Georgia Institute of Technology

Office of Radiological Safety
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Atlanta, Georgia 30332-0425
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December 19, 2007

Dwayne Blaylock
Research Engineer II
NRE 0425

Dear Mr. Blaylock:

The Georgia Tech Radiation Safety Committee, at it's December 17, 2007 meeting, approved your application for radiation producing equipment titled, "Mark 3 IEC Fusion Reactor." A copy of the approved Form A is attached.

This approval letter and a copy of the signed FORM A should be placed in your Radiation Safety Laboratory Notebook so as to be readily accessible to users, auditors, and inspectors.

Sincerely,

Nazia Zakir, M.S.
Radiation Safety Officer

NZ / snr

Attachment: FORM A (Radiation Producing Equipment)

Form A
Application for Authorized User (AU) Status for Acquisition and Use of Radiation Producing Equipment

1. Applicant Information (Attach résumé that substantiates experience working with radiation producing equipment.)

Last Name: Blaylock **First Name:** Dwayne **Date:** 10/01/07

Title: Research Engineer II **Email Address:** [redacted]

Department: NRE **Dept. Mail Code:** [redacted]

Office: Building: Neely Room: [redacted] Phone: [redacted]

Equip. Location: Building: Neely Room: [redacted] Phone: [redacted]

2. Project Information

Title: Mark 3 IEC fusion reactor

No. of Persons Working on Project: 25 (Submit a completed Form B, Radiation Worker Registration Form, for each person)

3. Equipment Specifications

Type: (X-Ray Diffractometer, Electron Microscope, etc.) Inertial electrostatic confinement fusion reactor

Manufacturer: Andrew Seltzman, (In House) **Model:** Mark 3

Serial Number: NA

Max. Voltage: 100kV **Operating Voltage:** 50kV

Max. Current: 30mA **Operating Current:** 15mA

Anticipated Workload: (Average number of hours per week that unit will be used) 2

4. Description: Provide a brief abstract of the experiment to be performed, including its purpose and/or objectives.

See attached

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5. **Security:** Specify how the equipment will be secured from unauthorized use and theft. Specify how equipment keys and/or passwords will be controlled.

The reactor will be stored and operated in the locked gate area of room 167 in the Neely buildings radiation controlled zone. The control computer will be password protected and removed when not in operation thereby preventing unauthorized use.

6. **Procedures:** (Note: Use additional sheets as necessary. Append references.)

a. Specify standard operating procedure for using equipment, including specimen installation and removal.

See attached SOP.

b. Specify emergency procedures to be used. Attach a copy of Emergency Procedures poster to be used.

Reactor operator and control computer will monitor radiation output and electrical parameters.

In case of electrical arc over on high voltage system reactor will automatically scram.

In case of other malfunction, manual scram will shut down reactor power.

Neutron radiation levels above 90mrem/h at reactor surface will cause system to automatically de-energize.

See attached emergency shutdown procedure in SOP.

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7. **Radiological Safety:** Describe the shielding of the unit and the room, the shutter and interlock controls, the beam intercept, etc. used to minimize personnel exposure.

Primary x-ray shielding will be provided by the 1/8" thick stainless steel shell of the reactor core, and will be augmented with lead foil if deemed necessary to reduce emission levels below required levels. Additionally, view ports and ceramic feedthroughs will be permanently shielded with lead foil to prevent x-ray exposure. Neutron radiation exposure will be minimized through distance and concrete blocks placed in between operator and reactor. The operator will use a real time neutron EPD to monitor any neutron dose.

8. **Radiation Surveys:** What instruments are available to be used for checking radiation levels? Describe the method and frequency of performing radiation surveys.

Ludlum model 2 with 44-9 pancake probe, Ludlum model 12 with Nancy Wood G-10-2A boron trifloride neutron detector BTI fast neutron bubble dosimeter (BT-BND), 30 bubbles/mrem sensitivity and additional radiation detection equipment provided by ORS. ORS will conduct an initial survey for the reactor and at intervals during runs. Surveys will be conducted at all possible leakage points and through shell casing every 5kV above 20kV. The operator will monitor neutron production on Labview.

9. **Operator Training:** State how and by whom operators will be trained in using radiation producing equipment. Specify how this training will be documented.

Radiation safety training will be provided by Georgia Tech as part of the Form RS-4b requirements.
Operator will also take RAM training and RCZ access training.

10. **Logbook:** State what information and data will be kept in the logbook.

Computer system will automatically log operating parameters including: Operating time, neutron output, accelerating grid voltage and current, ion injector extraction voltage and current, relevant temperature readings, and additional data as required by experiments to be preformed.
Additional radiation survey data will also be recorded.

Form A

Application for Authorized User (AU) Status for Acquisition and Use of Radiation Producing Equipment

In making application for Authorized User status, I acknowledge that I have reviewed the State of Georgia regulations, Georgia Tech Radiation Safety Policy Manual, and Office of Radiological Safety Procedure 9502 "Control and Accountability of Radiation Generating Equipment" and agree to adhere to these rules and regulations.

Signature: [signature] **Date:** 10/1/07

Comments and/or Amended Conditions:

1. Interim approval until Dec. 31, 2007.
2. HP and AU will be present during initial runs and intermittently through progressive runs.

Office of Radiological Safety Review and Approval

Nazia Zbi[signature]
Radiation Safety Officer

Date: 12/17/07

Radiation Safety Committee Review and Approval

[signature]
Chairman, Radiation Safety Committee

Date: 12-17-07

Interim Approval until Dec 31, 2007
Nazia Zbi[signature] RSO, 10/3/07

Chairperson RSC
[signature] 10/3/07

Standard Operating Procedure
Mark3 IEC fusion reactor

Reactor Prestart

1. Connect control computer to USB port and run Labview VI
2. Verify that "Grid HV" and "Ion HV" interlock switches are in the OFF position and that switch guards are down.
3. Verify that "Backing pump", "Turbo pump", and "Reactor cooling" switches are in the OFF position.
4. Release SCRAM switch on reactor front panel.
5. Turn rotary power switch from OFF to BPH (baritron preheat) and wait for baritron to reach operating temperature (If equipped with temperature stabilized baritron transducer).
6. Turn rotary power switch to on.
7. Initialize Labview VI to connect to reactor control boards.
8. Close reactor core atmospheric vent valve.
9. Set Labview throttle valve control to "Manual" and 100% or set to "Auto" and enter target pressure.
10. Open roughing valve (if equipped) and turbo pump fore line valve.
11. Activate backing pump.
12. When pressure is below 100mTorr as measured on reactor core baritron of convection gauge, activate turbo pump.

Fuel loading

1. Confirm that both the deuterium supply needle valve and the deuterium fill valve are closed.
2. Confirm that dryrite in drying column remains capable of absorbing heavy water vapor from the electrolyzer (blue color not red).
3. Fill the electrolyzer reservoir in the fuel converter module with electrolyte saturated heavy water.
4. Turn on electrolyzer power.
5. Open deuterium reserve tank evacuation valve.
6. Open deuterium fill valve.
7. Open deuterium supply needle valve until a small amount of deuterium is flowing through the fuel converter unit and reserve tanks.
8. Purge tanks and fuel converter with deuterium until sufficiently clear of air.
9. Close deuterium reserve tank evacuation valve.
10. Monitor reserve pressure with tank baratron / convectron until it reaches atmospheric pressure (At this point deuterium production will stop automatically until tank pressure drops below atmospheric).

Reactor power up to standby

1. Activate reactor cooling system with front panel switch.
2. Verify grid cooling loop has reached operating temperature.
3. Activate deuterium fuel flow from manual metering valve or Labview VI.
4. Turn on ion extractor power supply front panel switch.

5. Verify ion extractor supply control is set to remote.
6. Turn on Ludlum 12 neutron detector and activate logic pulse output by setting speaker switch to on.
7. Activate neutron flux monitoring in Labview and verify connection to neutron detector counter by toggling rotary switch on Ludlum counter between "Batt" and "1000x" several times to produce output pulses.
8. Turn on Hitek 3000 ion injector HV power supply
9. Set power supply control to remote.
10. Remove grounding connection from the grid HV supply output.
11. Connect grid supply to power mains.

Reactor operation

1. Turn on ECRF drive amplifier from Labview.
2. Activate ECRF injector RF ionization from Labview VI and set RF power above minimum critical power to sustain ionization.
3. Verify RF power is absorbed in injector cavity by monitoring reflected RF power in Labview.
4. Turn on Ion HV switch enabling ion injector extractor potential supply.
5. Turn on Grid HV switch enabling acceleration potential supply.
6. Exit and close safety cage.
7. Activate remote HV enable switch.
8. Activate Grid and Ion HV supplies in Labview.
9. Adjust ion injector and grid potentials to obtain desired neutron output.

Reactor Shutdown

1. Set Grid HV and Ion HV to 0V in Labview.
2. Deactivate Grid and Ion HV supplies in Labview.
3. De-activate remote HV enable switch.
4. Shut down ECRF drive amplifier.
5. Shut down fuel flow.
6. Open and enter safety cage.
7. Turn off Grid HV switch.
8. Turn off Ion HV switch.
9. Turn off Ion HV supply.
10. Disconnect grid supply to power mains.
11. Connect grounding connection from the grid HV supply output.
12. Close deuterium fill and supply valves.
13. Shutdown turbo pump.
14. Valve off reactor core.
15. After turbo pump has stopped, shut down backing pump and vent vacuum pumping system to atmospheric.
16. Turn rotary power switch to off and press the scram button on front panel.
17. Remove and cap heavy water tube.

Emergency Shutdown

The following actions will De-energizes HV supplies.

- Hit remote scram button at reactor control station.
- Click scram button on Labview interface.
- Open safety cage.

After any manually triggered scram due to radiation leakage or HV supply failure, all of the above should be implemented. Additionally the following actions should be preformed to ensure electrical safety:

1. Set Grid HV and Ion HV to 0V in Labview.
2. Deactivate Grid and Ion HV supplies in Labview.
3. De-activate remote HV enable switch.
4. Turn off Grid HV switch.
5. Turn off Ion HV switch.
6. Turn off Ion HV supply.
7. Disconnect grid supply to power mains.
8. Connect grounding connection from the grid HV supply output.

Mark 3 IEC Fusion Reactor Proposal

Inertial Electrostatic Confinement (IEC) is a unique fusion reactor concept in which deuterium ions are electrostatically accelerated in a spherically convergent manner and subsequently inertially confined by their momentum as they collide at a focal point resulting in their fusion. IEC fusion was initially developed by Philo T. Farnsworth in the 1960's utilizing the RF fields for ion acceleration and later modified by Dr. Robert Hirsch and Gene Meeks allowing for ion acceleration with electrostatic fields by the use of a spherical ion accelerating grid.

A Hirsch-Meeks type IEC fusion reactor typically consists of a spherical inner grid that is held at a negative potential in the order of 100kV and surrounded by a grounded spherical vacuum envelope. Traditionally in the simplest of the Hirsch-Meeks designs, the inner grid emits electrons that are electrostatically accelerated towards the vacuum envelope subsequently ionizing neutral deuterium atoms in the reactor. The ionized deuterium is then accelerated towards the center grid by the electrostatic field. Since the projected area of the grid only occupied a small solid angle, the majority of the accelerated ions pass through the grid structure and collide at a focal point where the fusion takes place.

Since earnshaw's theorem forbids the creation of a potential minimum in free space, it is not possible to electrostatically confine the deuterium ions at the focal point, however they may be inertially confined by their momentum once they pass the surface of the accelerating grid. In the limit where the accelerating grid is much smaller then the vacuum envelope, the monopole term of the multipole expansion is dominant, and the electrostatic field closely approximates a spherically symmetric source over the majority of the acceleration path of a given ion, generating a sharp focus and increasing plasma density limited only by space charge repulsion, thereby leading to a large fusion rate. In this manner a spherical source can be well approximated by an accelerating grid constructed out of 3 perpendicular rings if the aspect ratio of the grid diameter to the vacuum chamber diameter is small.

In a traditional IEC fusion reactor the maximum input potential to the central grid, and therefore the maximum fusion rate of the reactor, is limited by grid heating and a condition called thermionic runaway. Above a certain input power threshold and neutral species pressure within the reactor, any increase in grid temperature by ion bombardment increases the grids thermionic electron emission rate leading to greater neutral ionization rates within the reactor, continuously increasing ion bombardment heating until the grid melts. The central grid of an IEC fusion device may still melt even if a thermionic runaway does not occur, if ion bombardment heating can raise the grid temperature above its melting point. Further, ion bombardment heating causes increased sputtering and sublimation rates, leading to plasma impurities, grid erosion, and metal deposition on critical components such as ceramic feedthroughs, insulators and view ports. Further, thermionicaly emitted electrons are accelerated outward and collide with the vacuum envelope generating a significant amount of bremsstrahlung x-rays capable of damaging CCD cameras and requiring shielding when operating at higher acceleration potentials.

Several conventional approaches currently exist to address melting of the central grid, including the use of high melting point refractory metals such as tungsten for grid construction. While designing a reactor with these modifications does permit the central grid to withstand ion bombardment, these solutions create further problems that contribute significant energy losses and decrease neutron production efficiency.

The construction of a grid with a refractory material allows the grid to operate at higher temperatures increasing the radiative heat dissipation rate by the Planck's law, however the higher operating temperature also increases the thermionic electron emission rate requiring a significant increase in power supply current greatly decreasing reactor efficiency.

It is therefore proposed that an IEC fusion reactor test bed, the "Mark 3" be constructed for the purpose of researching the application of an actively cooled grid design to significantly reduce both power draw and x-ray emission by virtually eliminating thermionic emission current from the central grid, thereby increasing reactor efficiency.

No previously constructed IEC fusion system has used an actively cooled grid for several reasons, primarily the contact of the cooling medium with the high voltage grid. This requires the entire primary cooling loop to float at grid potential, often as high as 100kv, or the use of a non-conducting cooling medium. Further this requires the use of a high voltage dual liquid feed through, a component not commonly manufactured.

The implementation of an actively cooled grid system will significantly increase operation power and boost neutron fluxes by allowing higher input voltages. Further, by reducing thermionic emission by cooling the central grid, a lower current, higher voltage power supply can be used, increasing ion energies and reducing construction cost. The decrease in thermionic emission will virtually eliminate the generation of bremsstrahlung x-rays generated by the reactor reducing the amount of radiation shielding required.

It is further proposed to improve plasma energy and density by utilizing a set of 4 ion injectors to inject ionized deuterium beams into the reactor. A novel type of compact ion injector utilizing RF ionization at the electron cyclotron resonance will therefore be constructed to provide fuel for the reactor. The proposed ECRF injector design will differ from conventional ion injector design in the fact that the ECRF antenna coil will be biased at a high positive potential to provide the ion extraction field and surrounded by an axial ceramic insulation shroud, rather then the extractor cone being biased at a negative potential as in conventional designs. To conserve power and allow for a compact design the ion injector will be constructed with permanent magnets to provide the solenoidal field. It is anticipated that the ion injector will fit within a 2.75" conflate half nipple.

The deuterium beams emitted from the ion injectors will be focused through the open areas of the accelerating grid and aligned to collide at the focal point, resulting in a sharper plasma focus then in a reactor with passive ionization due to electron emission from the central grid. The use of ion injectors allows higher energy collisions by imparting additional energy above the electrostatic well potential of the grid to deuterium ions. Due the exponential dependence of the deuterium cross section on ion energy, any increase will significantly increase neutron output.

By implementing the above mentioned improvements to the IEC fusion reactor concept, it is anticipated that the resulting design will obtain higher neutron output levels and efficiencies then presently capable with conventional designs while.