FETAL RADIATION SHIELD

Limiting dosage of high-energy radiation to the developing fetus

Janae Lynch[1], Lauren Heinrich[1], Maura McDonagh[1], Emily Knott[1]

Advisor: Dr. Beth Meyerand[1] | Client: Dr. Zacariah Labby[2]

[1] Department of Biomedical Engineering, College of Engineering, University of Wisconsin-Madison, Madison, Wisconsin, USA

[2] Department of Human Oncology, School of Medicine & Public Health, University of Wisconsin-Madison, Madison, Wisconsin, USA

Abstract

Radiation exposure poses severe health risks to the **developing fetus**, thus pregnant patients undergoing radiation therapy require modified treatment plans. No universal protocol exists to shield the fetus, as current methods are **unsafe** and **expensive**. 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 five centimeters thick, safe, mobile, accommodates various treatment setups, and aims to shield the fetus from **50%** of stray radiation. The lead is encased in steel and is supported and raised by **linear actuators** and **screw jacks** working simultaneously. Simulation results revealed that our lift system provided adequate support for the **weight** of the shield. Future testing will determine if it attenuates the fetal radiation dose. Ultimately, the shield will **expand treatment options** for pregnant patients undergoing radiation therapy throughout Wisconsin.

Problem Statement

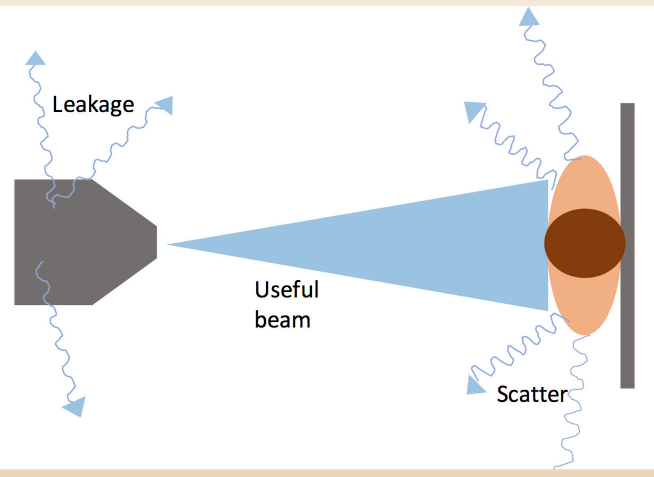
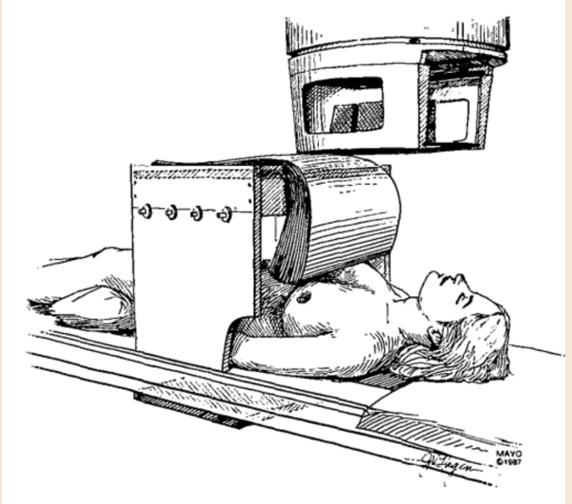


Figure 1: Stray radiation, based on [3].

The main sources of radiation that can interact with 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]. Without a shield, the risk of damage to the fetus is relatively low, at approximately 0.5% chance [2]. This device aims to provide an alternative to delaying treatment that is safe for both the patient and the fetus.



Figures 2 (left) and 3 (right): Primitive Shields. Examples of previously-devised methods of shielding pregnant patients, named the bridge over patient and table over treatment couch, respectively [4].

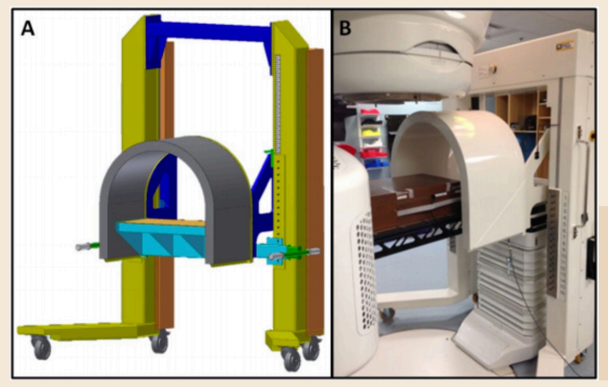


Figure 4: Michigan Shield Design. Images from Owrangi et al. depicting the University of Michigan's U-shaped shield, including a CAD model and photo of the final product [5].

As seen, 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. The apparatus devised for the University Hospital, thus, must be safer than these primitive shields and effective at blocking 50% of the radiation while also maintaining the budget of **$10,000 USD**. To achieve this, the team broke down this semester's goals into four parts: a **lifting mechanism**, **SolidWorks testing**, and a **fabrication plan**.

Final Design

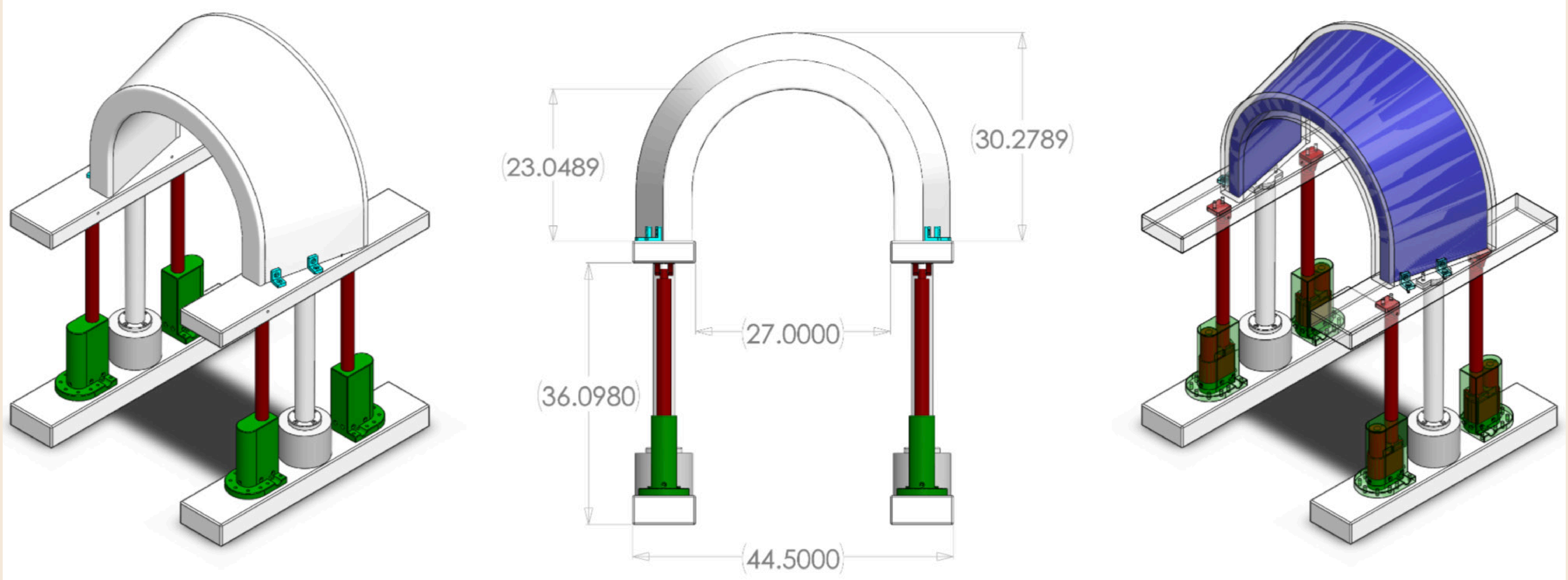


Figure 8: Proposed Shield and Support Mechanism. The shield, steel casing, supports, and bottom frame as seen from the isometric view (left), frontal view (middle), and transparent isometric view (right). Grey indicates high quality steel, red refers to purchased parts, green and teal indicate lower quality steel, and blue represents the fabricated lead shield.

Specifications

Weight of shield and casing = 1138.47 lbs

Volume of shield and casing = 7589.95 in^3

External surface area of casing = 1274.9962 in^2

Footprint = 717.75 in^2

Total Weight = 1475.8153 lbs

Components *per side*

- 2 heavy-duty linear actuators
- 1 screw jack actuator
- Removable enclosure
- Lower frame attached to mobility
- Upper frame attached to shield

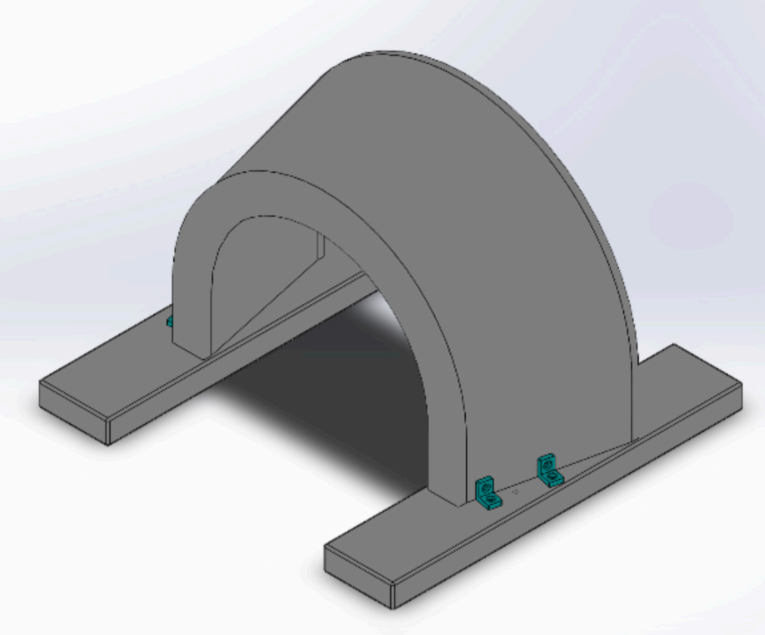


Figure 9: Shield with Steel Casing and Platform. An alternate view depicting the shield with its accompanying steel encasement and the brackets used to mount the shield to its platform.

Testing & Results

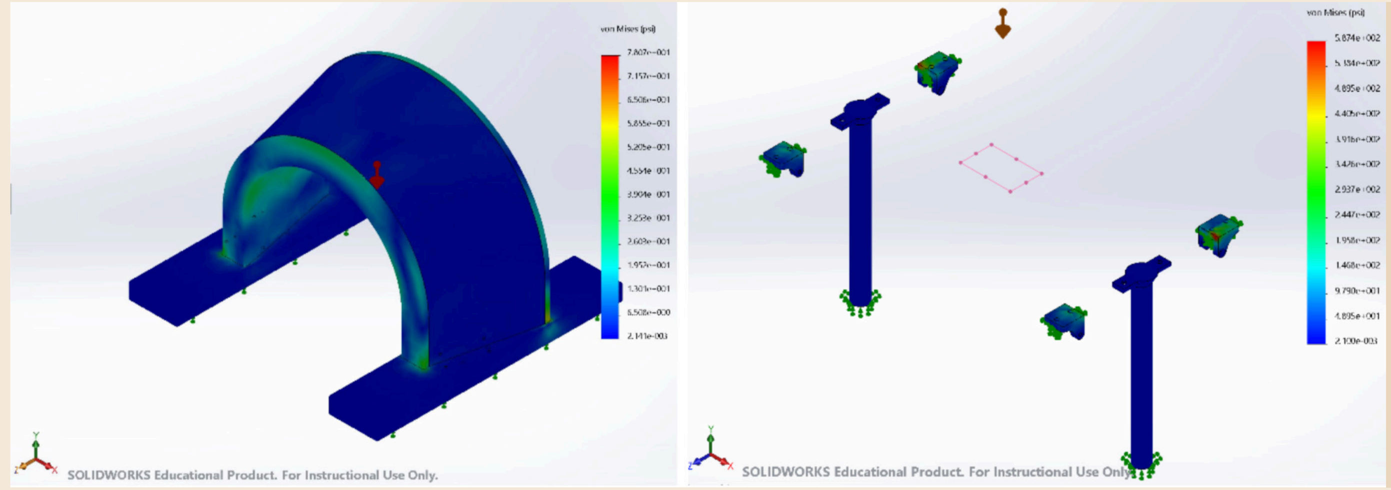


Figure 10: Stress Testing. A strain map for shield support mechanism under simulated gravitational stress (left) and of the screw-jack supports under simulated gravitational stress (right).

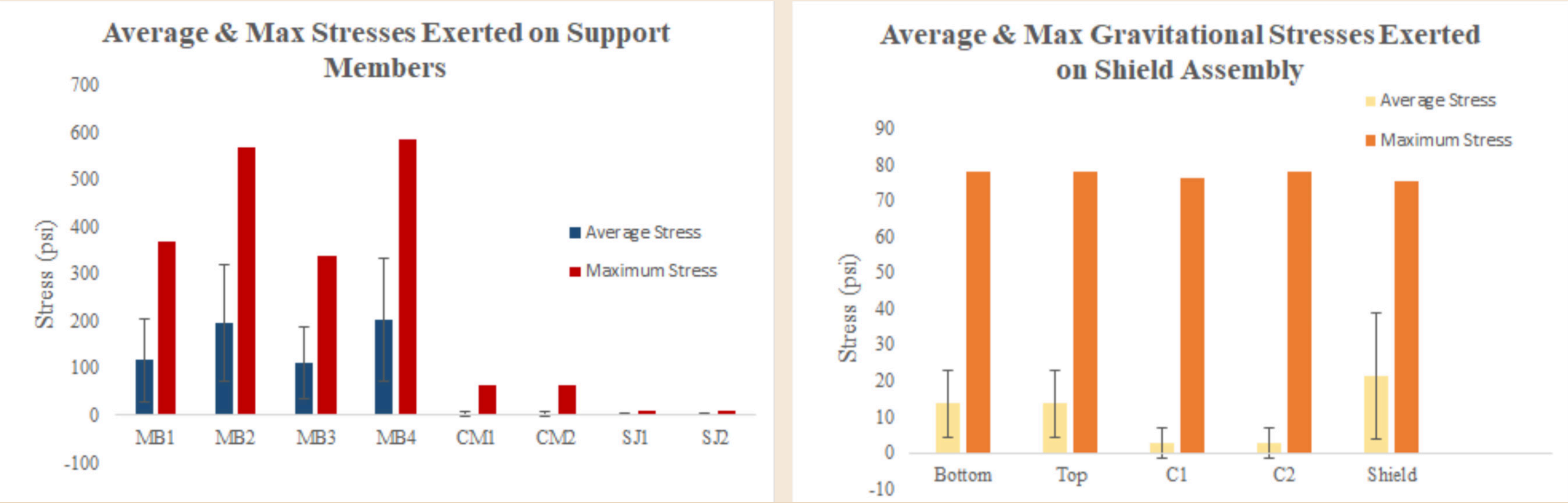


Figure 11: Simulation Analysis. Graphs depicting the stresses exerted on members of the support system (left) and gravitational stresses exerted on different faces of the shield assembly (right).

Previous Work

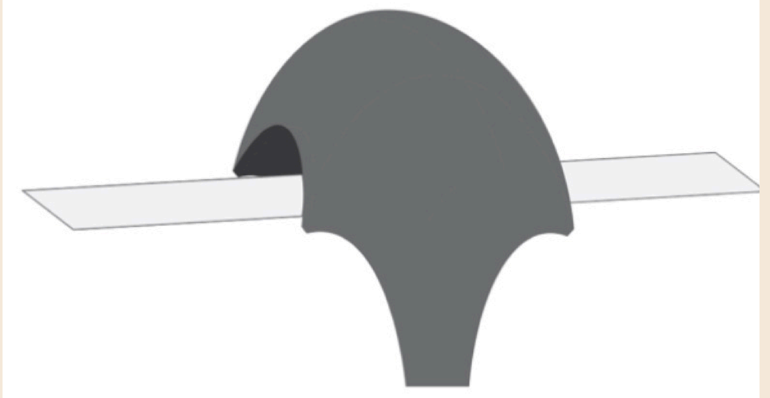


Figure 5: Helmet. Sketch of a preliminary shield shape designed in Fall 2017, with treatment table.

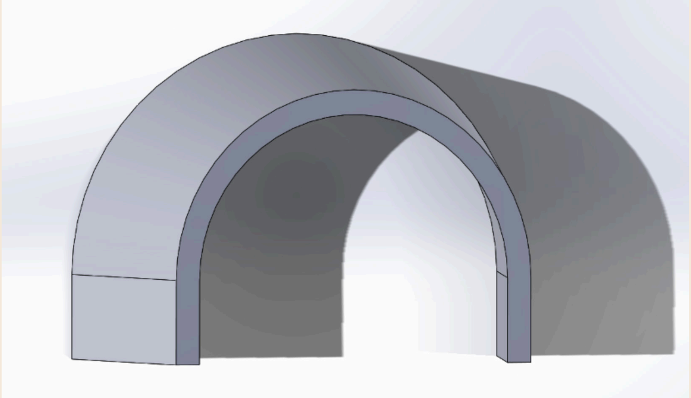


Figure 6: High-Waisted Skirt. SolidWorks rendition of the shield shape from Fall 2017.

Last semester, the team focused on designing a shield shape to accommodate a variety of patient sizes while also maximizing radiation blockage. The final shield shape, the High Waisted Skirt, was the product of many iterations and named for its flared geometry.

Design Criteria

This semester, the team focused on designing a mechanism to raise and lower the previously-designed 5cm-thick lead shield.

SAFETY REQUIREMENTS

- Must be capable of fully supporting the shield weight
- Must allow for control over raising and lowering

PHYSICAL REQUIREMENTS

- Must be able to be moved throughout hallways and stored
- Must fit within door frame (122 cm wide)
- Must accommodate force plate (137 cm diameter)
- Must straddle treatment table (53 cm wide)
- Must accommodate all table heights (from 116 cm to 127 cm)

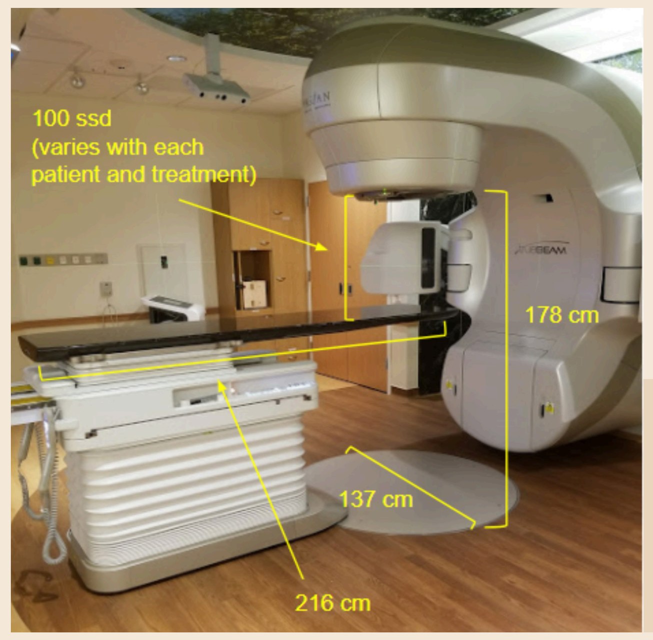


Figure 7: Typical Treatment Room at Department of Human Oncology. This image depicts the dimensions from the floor to the head of the machine at its highest configuration, as well as the length of the treatment table and force plate.

Future Work

DESIGN
- Mobility
- Power and controls
- Safety mechanisms

TESTING
- Physical testing
- Monte Carlo simulation
- Phantom testing

FABRICATION
- Shield
- Lifting mechanism
- Assembly

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.