FETAL RADIATION SHIELD

FOR PREGNANT PATIENTS RECEIVING RADIATION THERAPY

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Abstract

One in every 1500 pregnancies in the United States is complicated by radiation therapy. Therapy for affected patients must be adjusted in order to reduce the fetal radiation dose. Typically, the angle of treatment is altered to accomplish this as there is **currently no standard protocol** to physically shield the fetus. The Department of Human Oncology at University Hospital has requested that a shield be designed that will block leakage from the head of the radiation machine as well as radiation scatter to the sides of the abdomen. Although several shield designs have been developed, they were **discontinued due to safety and cost** concerns. A shield that is **5-6 cm in width** and **made of lead** will be fabricated that is safe for the patient and medical personnel, mobile, and **able to shield 50% of radiation leakage and scatter**. In order to construct this device, a **SolidWorks model** and **non-functional prototype** will be created to evaluate the design before final fabrication will be completed, likely by a third-party source. Mechanical and clinical testing will also be necessary to evaluate the safety and effectiveness of the device.

Problem Definition

The main concern pregnant women face when receiving radiation therapy is the potential for their child to develop serious malformation. Without a shield, this risk is already quite low at approximately 0.5% chance [1], with the risk being greatest during the first week of pregnancy, when radiation effects can be lethal. After this, concerns mostly include increased risk of growth retardation, childhood cancer and microcephaly [2, 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 [2].

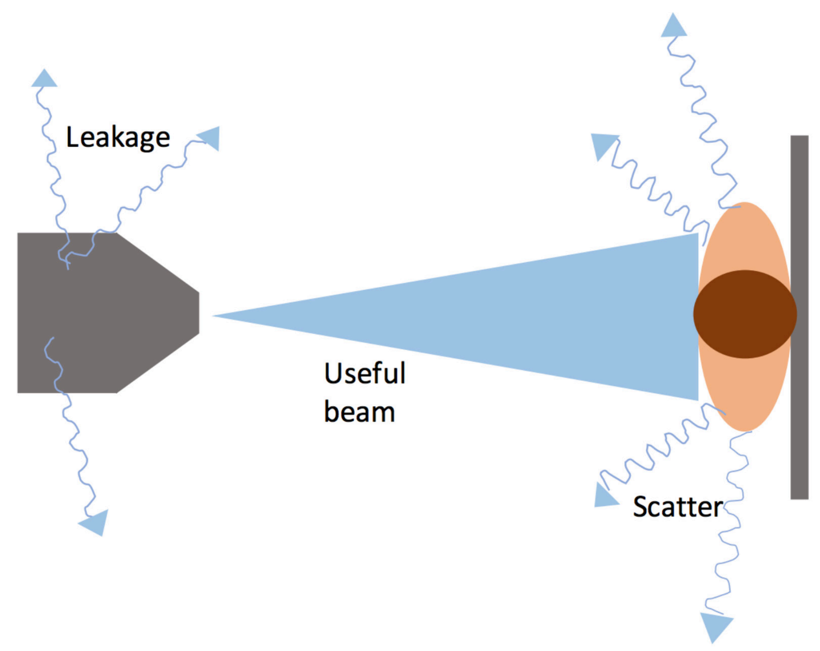


Figure 1: Radiation scatter explained, derived from [4].

MATERIAL AND SHIELD THICKNESS

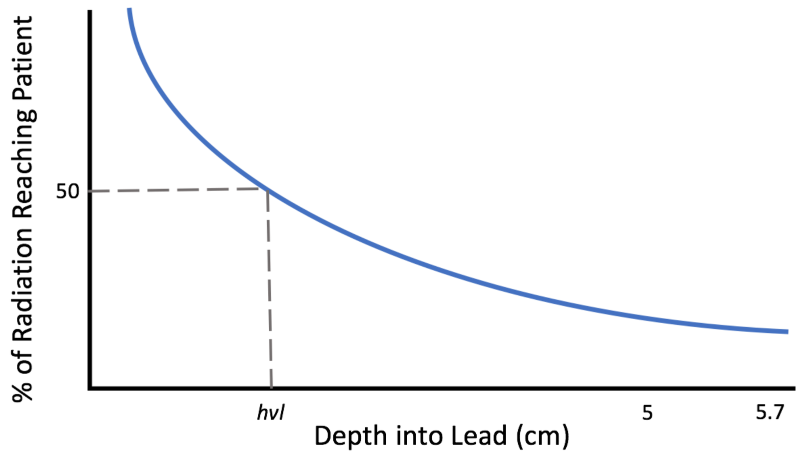


Figure 2: Rough depiction of the radiation capable of reaching the patient as a function of depth into lead, derived from [4].

Lead is the material most commonly used to block radiation [4]. The generally accepted thickness of lead required to block 90% of all radiation is roughly 5.7 cm [4], as depicted in Figure 2. Reported values for the half-value layer of lead, the thickness required to block 50% of radiation, vary, but are less than 5 cm. Thus, in order to block at minimum 50% of radiation reaching the fetus, the team decided to design a shield that is 5 cm thick.

Final Design

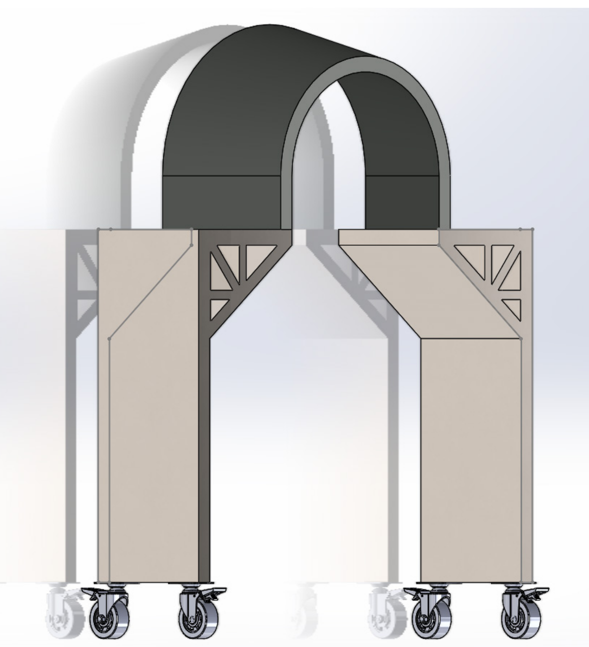


Figure 3: SolidWorks model of shield and support system, without jack-lifts.

SHIELD DESIGN

Based off of "high-waisted skirt" design from preliminary design brainstorm, not initially chosen in design matrix.

- 5 cm-thick lead
- Smaller U: 33 cm-radius semi-circle, extended 10 cm
- Larger U: 43 cm-radius semi-circle, extended 10 cm
- Design "flares out" towards larger U in a straight line, covering a total of 55 cm top-to-bottom
- Total weight: 3737 N, or 841 lbs

The high-waisted skirt shield shape will accommodate a large range of women in various stages of pregnancy.

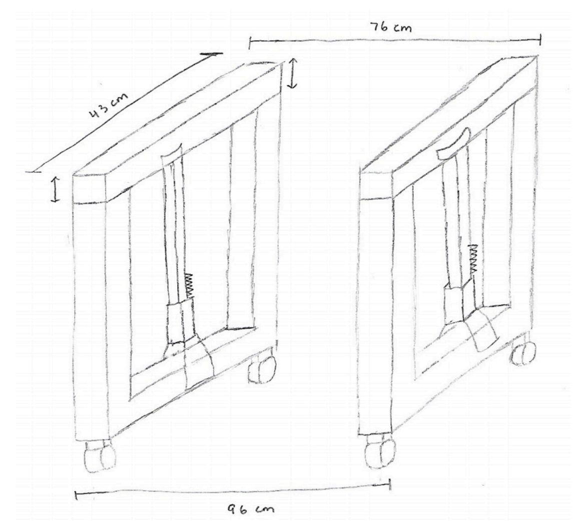


Figure 4: Sketch of the jack-lift system designed to lift the shield.

SUPPORT MECHANISM

Designed to support weight of shield and allow for translational and lifting movement required.

- Shield rests on two trapezoidal platforms
- Truss system supporting platform of shield
- Jack-lifts, one per side, raise and lower platforms and truss system
- Multi-directional wheels, as the design will need to be wheeled in sideways, but positioned straight-on
- Material not yet chosen

Testing & Results

RADIATION TESTING

- Most important part of testing in order to confirm efficacy of the design in shielding
- Impossible to do without physical lead shield
- Monte Carlo Radiation Simulation – only models targeted beam, not scatter or leakage
- No software modeling of scattered radiation due to variability/unpredictability

STRESS TESTING

- Linear static test for identifying most likely points of failure
- Expected maximum displacement of the shield (2.99855E-5) near 0, as expected
- Most likely to fail at corners, especially during movement
- Further stress testing will be necessary with support mechanism as failure is more likely

SURFACE AREA

- Surface area of the shield is used as an estimate correlated to body covered, 5963.82cm^2
- Difficulty in determining actual percentage of surface area of bodies, as patient size will vary

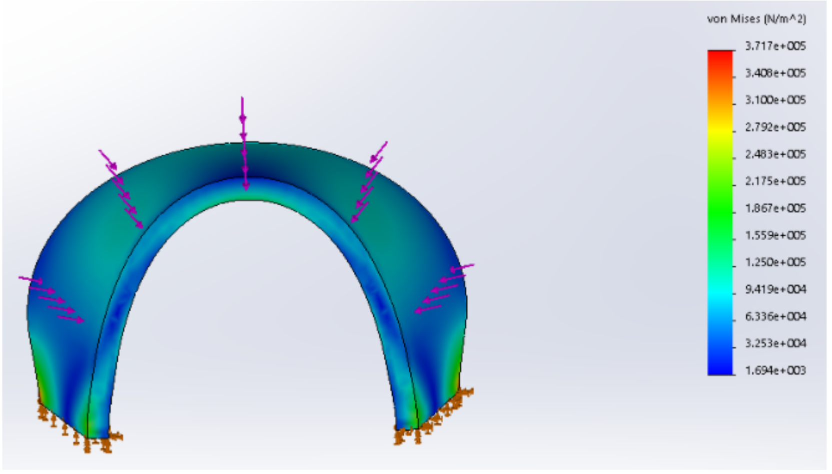


Figure 5: Static stress testing of shield design, depicting most likely points of failure and deformation.

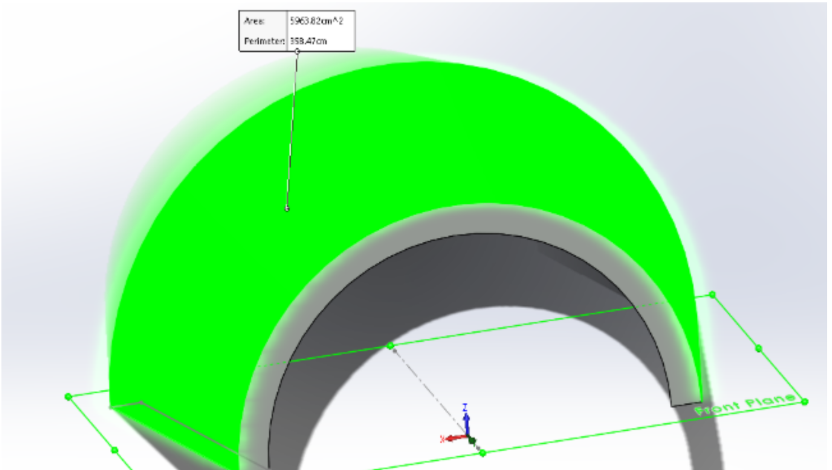


Figure 6: Depiction of surface area of shield, gives rough indication regarding coverage of patient during use.

Design Criteria

GOAL

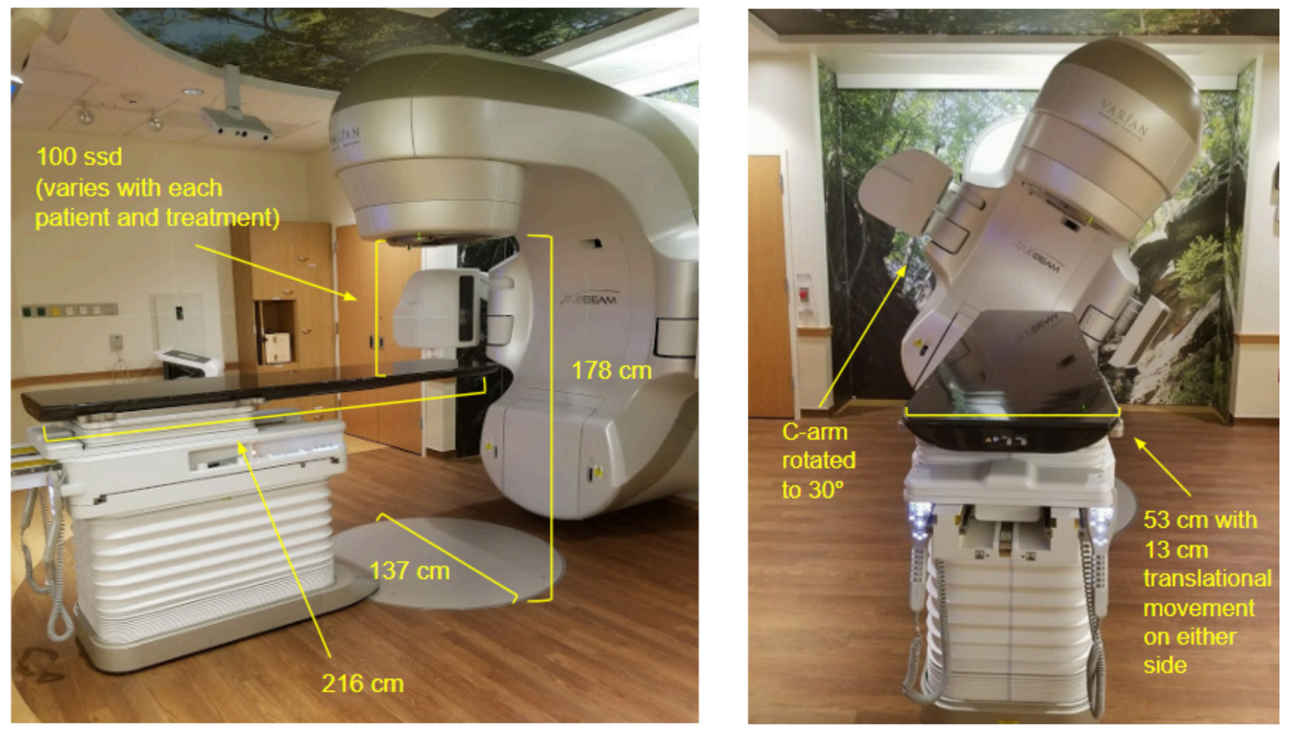
Design a 5cm-thick lead shield and corresponding support system that will physically block at least 50% of all radiation leakage to the fetus and is safe for all parties involved.

SAFETY REQUIREMENTS

- Design must not incur more of a safety concern to fetus than the radiation itself
- No exposed lead must come in contact with the patient

PHYSICAL REQUIREMENTS

- Must be able to be moved from room-to-room
- Must fit within 122 cm-wide door frame
- Must accomodate 137-cm diameter force plate
- Must be able to straddle a 53 cm wide table
- Must be able to accommodate all table heights, ranging from 116 cm to 127 cm



Figures 7 (left) and 8 (right): Typical Treatment Room at Department of Human Oncology. The left 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. The right image depicts the C-arm rotated 30^0 from vertical and the width of the treatment table.

Future Work

The team will be working with Swift Engineering and Manufacturing to manufacture the final shield. We are currently awaiting a quote.

TASKS FOR SUBSEQUENT SEMESTERS

- Finalize support design - materials selection and SolidWorks testing
- Manufacture shield
- Test efficacy of shield to block radiation using phantom
- Manufacture support
- Assembly of shield and support
- Additional testing and implementation

References

[1] 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.
[2] 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.
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[4] P. J. Biggs, "Radiation Shielding for Megavoltage Photon Therapy Machines" Boston, Massachusetts Harvard Medical School, 2010.