MICROFOCUS X-RAY SOURCE PROJECT*

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ABSTRACT

At the Cornell High Energy Synchrotron Source (CHESS), scientists in all fields and from all over the world utilize the high powered x-rays generated by the synchrotron. The issue is that there is such a high demand for beam time that not every group gets to do all the experiments they want, especially if there are any failures in existing machinery. Therefore an outside source, not tied into the synchrotron, would be a benefit. For this summer program the task has been to design and build all required safety features for this x-ray source. These features include lead shielding, safety interlocks, radiation signs, personnel badges, and a shutter box. The source itself will be used in a variety of tasks, ranging from capillary testing to phase contrast imaging.

SOURCE INFORMATION

The source is the Nova600 Microfocus X-Ray Source from Oxford Instruments. The package includes the source, a controller unit, and a water chiller. The chiller is the K-O Concepts model LCR-Max. The controller is used to control the current and voltage of the source as well as insure all interlocks are being satisfied. It can also be hooked up to a computer by RS-232C for ease of use. The chiller keeps the source at an acceptable temperature by using water or some mixture of water and inhibited propylene glycol (IPG) or alcohol [1].

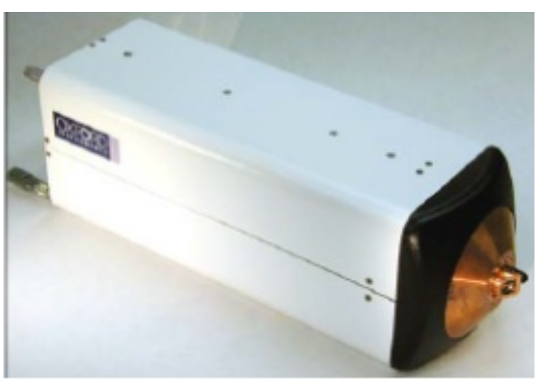

Figure 1: Nova600 Microfocus Source

Specifications

The source has a maximum voltage of 90 kV, a maximum power of 80 watts, and a maximum current of 2 mA. The tungsten target releases x-rays in a 60 degree cone, meaning a large portion of the shielding will receive hits from primary photons. For more information on the source specifications see table 1.

X-Ray Source Specifications	
Anode Current	.3 to 2 mA
Anode Voltage	10 to 90 kV
Maximum Power	80 W
Focal Spot Size	13 to 20 μm
Cone Angle	24.5°
Minimum Distance Focus/Object	4 mm
Target Angle/Viewing Angle	15/30°
Exit Window Diameter	9.50 mm
X-Ray Tube	Integrated/Sealed
Cooling Method	H_2O 0.15 L/min @ 15 psi
Target Material	Tungsten (W)
Window Material	Beryllium
Window Thickness	245 μm
Cathode Type	Dispenser Cathode
Window Position	End Window
Environment Temperature	+10° to +55° C
Operation	Continuous
Approximate Weight	10 kg
Control	RS-232 Null Modem Cable
Software	Allows control of Voltage, Power, and Focus
Settling Time	2 hrs

Table 1: Microfocus Source Specifications

SHIELDING CALCULATIONS

Unshielded Dose Rate

Between calculations and experiments run using existing hutches, it has been determined that the dose rate at the source is 1×10^6 mrem/hr. Keep in mind that the dose decreases with distance as an inverse square (see equation one).

$$D = \frac{kSEB\mu}{\rho 4\pi r^2} \quad (1)$$

*Works supported by the National Science Foundation

Shield Thickness

In order to protect all personnel from this high dose rate, shielding is required. The material used is lead because of its attenuation quality as well as its low cost of production. Due to the complexity of the shielding calculation, the simplest way to determine lead thickness is to use the program XOP. By inputting an energy range and shield thickness, the output will be a graph of photon energy versus percent transmission. The graph below is for 6mm thick lead (Figure 2). This is twice as thick as required by federal standards, but because the public will have access to the facility it is important to keep the radiation level below that of background radiation.

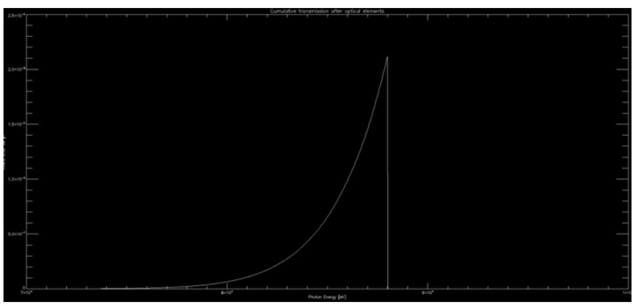

Figure 2: Photon Fluence vs Percent Transmission (XOP)

Shielded Dose Rate

The percent transmission for 6mm thick lead is $2x10^6$ %. This leads to a dose rate of 0.02 mrem/hr if the shield is directly against the source. Because the closest location an x-ray will strike the shield is about a meter away, the dose will be significantly less; well within that of background radiation.

Room Design

Shield Design

No matter how thick the lead is, it will not matter if there are any leaks in the wall, it must be a perfect dark room. The theory is simple; no direct lines of sight, the difficulty lies in the manufacturing. Any individual can build a room in which there are no gaps or cracks, but it takes work to make one with a constrained amount of material and available space. The simplest solutions to cracks are to overlap pieces or attach a piece to cover the crack. We decided a covering piece would be most appropriate, see figure 1.

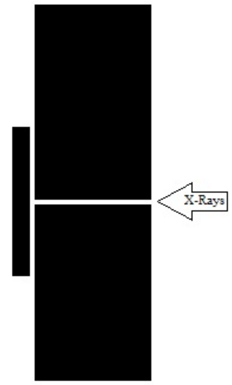

Figure 3: Gap Coverage

Where the roof meets the wall will be another gap, this time an additional slice of lead is not required though. By bending the top piece 90 degrees it can be used to cover the line at which the two lead sheets connect. Figure 4 illustrates this design.

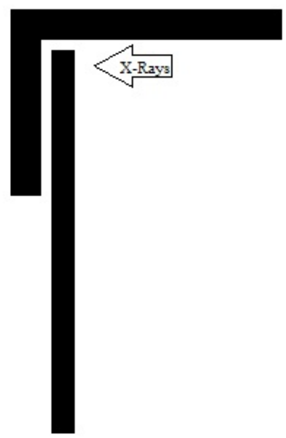

Figure 4: Overhang

Frame Design

The material chosen for framing is 80/20, commonly referred to as the industrial erector set. The reason for this choice is simple, the diversity of the available parts as wells as the many attachment points make realizing designs extremely easy. Figure 4 displays the general frame design. Because the beams are made through extrusion, they are very structurally sound. Even though the roofing beams are laid on their weak side (2,1instead of 1,2) the support provided by the columns and the wall, as well as the materials high ultimate tensile strength, will easily support the lead panels.

Figure 4: Framing

Windows

The lead paneling comes in 48 inch by 48 inch sheets. It is about a quarter inch thick with less than an eighth of an inch of aluminum on both sides to protect personnel from the potentially hazardous lead. Additionally, two windows will be installed so individuals on a tour or exhibition of the facilities can see the experiments being run inside the hutch. The windows will be half inch thick leaded glass, equivalent to one eighth inch lead. They have less attenuation value than the quarter inch thick lead panels. This is still acceptable because the closest window is about two meters from the source, so the dose rate is severely less.

Door

The door is always the weakest link in a sealed room because it is the only point that cannot be permanently sealed. The initial design called for a sliding door. This had potential because all the existing CHESS hutches use sliding doors, there is no moment arm to worry about, interlock buttons are easy to install, and it takes up no additional room. It was decided not to use one because it took the optimal space for the windows, it is significantly more difficult to put together, and the geometry of the room lends a hand towards a swinging door.

Figure 5 shows the doors placement, within the 45 degree segment of the wall. This location is perfect because it is directly behind the source, therefore only secondary x-rays will ever reach it. This is also the location at which all controls will be placed, so a user need only stand up and he or she will be at the entrance.

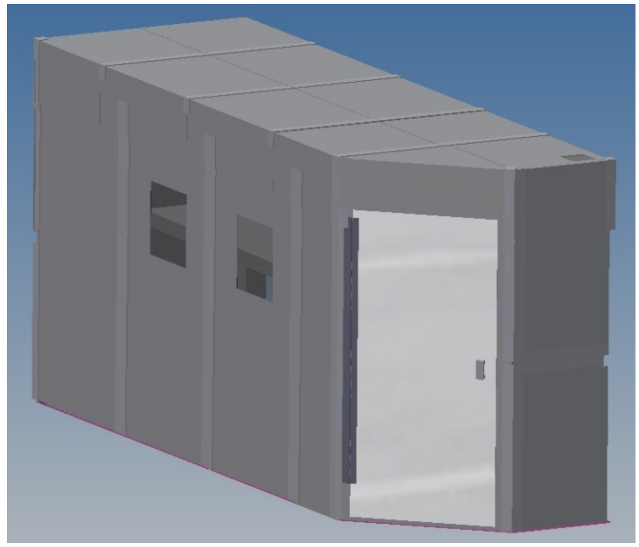

Figure 5: Windows and Door

Safety

Keys

The door to the hutch will be locked with a kirk key, which utilizes the method of trapped key interlocking. This is when there are two locks but only one key. In this case the door will have a lock and the power supply will have a lock, so the door cannot be unlocked while the power is on.

Shutter vs. Switch

A recurring issue for a while has been the sources warm up time: two hours [2]. This means there is a wait of two hours from when the source is turned on to when it can be used. This is not a major problem in itself, but every time it is turned off there is cooling that takes place, which means there is a wait once it is turned back on while it resumes the appropriate temperature. Because users will be entering the hutch throughout the day to manage their experiments, the x-rays will have to be controlled.

This can be accomplished in one of two ways; a shutter box or a high voltage switch. By placing the source in a lead shielded box with a tungsten shutter on it the source can stay on while only the shutter has to open and close. The high voltage switch completely turns off the x-rays while allowing the filament to stay on, preventing cooling from occurring. The switch is more attractive becomes it appears more streamlined, there are no mechanical pieces to worry about, but it was decided against. This is largely the fault of the company from which the source was purchased. In order to set up a high voltage control switch there is a lot of information about the circuits that is required, unfortunately the company has provided little to no assistance in that category. As such the solution is a shutter box.

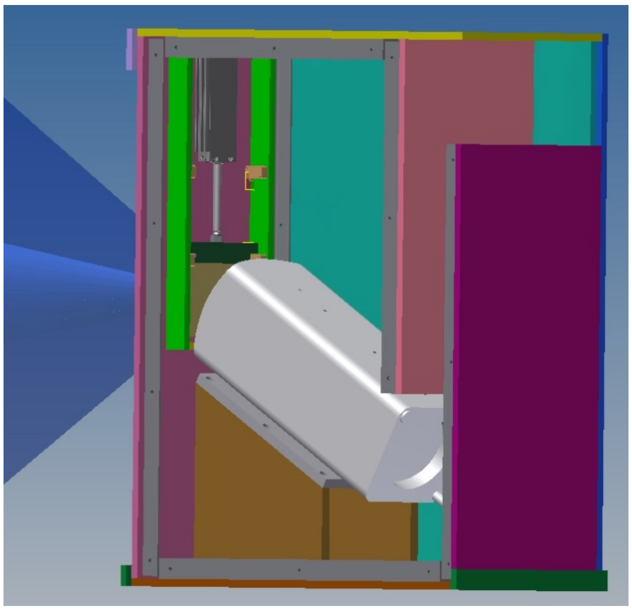

Figure 6: Shutterbox

Interlocks

Built into the controller are two interlocks; a thermal interlock and a door interlock. The thermal one is necessary because heat is the primary method from which the source can become damaged. So, if the temperature rises above 95 degrees Celsius or the flow rate drops below 0.1 liters per minute, the unit will automatically turn off.

The door interlock is designed for personnel safety; if the door is somehow opened the shutter will close to keep any individuals from being exposed to radiation. The mechanism is a small button that depresses when the door is shut. Additionally, if either interlock is tripped, the controller must be manually reset to open the shutter. Lighted display panels will be installed to show what parts of the interlock system are being met. The image below is a sketch of those panel designs; they also describe the interlock logic.

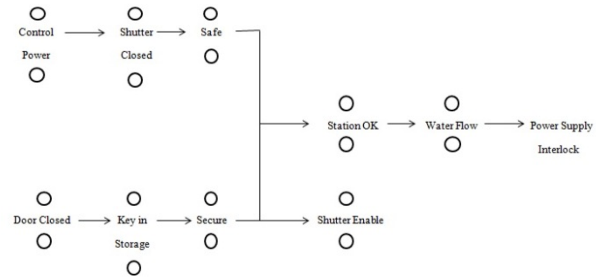

Figure 7: Shutter Logic

Miscellaneous Safety Features

On the access point to the hutch a sign will be placed which displays a radiation symbol and the words CAUTION – X-RAY RADIAITON. This sign will light up when the source is in use and the shutter is open. The light will be tied into the interlock system so if the bulb burns out the source cannot be turned on.

Once the hutch is fully built, the source will be put inside and turned on to allow a careful examination of the outside using a Geiger counter. Any leaks that were missed in the design will be found and patched. After this initial study, an additional search will be made once a year to guarantee the shielding is meeting all guidelines.

Below are the procedures for working with the Microfocus source.

- The X-ray generator will be disabled at all times that it is not in use by removing the interlock and enable keys.
- Set-up will come under the supervision of a CHESS Safety Committee member who will survey the area with a Geiger counter after the unit has been installed.
- Entries will be made into the CHESS Safety Log-book after the tests.
- The Microfocus unit will only be maintained under the supervision of the Permit Holder.
- Any alteration to the Microfocus setup will have to be approved by the CHESS safety committee and supervised by the Permit Holder.
- First time users of this system must first receive instruction and then permission from the Permit Holder.
- A list of authorized users will be maintained in a log-book.

- Upon startup of the X-ray generator, the user shall enter the date, operator name, operating conditions of max kV and mA into the Microfocus Source's log-book.
- The power supply key will be locked up in lock-box in the CHESS operations area when the equipment is not in use.

Issues

Asbestos

The image below is of the room in which the hutch is being built, prior to any work. Note the black tabletop; it is affixed to the cabinet with asbestos glue. Due to this it could not be removed by any CHESS workers, a special team had to be called in from the Cornell Environmental Health and Safety (EH&S).

Figure 8: Rooms Initial State

Gas/Water Lines

Once the asbestos was removed and the cabinets were pulled out, the plumber could be called in to cut off the gas and water lines. Unfortunately it took the plumber a number of weeks to arrive. Once he came and removed the pipes, there was still a nub left poking from the wall, so the shielding has to sit a few inches from the wall to fit the cut pipes.

Shipping Times

The major source of trouble with this project has been shipping times. There is nothing to be done once everything has been designed and all there is to do but wait for materials. The reasons provided for the continuing extensions have ranged from a truck breakdown to just plain forgetting to ship the order.

Company Difficulties

The companies that have manufactured the source, chiller, and framing material have not helped to make this project easy. As previously stated, the framing material took so long to arrive because the order was neglected, and a shutterbox is required because the source manufacturer has relayed minimal circuitry information. There have also been a number of small issues that have plagued the process, such as the chillers pressure gauge. The company that manufactured the chiller neglected to test the pressure gauge prior to shipment. Fortunately the replacement was very simple.

Current State

At this point in time the lead paneling has yet to arrive. Once it does it will be a simple matter of cutting and bending the pieces. The difficulty will lie in placing them on the frame; each panel weighs over 200 pounds each.

Acknowledgements

This work is supported by the National Science Foundation under Grant No. 0841213.

References

[1] K-O Concepts, Inc., "Operations Manual," July 2009, http:// www.k-oconcepts.com

[2] Oxford Instruments, "Nova600 Microfocus X-Ray Source User Manual," http://www.oxfordxtg.com