Mount Sinai Experience in Reducing and Removing the Risks of Malicious Use of Radioactive Materials

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Abstract
Since September 11, 2001, the United States government has been making efforts to minimize the risk of terrorist attacks using Radioactive Dispersal Devices (RDD). Due to the unique characteristics of the cesium chloride (Cs-137) used in medical and research irradiators, it could be potentially used as an RDD. To reduce the risk of malicious use of radioactive materials, Mount Sinai at New York City has adopted several measures. Since 2010, we started to prepare for possible radiological emergencies. We had drills with the Fire Department and Police Department; we purchased equipment to detect, survey, and decontaminate radioactive materials; we implemented enhanced security in facilities having radioactive materials in quantities of concern with the collaboration with the US Department of Energy (DOE); biometric systems, 24/7 video monitoring devices, and radiation detectors with alarm (RMS system) have been installed. The Radiation Monitoring System (RMS) is connected to local law enforcement agencies (LLEA) so that the armed force can intervene timely. Another measure was to limit the number of people who can access the radioactive materials in quantities of concern. A single individual was designated to irradiate the specimen for all the researchers to reduce the number of people accessing the irradiators. The adoption of these measures has reduced the risk significantly already; however, the best way to remove the risk of these radioactive materials being used as an RDD permanently is to find alternative technology to replace these high-activity radioactive sources.

Mount Sinai physicists started comparison studies of radiation dose distribution between the cesium irradiators and x-ray irradiators. Five different comparison studies using cells and mice in both cesium irradiators and x-ray irradiators were performed and the results were comparable. As a result, Mount Sinai decided to completely remove all the cesium irradiators and replace them with x-ray irradiators.

Mount Sinai successfully removed two of the four cesium-137 irradiators in 2016 through the Off-site Source Recovery Program (OSRP). One of the removed irradiators was a blood irradiator and the other one was a biomedical research irradiator. Two x-ray irradiators were installed to replace these cesium irradiators. In 2017, Mount Sinai continues the comparison studies side by side. After 2 months of operations, 895 bags of blood specimen were irradiated without any x-ray downtime or interruption in operation of the x-ray blood irradiators. Presently we are scheduling the permanent removal of last blood irradiator. Our plan is to have Mount Sinai free of remaining radioactive irradiators soon.

Introduction

When, Not if- According to the Pool Re report of December 2016 under the title of "Terrorism Threat and Mitigation Report" by Ed Butler, the head of the Risk Analysis at Pool Re, the international terrorist threat level to UK remains at SEVERE (attack is highly likely) despite no major attacks recently. One has to note that September 11 happened in US and US has much larger border with other countries than UK. The threat level in the US is probably not less than UK and perhaps even higher.

Unfortunately we are in an era that a small group of people are trying everything to hurt innocent people as badly as possible. There have been numerous articles showing that ISIS (known as DAESH in Europe) is trying to get their hands on high activity radioactive sources to make Radioactive Dispersal Devices (RDD). Mount Sinai realized that the dispersion of cesium irradiator source would cause a disastrous outcome if someone uses it maliciously against the public, especially in the densely populated area like New York City.

Mount Sinai

Mount Sinai Medical Center was founded in New York City in 1852, the name was changed to Mount Sinai Hospital in 1866 to reflect the fact that it serves an integral part of the general community. In the late 1950s, the hospital began plans to establish its own medical school, an unusual move for a hospital. With its chartering in 1963, Mount Sinai School of Medicine, now called the Icahn School of Medicine at Mount Sinai, became the first medical school to grow out of a non-university in more than 50 years. The Mount Sinai Health System formed in September 2013, combined the operations of Continuum Health Partners and the Mount Sinai Medical Center. The Mount Sinai Health System is structured around seven hospital campuses and the Icahn School of Medicine at Mount Sinai. The seven hospitals are: Mount Sinai Beth Israel, Mount Sinai Brooklyn, The Mount Sinai Hospital, Mount Sinai Queens, Mount Sinai West (formerly Mount Sinai Roosevelt), Mount Sinai St. Luke's, and New York Eye and Ear Infirmary of Mount Sinai.[1] Mount Sinai Health System includes close to 50,000 employees and the largest health care institution in state of NY

As part of hazard location analysis, there are several specific points that makes Mount Sinai a potential soft target for malicious use of high activity radioactive materials:

- Location in New York City and near subway stations: Terror groups constantly threaten to attack public transportations. They attacked trains in Spain and UK, etc. If attacks happen in New York City, with or without involving radiation, Mount Sinai expects to accept injured individuals. There have been at least 20 known terrorist attempts since 911 towards NYC. [2] Mount Sinai is located in New York City with many subway entrances located within less than a mile.
- Hospital Entity: "Soft targets" are relatively unprotected or vulnerable to terrorist attacks. Typical soft targets are civilian sites where people congregate in large numbers, and hospital is one of the typical soft targets.[3] Terror groups would target hospitals to delay the response to mass casualties. Mount Sinai is a major hospital in NYC.
- RDD ingredient: Mount Sinai had originally 4 cesium irradiators. Two of irradiators were disposed in 2016 through the Off-site Source Recovery Program (OSRP). These remaining radioactive sources could be used as dirty bombs.
- Jewish entity: There have been terrorist attacks targeted on Jewish organizations that caused large casualties. The most renowned ones include 1992 attack on Israeli embassy in Buenos Aires[4] and the AMIA bombing (AMIA; Argentine Israelite Mutual Association).[5] In 2009, FBI arrested four suspects in alleged plot to bomb Bronx synagogues and to shoot down planes.[6]

Cesium Chloride Irradiators and the Security Issues

^{137}Cs self-shielded irradiators have been used for many years for blood products, biomedical, and small animal irradiations. Approximately 10% of donated blood, about 3 million units per year[7], is irradiated in a production mode by blood centers and medical institutions largely to prevent transfusion associated graft vs. host disease (TA-GvHD) for certain patients. Biomedical and small animal irradiations are performed mostly for research purposes at universities and hospitals.[8] ^{137}Cs was selected for irradiation purposes because of its desirable single (662 keV, for unshielded photons) energy spectrum, moderate shielding requirements relative to some other radioisotopes (e.g. Co-60), long half-life, and relative low cost (byproduct of the nuclear irradiators).
In 2008, the U.S. NAS published a landmark report *Radiation Source Use and Replacement*, which examined the feasibility of replacing high-risk radioactive sources with less risky (and most likely non-isotopic alternatives) in order to forestall an act of radiological terrorism. The report expressed particular concern about the threat posed by the continued use of one isotope—cesium chloride—whose unique characteristics make it especially susceptible to be being used by terrorists.

Terror group could disguise as doctors to enter the irradiator facility and blow up the irradiator to create a huge radioactive contamination. They may bring the source to the rooftop or to the streets and spread it all over the area. The report recommended that government policies be enacted that would lead to the substitution of less hazardous technologies.[9]

There is no liability insurance coverage provided to compensate the indirect damage from malicious use of CsCl irradiator. Current insurance plans only cover the physical damage directly resulted from the explosion of a dirty bomb. The contaminated items and the cleanup cost are not covered by the insurance. This could be a significant financial burden to the institutions which possess quantities of concern radioactive sources if these are used maliciously. Also, there is not yet a precedence case on how to prevent or stop the cyber-attack on the CsCl irradiator's security system. Majority of security connections between the irradiators and security command centers as well as the Local Law

Enforcement Agencies (LLEA) are connected through the internet. The breach of security system could give the terrorists longer time to take the sources out.

Goiania Accident 1987[10]

The Goiânia accident was a radioactive contamination accident that occurred on September 13, 1987, at Goiânia, in the Brazilian state of Goiás, after an old radiotherapy source was stolen from an abandoned hospital site in the city. It was subsequently handled by many people, resulting in four deaths. About 112,000 people were examined for radioactive contamination and 249 were found to have significant levels of radioactive material in or on their bodies. [10]
The radiation source in the Goiânia accident was a small capsule containing about 93 grams (3.3 oz) of highly radioactive cesium chloride (Cs-137 CsCl) encased in a shielding canister made of lead and steel. The source was positioned in a container of the wheel type, where the wheel turns inside the casing to move the source between the storage and irradiation positions. The IAEA states that the source contained 50.9 TBq (1,380 Ci) when it was taken and that about 44 TBq (1200 Ci, 87%) of contamination had been recovered during the cleanup operation. [10] Eventually, the important lesson learned was that less than 100 grams of CsCl powder resulted in more than 40 tons of radioactive waste. Disposal of radioactive waste is expensive to begin with but we are no longer talking about grams of radioactive waste rather tons of radioactive waste.

National Academy of Sciences (NAS) Report and Recommendations

As mentioned earlier, in 2008, the U.S. NAS published a landmark report *Radiation Source Use and Replacement*, which examined the feasibility of replacing high-risk radioactive sources with less risky (and most likely non-isotopic alternatives) in order to forestall an act of radiological terrorism. The report recommended that government policies be enacted that would lead to the substitution of less hazardous technologies. The Academy's conclusions were partially embraced by the United States government. In 2010, an interagency Task Force on Radiation Protection and Security submitted its quadrennial report to the President and Congress. The report emphasized the security measures that had been implemented to protect existing risk-significant radiological sources. It concluded that for cesium chloride, ―"immediate phase-out would not be feasible because the sources are extensively used in a wide range of applications in medicine, industry, and research."[11] However, it concluded ―That a gradual stepwise phase-out could be feasible as alternatives become technologically viable and if disposal pathways are identified. "It also noted that ―While alternatives exist for some applications, the viability, relative risk reduction achievable, and state of development of these alternatives varies greatly."[3]

Global Effort

France started in 2006 a 10 year plan to remove the cesium irradiators. They had 30 irradiators and they have completely replaced them with x-ray irradiators. Norway finished replacing all 13 cesium blood irradiators with x-ray blood irradiators in 2015. Japan has started replacing the cesium blood irradiators 20 years ago, and 80% of the cesium blood irradiators were replaced by x-ray irradiators.[12]

Mount Sinai's Plan

Mount Sinai was aware of the risk that the CsCl irradiator sources may be used maliciously by the terrorist group which will pose a great danger to the public. Therefore, since 2010, Mount Sinai has planned and collaborated closely with the government agencies such as the New York City Department of Health and Mental Hygiene (NYCDOHMH), New York Police Department (NYPD), and the Department of Energy National Nuclear Security Administration (NNSA), to minimize the risk of malicious use of radioactive materials in quantities of concern. Mount Sinai adopted a three-phases plan to eventually remove the CsCl irradiators from all the campuses. The three phases are:

Phase 1- Preparation to respond to Radiological Incidents: Get ready for the worst case scenario

Phase 2 - Reduce the risk: Harden Security, Limit Access, FBI background check on staff with access,

Phase 3- Remove the risk: Use Alternative Technology and dispose all CsCl irradiators

The details of each phase are described in the next sections.

Phase 1- Preparation to respond to possible Radiological Incidents

Drill with Fire Department and Police Department

To prepare for accepting patients contaminated with radioactive materials in a mass casualty event, Radiation Safety has developed an Standard Operating Procedures (SOP) regarding emergency handling of mass casualty radiation accident cases. The Radiation Safety Office staff took part in periodic drills in Mount Sinai Medical Center. The content of the drills included setting up check points to survey patients coming in the medical center for help, decontaminating patients, and treating patients who receive high radiation doses. Mount Sinai has designated decontamination areas and showers. In a real mass contamination incident, people may be directed to a large area close to the emergency room where contamination screening could be performed.

Figure 1. (Left) The drill simulated a radiological incident with Radiation Safety staff in Mount Sinai. (Middle) showers (hot and cold) for decontamination. (Right) FDNY truck parked outside of Mount Sinai during the drills.

Proper Radiation Equipment

Mount Sinai purchased proper radiation equipment such as portal monitors, area monitors, personal radiation detectors, the identifinder, and decontamination kits for possible use.

The personal radiation detectors are distributed to the security staff and emergency response staff for daily use to detect the presence of any abnormal radiation level in the medical center. The staff are trained to use the detector and respond to any abnormality detected. The personal radiation detector is the same model used by the NYPD and local regulatory agencies so that in a real emergency we could talk the same language as the LLEA. The area monitors along with alarms were installed in the entrances in Mount Sinai Medical Center to detect any abnormal exposure. These radiation Alarms are checked on a regular basis for proper operation.

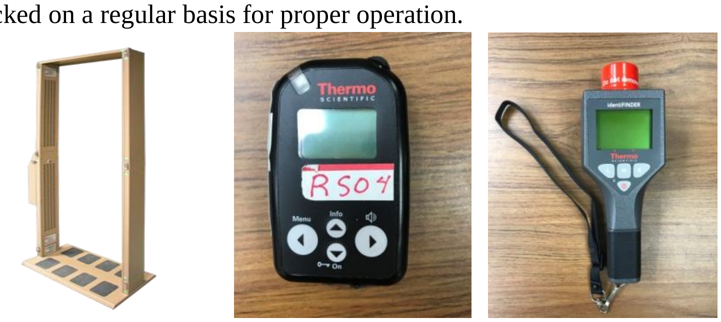


Figure 2. (Left) Portal monitor which can be used to used for Beta/Gamma personnel contamination monitoring and meets the FEMA standard for Emergency Response Portal Monitoring. (Middle) Personal radiation detector that we distributed to our security personnel to detect abnormal radiation level. (Right) Identifinder is used to identify unknown radioisotopes.

Phase 2- Reduce the risk: Harden Security, Limit Access, FBI background check on staff who has access and Pre-arranged Plan with LLEA,

Mount Sinai Started Phase 2 to reduce the risk in 2008 as the NAS made recommendation about the security of high activity radioactive sources. Below are the measures taken by Mount Sinai to reduce the risks.

Pre-Arranged Plan with NYPD

To prepare for actual or attempted theft, sabotage, and diversion of radioactive materials in quantities of concern, Mount Sinai Medical Center developed a pre-arranged plan with NY Police Department. The pre-arranged plan includes the procedure, the important contact information, the risk assessment form, and the radioactive material exposure log.

Harden Security- Collaboration with US-DOE-NNSA

Mount Sinai collaborated with the US Department of Energy (US DOE) and National Nuclear Security Administration (NNSA) to enhance the security of irradiators through the Global Threat Reduction Initiative (GTRI) program which is now known as Office of Radiological Security (ORS). Biometric access was also installed on the entrance to the irradiators. To enter the room, a person with unescorted access has to use both the ID card and fingerprint to open the door. Security enclosures were added to protect the irradiators. The Radiation Monitoring System (RMS) and other radiation detectors and monitoring systems for the irradiators were also installed and connected to the Police Department and Mount Sinai's Security Command Center for remote monitoring. Mount Sinai was the first to be connected to Lower Manhattan Security Initiative (LMSI). With the enhancement of security, the time required for diversion of the irradiator source was delayed to four times of the original estimation. This delay not only makes it more difficult to sabotage the irradiator, but also allows the law enforcement agencies to have more time to stop the malicious activity. The RMS system is checked on a regular basis to make sure that it is working properly.

Figure 3. The biometric access control at the bullet proof window entrance of the irradiator and the RMS system provided to Mount Sinai by the US DOE-NNSA-ORS.

Limit Access

At one point in 2008, there were about 144 researchers had access to the research irradiator. These individuals were mostly graduate students and post-doctoral fellows. The machine was breaking down very often. Mount Sinai decided to introduce single person operator to irradiate animals and cells for all the researchers. Currently, we limit the unescorted access to the research irradiator to a primary individual as well as a backup person.

In the Blood Bank, because Mount Sinai's blood bank is a 24-hour operation, there are 3 shifts a day. It used to be all the staff in blood bank could access to the irradiator. After 2008, we authorized the unescorted access to the blood irradiator only to the managers and a few senior staff in each shift.

A few senior staff in Mount Sinai's Security Department as well as Radiation Safety underwent FBI background check and were given unescorted access to these facilities to respond to any emergency.

Background Investigation

For people who seek the authorization of the unescorted access, Mount Sinai conducts a very strict background investigation. The background check includes the identification verification, the reputation review, the employee history of the last seven years, the FBI background check of criminal history, and the FBI finger printing process. The purpose of such strict background investigation is to make sure that people having unescorted access to the irradiators are trustworthy and reliable. The individuals who are granted the unescorted access are subject to the re-investigation every 10 years until they no longer need the access to the irradiators.

<u>Phase 3- Remove the risk: Use Alternative Technologies and dispose all radioactive irradiators</u>

After phase 2, the risk has already been reduced significantly. Moreover, with the development of the non-isotopic alternative technologies, the CsCl irradiators could be replaced and removed from medical and research facilities. Therefore, Mount Sinai decided to collaborate with the US DOE and NNSA to proceed with comparison studies and permanently remove the CsCl irradiators.

Feasible Non-Isotopic Alternative Technologies: Blood Irradiators and Biomedical Irradiators

- Blood Irradiators

In 2010, an interagency Task Force on Radiation Protection and Security submitted its quadrennial report to the US President and Congress. The Task Force report noted that for blood irradiation, ―x-ray technologies were cost competitive with radionuclide technologies on an annualized basis although concerns remained about their throughput and reliability. Other technologies, such as linear accelerators (LINACs), could be used for blood irradiation in addition to their principal use in cancer treatment. [9]

We found that there are two x-ray blood irradiators for human use approved by the US Food and Drug Administration (FDA) available in the market - Raycell, manufactured by Best Theratronics and Rad Source‘s RS3400. These two x-ray blood irradiators meet the American Association of Blood Banks (AABB) recommendation that a radiation dose of 25Gy (minimum 15Gy) for treating blood in order to prevent GVHD.[13] There is one published study concludes that small differences in RBC membrane permeability are found between gamma-irradiated and X-ray-irradiated units. However, these differences are not likely to be clinically important.[14] In a 2011 UK guideline by the British Committee for Standards in Haematology blood transfusion task force, blood x-ray irradiation was recommended as a suitable, safe alternative to gamma ray irradiation. [15]

- Biomedical Irradiators

In 2013, a new research building includes an animal facility was open in Mount Sinai. The researchers decided to acquire a new biomedical irradiator since the animal facility is far from the existing Cs-137 irradiator facility. We started to investigate the options. At that time, there was not many published paper available about the comparison of x-ray irradiators and Cs-137 irradiators. There was one paper published by B. R. Scott indicated that x-ray sources such as the X-RAD 320 Unit can be used as successfully in studies of radiation cytotoxicity in culture as in the case of ^{137}Cs sources.[16] After considering that in the near future we might need to dispose the Cs-137 irradiators, and there was not sufficient published data about the comparison between Cs-137 and x-ray irradiators, Mount Sinai made a decision to get an x-ray irradiator (RS2000, RadSource, 160 kVp) so that we can do the comparison studies to prepare ourselves for the eventual transition to x-ray irradiators.

There are several options in the market for biomedical irradiators. Among the various models, the maximum energies vary from 160 kVp to 450 kVp. Other differences among the irradiators should be considered including the irradiation chamber size, the irradiator size, the cooling method, and the accessories of the irradiator etc. Unlike the blood irradiators which are FDA approved, there is not a criterion to determine which models of x-ray biomedical irradiators to acquire. Also, as previously mentioned, there are not many published studies showing that the x-ray has equivalent effect on cells and animals in all the applications compared to cesium irradiators. Therefore, with the new x-ray biomedical irradiator, Mount Sinai's physicists and researchers started to work together to do the comparison studies to see the feasibility of completely phase out the Cs-137 research irradiators and to replace them with x-ray irradiators.

Dosimetry Measurements

- Dose Distribution

The dose distributions in the irradiators were provided by the manufacturers at the commission of each irradiator. You can see that the dose distribution in the x-ray irradiator (±3.8%) is more homogeneous than in the Cs-137 irradiator (±20%) at the location (level) for mice irradiation. There are large differences in source geometry, essentially between the point source (x-ray) and the line source (Cs-137 source). This is very important point because in cesium irradiators, the sample is rotated during the irradiation and if the mice move closer to the edge of the cage, then it will give completely different results than mice in the center of the cage. In x-ray irradiator there is no rotation of samples.

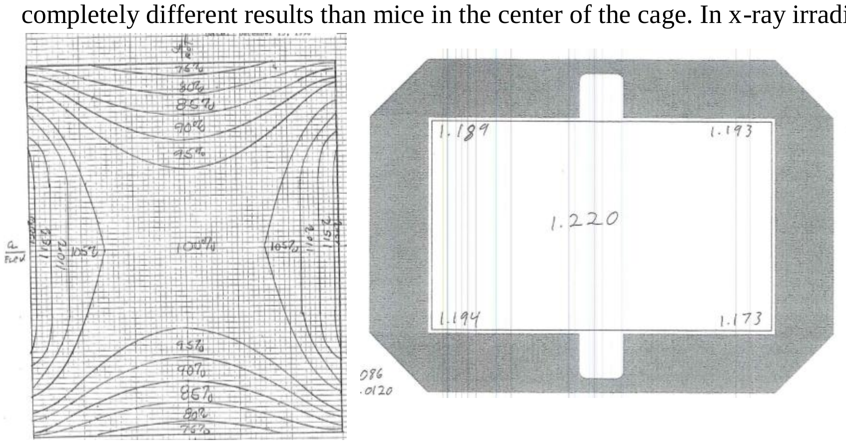


Figure 4. The dose distribution in the irradiators provided by the manufacturers. (Left) The isodose map in JL Shepherd Mark I-68 Cs-137 irradiator at location 3 measured with a film and provided by JL Shepherd. (Right) The Dose rate measurements in RS2000 x-ray irradiator at level 1 with RAD+ reflector.

- Percent Depth Dose (PDD) Measurement
The PDD curves were measured with EBT 2/ EBT 3 films sandwiched between different thicknesses of solid water phantom slabs and in small rodent phantoms in JL Shepherd Mark I-68 Cs-137 irradiator and RS2000 x-ray irradiator (160 kVp, 25 mA) respectively. The measurements in small rodent phantoms were performed by Mr. Mark Murphy from Pacific North National Lab (PNNL) using Mount Sinai's irradiators.
The PDD measurements show very similar curves for 160 kVp x-ray and Cs-137 (662 keV) in both solid water phantoms and small rodent phantoms. The measurements in small rodent phantoms also show x-ray has more backscatter – contributing more doses and the Cs-137 field has significant Compton/scatter percentage.

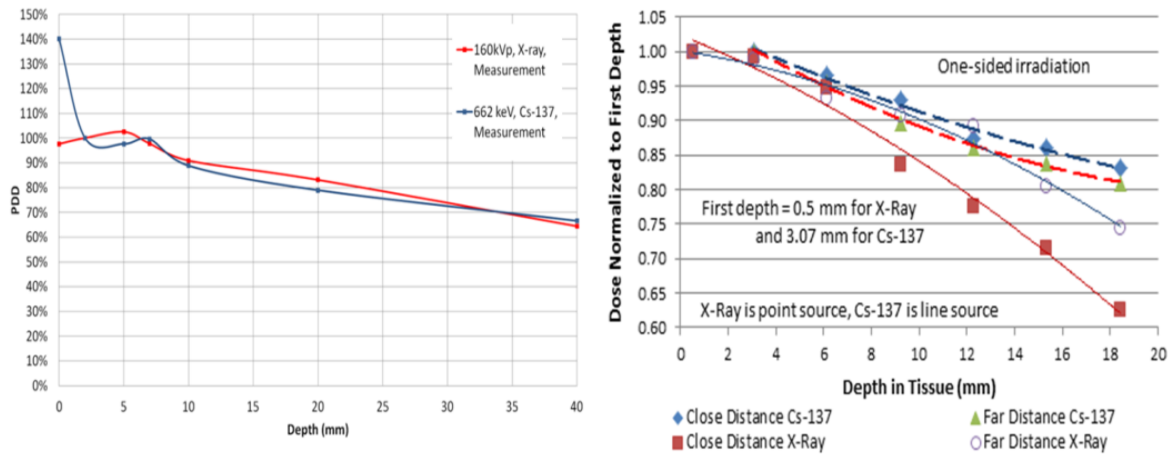


Figure 5. The PDD Curves comparison for 160 kVp x-ray (RS2000) and Cs-137 (JL Shepherd Mark I-68). (Left) The PDD curves measured with EBT 2 films solid water phantoms. (Right) The Dose rate measurements in RS2000 x-ray irradiator at level 1 with RAD+ reflector.

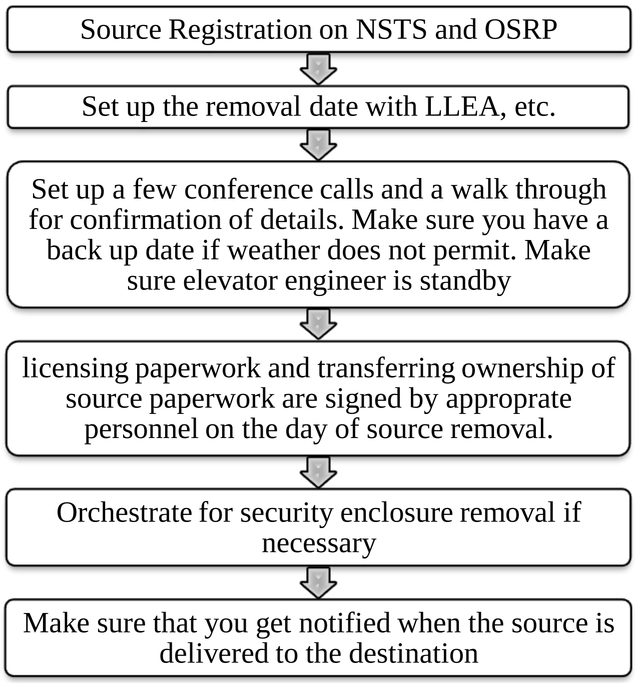
Comparison Studies
The researchers in Mount Sinai use the irradiators for many different purposes. The major applications include bone marrow ablations in mice, suspension of cell cycle, and treatment of tumors implanted in mice. We have some researchers who did comparison studies for different applications to see if x-ray irradiation can give similar results as Cs-137 irradiation or what the dose is for x-ray irradiation to have equivalent effect as in Cs-137 irradiation.

- Bone Marrow Ablation
Dr. Miriam Merad's lab compared the bone marrow ablation on 35 mice with x-ray whole body irradiation. The dose was 6 Gy each time, two times with 12-24 hours interval, total dose 12 Gy. Only 1 mouse died out of 35 mice for 50 days survival. The result of the Chemerism shows that all recipients were around 90% of donor origin which is similar to Cs-137 irradiation. Dr. Merad's lab performed another bone marrow ablation experiment and the result shows 100% of donor origin which is also similar to the result of Cs-137 irradiation. A published study also concluded that both the X-ray and Cs-137 sources used in this experiment provided similar results with regard to long-term peripheral blood reconstitution after bone marrow ablation.[17]
- Cell Irradiation
Dr. Heeger's lab tried to grow human B cells on irradiated human fibroblasts. The standard irradiation dose for this procedure using Cs-137 irradiator is 43Gy, and Dr. Heeger's lab compared the results of various doses of x-ray to find the equivalent effect. The results indicate that 20-60Gy x-ray has equivalent effects to standard 43 Gy cesium irradiation, and that x-ray doses above 80Gy impair fibroblast and B cell growth.
Dr. Brody's lab assesses the effect of irradiation on survival of A20 lymphoma cell line. They found that for x-ray irradiation, apoptosis is induced in a dose dependent manner, increasing from 25% at 9Gy to 60% at 75Gy, and doses over 75Gy did not show a further increase in apoptosis induction.
- Mice Brain Irradiation
Dr. Hadjipananyis' lab did experiments of brain irradiation on 12 mice (other body parts were spared). The dose was 10 Gy (5 Gy each time, 48 hours interval). 12 mice all survived 30 days which is similar to the result of cesium irradiation.

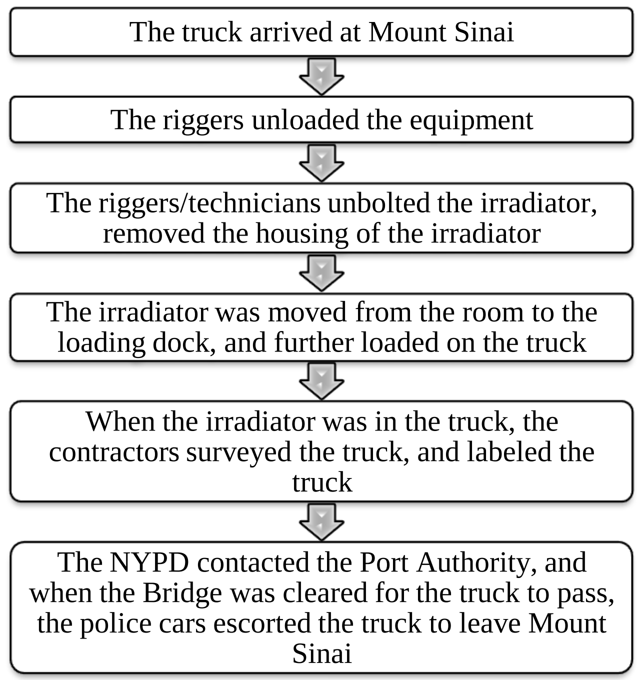
Dispose of Radioactive Irradiators

Mount Sinai disposed the first cesium irradiator in October 2016 and the second one in December 2016. The disposal arrangement involved collaboration of many departments within the institution (Radiation Safety, Blood Bank/ Animal Facility, Security, Engineering, Loading Dock, Emergency Room) as well as with the regulatory agencies, Police Department, Highway Patrol, and office of emergency management etc. Below diagrams briefly describe the process of the disposal of radioactive irradiators.

From Source Registration to Source Transferred



On the Day of Source Removal



Mount Sinai's Decision Making on Procurement of X-ray Irradiators

There are many factors that Mount Sinai considered when choosing an x-ray irradiator for purchase. The factors include FDA approval (Blood), the maximum energy, the irradiator chamber size (to have large through put), the irradiator size (considering our space is limited), the self-cooling system, the add-ons (collimators, adjustable shelves etc.), the price of the machine and the warranty cost, the renovation Cost, the downtime, and the experiences of other users.
We first searched on-line for the available machines, and narrowed down to 2-3 models. We invited the manufacturer representative to Mount Sinai to demonstrate their units to the researchers/ blood bank staff. We collected the opinions and made the final decision on which machines to buy.
Both x-ray irradiators were installed and commissioned in January 2017.
- **Blood Irradiator**

There are only two blood x-ray irradiators available in the market: Best Theratronics Raycell and RadSource RS3400. We eventually choose RadSource RS3400 for the below reasons:

- It is a FDA approved unit.
- Raycell unit requires clean water supply to cool down the x-ray tube. This is difficult for Mount Sinai blood bank, we need to do a total renovation to get clean water supply which will cost a lot of money and time. RS3400 requires minimal renovation for us.
- Because of the cooling issue and the number of x-ray tubes, Raycell has a higher chance of burning out the x-ray tube. RS3400 is more stable with less downtime.
- Capacity. Raycell can irradiate only 2 units per irradiation comparing to RS3400 which can irradiate 6 units at a time.
- Raycell machine is more expensive than RS3400, but the warranty is cheaper than RS3400 so the cost pretty much evens out.

- Other users' experience: Red Cross has bad experience with Raycell, and Blood One in Florida has good experience with RS3400.

Figure 6. (Left) RS3400 blood irradiator installed in Mount Sinai. (Right)X-RAD 320 Biomedical irradiator installed in Mount Sinai.

- Research Biomedical Irradiator

Unlike x-ray blood irradiators, there are many options for biomedical irradiators available in the US market. We first narrowed down to Faxitron MultiRad 350 and Precision X-ray X-RAD 320. After invited the manufacturers to demonstrate their machines, X-RAD320 was chosen for the below reasons:

- Energy: up to 320 kVp.
- Irradiator chamber size: One of the biggest in the market.
- Irradiator size: fits our room.
- Self-cooling system.
- The add-ons: dose measurement exposure control, motorized specimen shelves, adjustable Collimation Fixtures.
- Price of the machine and the warranty cost.
- Lower room renovation Cost.
- Shorter downtime: the company is at Connecticut, within two hours they can come to Mount Sinai, so we expect a quicker fix if the machine needs repair.
- The review from other users: This X-Rad series irradiators is one of the bestsellers in the world.

The Next Step

Mount Sinai still has one cesium blood irradiator and one cesium research biomedical irradiator. The plan is to keep both x-ray and cesium irradiators running together to do comparison studies and as a backup to each other for one year before the final disposal of the cesium irradiators.

Mount Sinai Blood Bank staff finished the validation procedures before using the x-ray irradiated blood on patients. About 900 units of x-ray irradiated blood were used on patients in the first month. During the first few weeks of using a new x-ray irradiator, it is expected that some "faults" would occur during the irradiation due to the parts are not fully conditioned. The manufacturer suggests that if there are three interruptions during one irradiation cycle, then the blood cannot be used as irradiated blood. Mount Sinai Blood Bank staff keep a record that every time the fault occurs and noticed that the occurrence of the faults has decreased a lot since the beginning, and there have never been more than 3 interruptions in one cycle of irradiation so far. In fact about 100 bags of blood were irradiated in one day to evaluate the machine under stress condition and operation went smoothly. The Blood Bank staff are satisfied with the operation and the throughput of the x-ray irradiator.

Some researchers in Mount Sinai have already conducted the comparison studies for their own protocol adjustments. As the results mentioned in the previous section, the researchers found similar x-ray irradiation outcomes as using the cesium irradiator in bone marrow ablation. For cell irradiation, the researchers created a calibration curve for the x-ray irradiation on different cell lines to find the dose corresponds to the effect that they desire. We encourage all current researchers in Mount Sinai to conduct the comparison studies to prepare themselves for the final disposal of cesium irradiator. The researchers should collaborate with the medical/health physicists to plan for the comparison studies and the creation of future protocols using x-ray irradiators.

Conclusion

In this report, we summarized the effort we have made since 2010 to reduce and eventually remove the cesium irradiators with the collaboration with many other institutions, regulatory agencies, law enforcement agencies and US government agencies. Since the reliable alternative technologies are available now, we do believe that phasing out the cesium irradiators will eliminate the risk of using the high activity radioactive sources as possible Weapon of Mass

Disruption (WMD). We do appreciate the help of US government OSRP program as well as the US-DOE-NNSA during the last 7 years, and we highly recommend all institutions to take advantages of the help these agencies offer. Some final points:

- Cs-137 was not engineered for irradiation purposes rather it was one of the by-product from nuclear power plant operation.
- The dose distribution in x-ray irradiator is much more homogeneous in cesium irradiator.
- The dose deviation in x-ray irradiator is much smaller than in cesium irradiator.
- Our preliminary depth dose measurement has shown that cesium irradiators give higher skin dose of more than 30% than that of x-ray irradiator. We encourage any institution with Monte Carlo calculation capability to verify our measurements.
- X-ray irradiators will not be covered under 10CFR part 37 regulations and therefore there will not be any need to have any FBI background check on the staff incurring security cost and licensing cost.
- Institutions should use the US government program called "Off-site Source Recovery Program" to dispose high activity cesium sources otherwise in the near future it will cost them about $250,000 to dispose each cesium irradiator.
- Institution's leadership and management should check their insurance coverage very carefully for radioactive decontamination cost from a possible dirty bomb incident. They must remember from Brazil experience that 80 grams of cesium powder resulted in more than 40 tons of radioactive waste.
- The governments of Norway, France and Japan must be commended for their decisions to remove such sources from their societies. Perhaps this is one way we could help to fight and reduce the risk of malicious use of high activity radioactive sources.

Acknowledgment:
The help from Wen-Ya Hsu and Brandon Boswell of Radiation Safety at Mount Sinai is greatly appreciated.

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