 10CFR851.

21.4. Aerosol Inhalation and Ingestion

The aerosol generation equipment used with the Particle Injector will create an atmospheric suspension of nanomaterial that could be smaller than 100 nm. Some safety hazards are associated with inhalation, dermal contact and ingestion of such nanomaterials. The users of the system shall

- Follow the guidelines of the SLAC Nanomaterial Safety Plan
- Attempt to work with lowest risk level of nanomaterials at all times:
    - Low-risk level (green) – bound or fixed nanostructures
        - Solid materials with imbedded nanostructures
        - Solid nanomaterials with nanostructures fixed to the material's surface
    - Medium-risk level (yellow)
        - Nanoparticles suspended in liquids
    - High-risk level (red)
        - Dry, dispersible nanoparticles, nanoparticle agglomerates/ aggregates
        - Nanomaterials determined to be high risk based on safety assessment (see Section 3.1.3, "Safety Assessment")
- All work with high-risk level nanomaterials shall be reviewed and approved by the Nanomaterials Safety Committee
- All work with medium risk level nanomaterials shall be performed with quantities <100ml
- Avoid handling nanomaterials in the open air in a free particle state. Whenever possible, handle and store dispersible nanomaterials, whether suspended in liquids or in a dry particle form in closed (tightly sealed) containers.
- Clean up dry engineered nanomaterials with wet wiping
- Transfer nanomaterial samples between workstations in closed labeled containers (microcentrifuge tubes)
- Read the Nanomaterial Safety Plan of the ES&H manual (exhibit, Chapter 40)
- Complete ES&H course on Nanomaterials Orientation and Laboratory Safety Training