FETAL RADIATION SHIELD

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ABSTRACT

Pregnant patients undergoing radiation therapy require modified treatment plans due to the health risks to the fetus posed by the radiation. 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 and mobile, and can accommodate 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. Four locking caster wheels and two ball casters 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

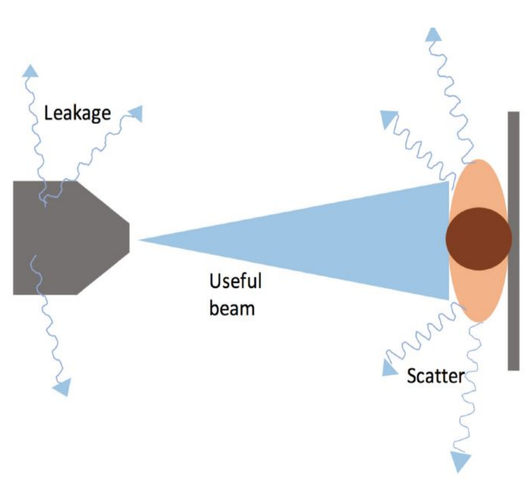
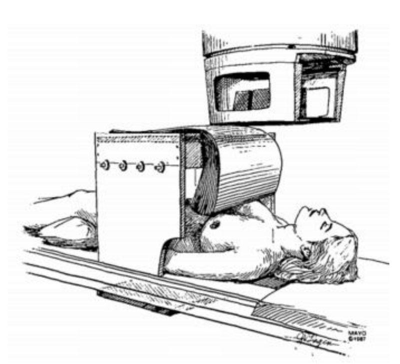


Figure 1: Stray radiation, based on [3].

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 3), 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 4).



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].

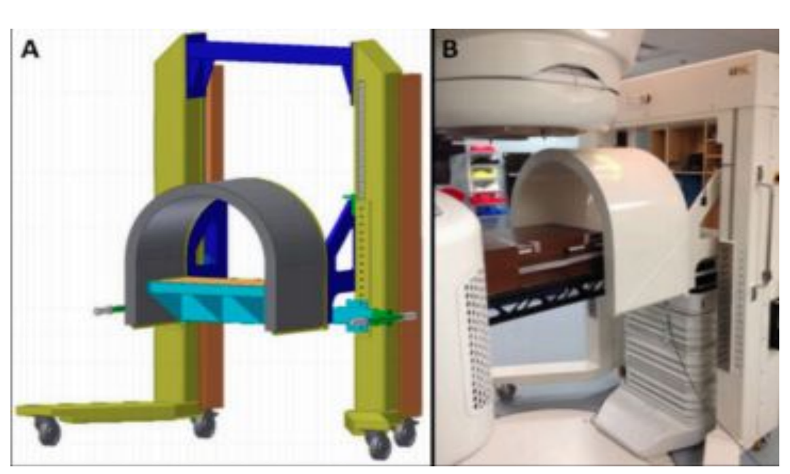


Figure 4: Fetal radiation shield made by the University of Michigan [5].

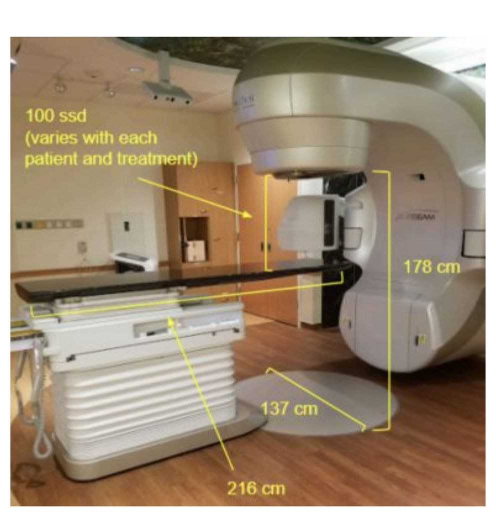


Figure 5: Typical Treatment Room at Department of Human Oncology.

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 $10,000.

PREVIOUS WORK

- Semester 1: Design shield shape
  - Final design: "High-Waisted Skirt" to block as much scatter radiation as possible
- Semester 2: Design lifting and support system
  - Final design:
    - Primary raising and lowering: Four linear actuator
    - Secondary support: Two power screws
  - See Figure 6 for assembled design
- Various SolidWorks testing on design to ensure mechanical stability, but more testing needed

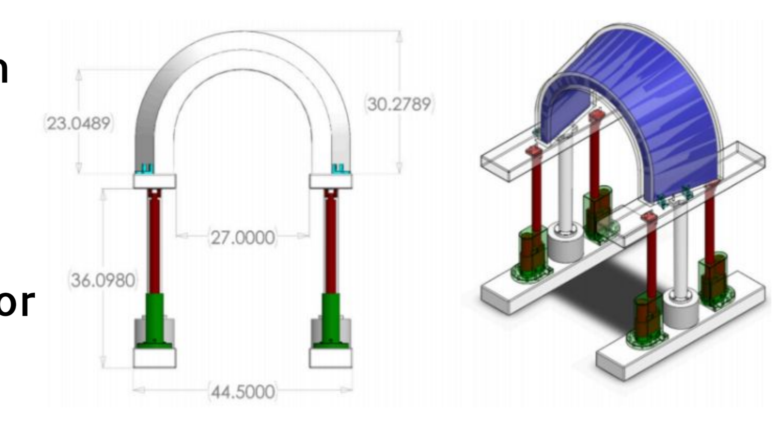


Figure 6: "High-Waisted Skirt" shield design with support assembly.

FINAL DESIGN

- Objectives
  - Redesign shield shape to reduce cost
  - Design mechanism for transporting shield assembly
  - Modify lifting mechanism to account for transportation and shield
- Shield:
  - Half-cylinder shape with front lip
  - Steel casing
  - Weight: 957 lbs
- Transportation system:
  - Four swivel caster wheels with foot pedal brakes
  - Two ball casters
- Support system:
  - Two power jack screws
  - Four electrical linear actuators

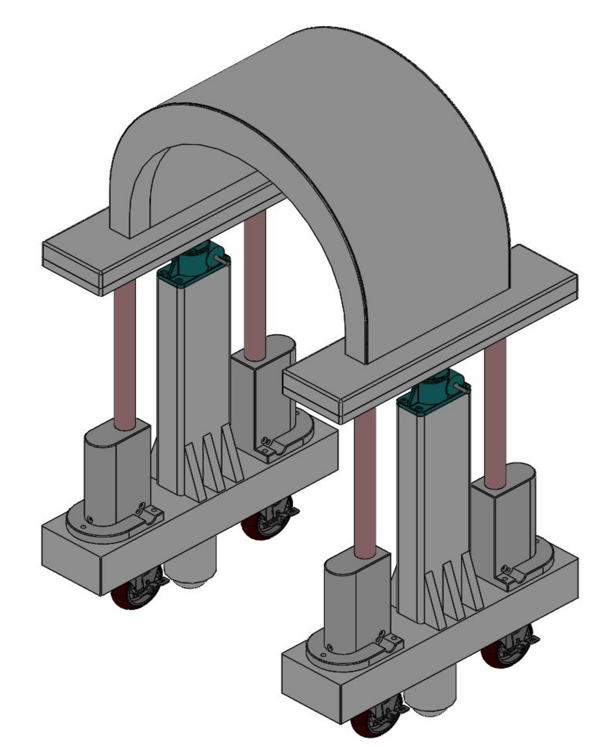


Figure 7: Modified shield design with support and transportation mechanisms

TESTING AND RESULTS

- Static load tests performed in SolidWorks to determine if steel casing could support weight of lead
- Assumptions
  - Forces due to gravity
    - Weight of A36 steel
    - Weight of lead shield
    - Weight of top casing neglected
  - Bottom faces of shield and casing treated as fixed
- Aims
  - Analyze the capability of the steel casing in supporting the weight of the lead
  - Determine where the steel casing is mostly likely to fail
  - Show total displacement that is a result of the reaction forces

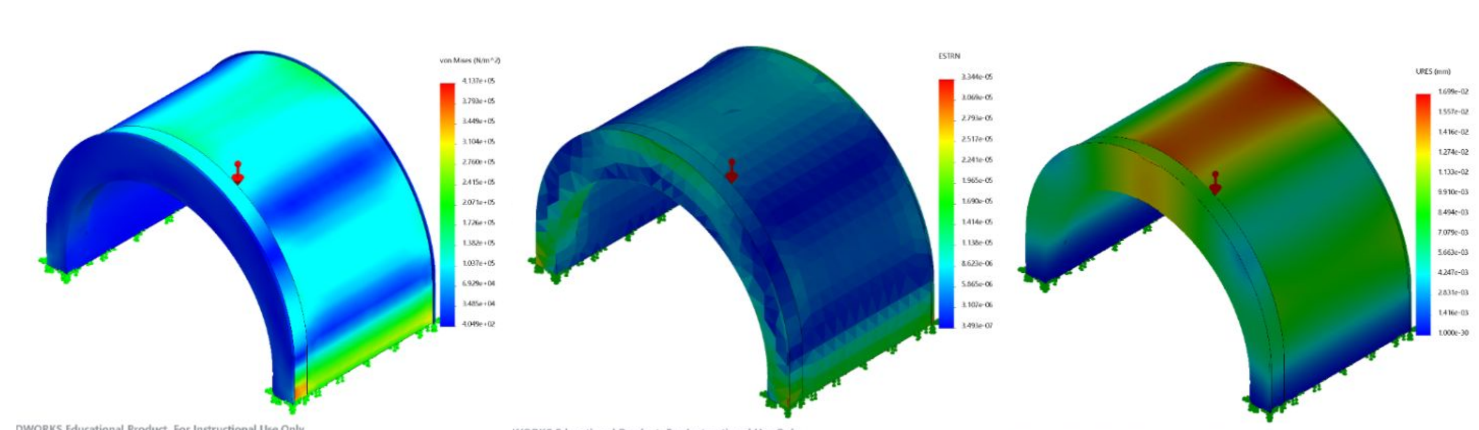


Figure 8: From left to right, the stress, strain and displacement due to gravity of the lipped half-cylinder shield. Gravitational testing was performed in SolidWorks. Green arrows indicate fixed geometry. Red arrow indicates direction of gravity.

	Von Mises Stress (kPa)
Average	13.17
Std.	9.053
Max	77.25
Min	0.4049

Table 1: Results of gravity simulation test.

DISCUSSION

- Lead and steel casing are safe when stationary
  - Max von Mises stresses on shield when stationary significantly lower than yield strengths of steel
  - Relatively small displacement of lead
- No risk of collapsing due to gravitational forces
  - Minimal stresses over top ridge of shield, which will be directly above patient
  - Failure likely to occur at sides, which is less likely to cause harm to patient
- Monte Carlo simulation not feasible
- Succeeded in significantly reducing total assembly cost but still over budget at $11,344.92

FUTURE WORK

- Additional SolidWorks testing
  - Stress testing of shield on all supports
  - Dynamic testing
  - Fatigue testing
- Reduced price for power jacks
- Integrate power and controls for lifting
- Physical prototyping and full shield assembly
- Third party testing to ensure safe design
- Phantom testing to test efficacy of shield
  - Use Solid Water^{TM} and ionizing chambers after shield has been assembled
  - Testing site available in Department of Medical Physics at UW Hospital courtesy of Dr. Wesley Culberson
- Implementation of shield in Department of Human Oncology

Figure 9: Example of how testing will be done with Solid Water^{TM} [6].

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