FETAL RADIATION SHIELD

Team Members: Lauren Heinrich, Janae Lynch, Megan Skalitzky, Lena Hampson
Clients: Dr. Zacariah Labby
Advisor: Dr. Beth Meyerand

ABSTRACT

Pregnant patients undergoing radiation therapy require modified treatment plans due to the health risks to the fetus posed by radiation. Currently, no safe or affordable universal protocol exists to shield the fetus. The Department of Human Oncology at the University Hospital desires a shield capable of protecting the fetus from radiation leakage and scatter. The final design is a lead shield that is 5 cm-thick, encased in steel, mobile and accommodating of various treatment setups, with the aim of shielding the fetus from at least 50% of stray radiation. The shield shape is a lipped half-cylinder. A system of linear actuators and screw jacks supports raises and lowers the lead shield and four locking caster wheels will be used to transport the shield. Simulation results revealed the lift system to provide adequate support for the weight of the shield. Future testing will entail rigorous third-party testing of the mechanical supports and testing the ability of the shield to attenuate fetal radiation dose.

PROBLEM STATEMENT

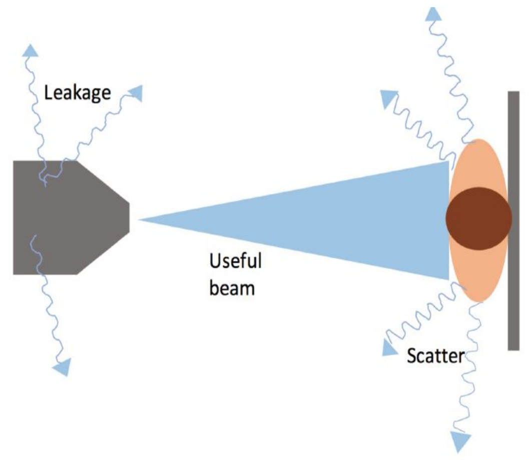
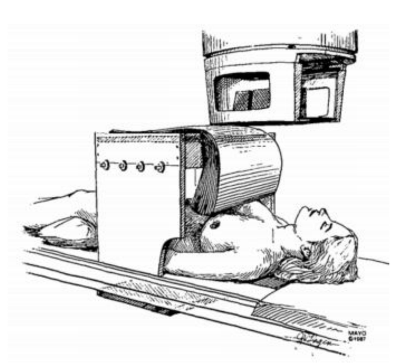


Figure 1: Stray radiation, based on [3].

The main sources of radiation that can affect the fetus include photon leakage through the head of the machine, radiation scatter from the collimators, and radiation scattered within the patient from the treatment beams [1]. With a shield, the risk of damage to the fetus is relatively low, at approximately 0.5% chance [2].

As depicted (Figures 2), previous methods of shielding pregnant patients from radiation were often assembled over the patient, making them very unsafe and impractical. The University of Michigan shield, while safer and capable of accomplishing much of what this project aims to do, was outsourced and had a much larger budget (Figure 3).



Figures 2 Example of previously devised method for shielding pregnant patients. Here, lead sheets are stacked across a bridge over the patient on the treatment couch[4].

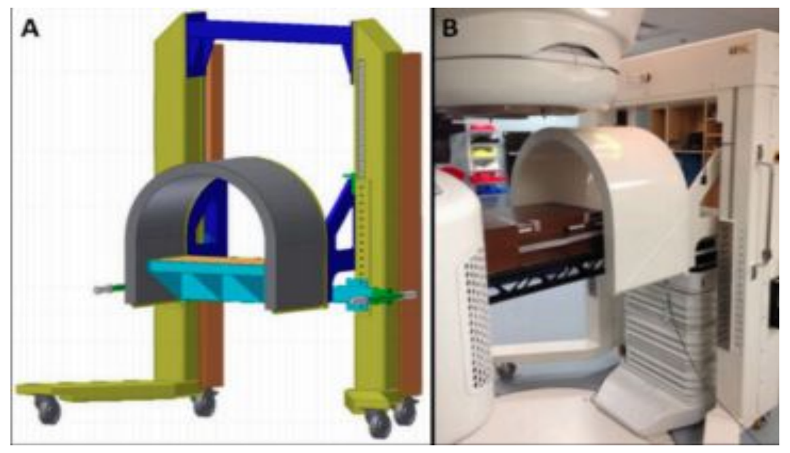


Figure 3: Fetal radiation shield made by the University of Michigan [5].

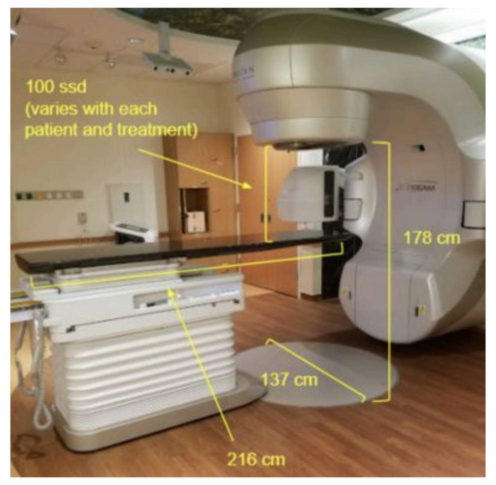


Figure 4: Typical Treatment Room at Department of Human Oncology.

A radiation shield must reduce fetal radiation dose by a minimum of 50% and cannot pose an additional safety risk for the patient. Furthermore, the shield must accommodate various body shapes and sizes. It must also be mobile for transport between storage and treatment suites (Figure 5). Support and transportation mechanisms with high factors of safety (~3) and fatigue limits must also be incorporated into the design. The full assembly must cost no more than $15,000.

PREVIOUS WORK

Semester 1: Shield Shape
- High-Waisted Skirt

Semester 2: Lifting System
- Dual lift system

Semester 3: Transportation System
- 6 swivel casters

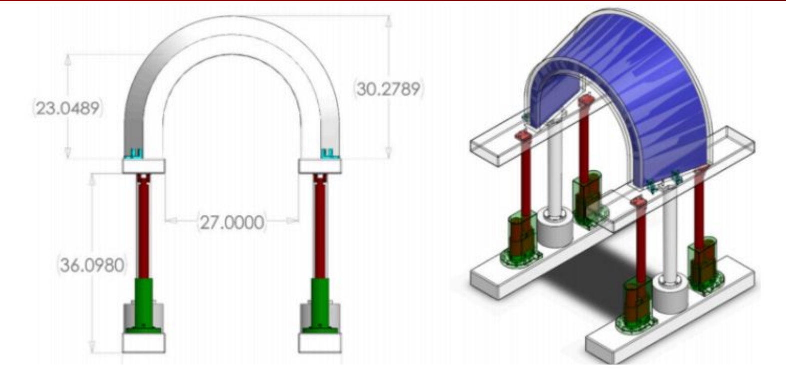


Figure 5: "High-Waisted Skirt" design with support assembly.

FINAL DESIGN

Objectives
- Redesign shield shape to reduce cost
- Modify lifting mechanism

Shield
- Half-cylinder shape with front lip (1361 lbs)

Transportation
- 4 caster wheels with foot brakes

Support
- 2 screw jacks
- 4 linear actuators

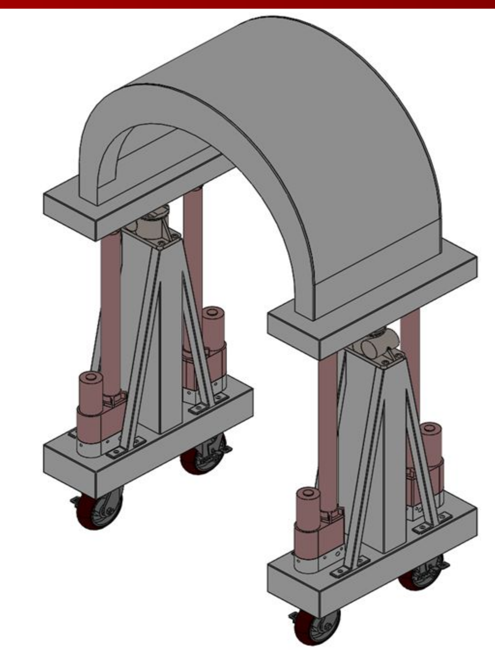


Figure 6: Modified shield design

TESTING

STATIC TESTING

Shield and Shield Casing
- Objective: Determine if steel casing around the lead can support the weight
- Assumptions:
  - Bonded steel casing (excluding top cover)
  - Rigid and fixed support system
- Forces: Gravity (-9.81 m/s^2)

Support System
- Objective: Determine if the support frame can support the weight of shield assembly
- Assumptions:
  - Bonded frame and wheels
  - Rigid and fixed wheels
  - Simplified application point for forces
- Forces: Gravity (-9.81 m/s^2); Resultant forces on individual supports

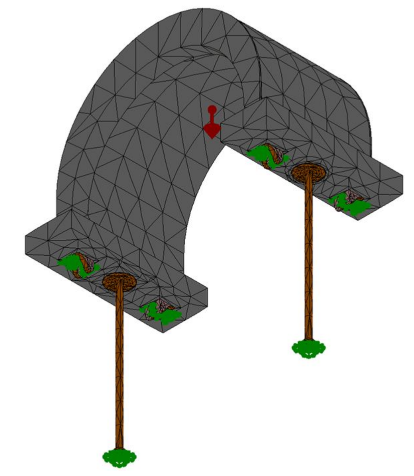


Figure 7: Mesh of static testing of shield casing. Green arrows indicate fixed geometry; red arrows indicate gravity.

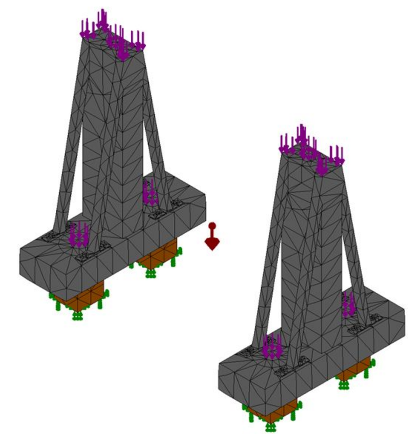


Figure 8: Mesh of static testing of shield casing. Green arrows indicate fixed geometry; red arrows indicate gravity.

DYNAMIC TESTING
- Objective: Determine if the initial acceleration conditions contribute significantly to stress on shield casing
- Assumptions:
  - Bonded shield casing
  - No external forces
- Initial Conditions: V_y is +0.33 m/s

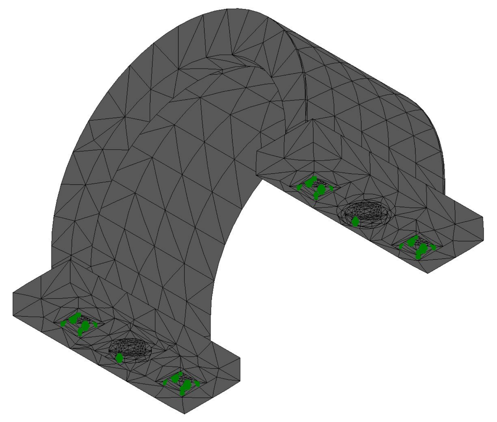


Figure 9: Mesh of dynamic testing on shield casing. Green arrows indicate applied velocities.

RESULTS & DISCUSSION

STATIC TESTING

Shield and Shield Casing
- Weight Distribution
  - Screw Jacks: 37%
  - Front Linear Actuators: 33%
  - Back Linear Actuators: 30%
- Steel casing never exceeds yield strength → Can support shield
- Lead exceeds yield strength but plastic deformation is minimal

Support System
- Support frame never exceeds yield strength → Plausible support frame
- Future design modifications
  - Accommodate synchronization system

DYNAMIC TESTING
- Stresses from initial condition are small → Lifting velocity contributes minimally to stresses on casing

FUTURE WORK

- SolidWorks:
  - Motion analysis on entire assembly
  - Fatigue testing on frame
- Design modifications:
  - Integrate power and controls
  - Minimize stresses on support frame
  - Reduce price of lifting components
  - Will collaborate with ME
- Physical Testing:
  - Third party validation
  - Phantom testing to determine efficacy
  - Prototype
- Implementation of shield in Department of Human Oncology

Figure 10: Example of how testing will be done with Solid Water™ [6].

ACKNOWLEDGMENTS

Dr. Zacariah Labby | Dr. Beth Meyerand
Dr. Wesley Culberson | Vulcan GMS | TEAM Lab

REFERENCES

[1] D. D. Martin; Review of Radiation Therapy in the Pregnant Cancer Patient; Clinical Obstetrics and Gynecology, Review vol. 54, no. 4, pp. 591-601, Dec 2011.

[2] M. Mazonakis, A. Tzedakis, & J. Damilakis; Monte carlo simulation of radiotherapy for breast cancer in pregnant patients: How to reduce the radiation dose and risks to the fetus?; Radiation Protection Dosimetry, Article vol. 175, no. 1, pp. 10-16, Jun 2017.

[3] P. J. Biggs, "Radiation Shielding for Megavoltage Photon Therapy Machines" Boston, Massachusetts Harvard Medical School, 2010.

[4] M. Stovall and C. Robert Blackwell, "501 Fetal dose from radiotherapy photon beams: Physical basis, techniques to estimate radiation dose outside of the treatment field, biological effects and professional considerations", International Journal of Radiation Oncology*Biology*Physics, vol. 39, no. 2, 1997.

[5] A. Owrangi, D. Roberts, E. Covington, J. Hayman, K. Masi, C. Lee, J. Moran and J. Prisciandaro, "Revisiting fetal dose during radiation therapy: evaluating treatment techniques and a custom shield [JACMP, 17(5), 2016]", Journal of Applied Clinical Medical Physics, 2017.

[6] "EASY CUBE - RW3 Phantom for Dosimetry QA in Radiation Therapy - LAP Laser systems for measurement and projection", Lap-laser.com, 2018. [Online].