Rapid Prototyping Applied to the Development of Lung Calibration Phantoms from Patient-Specific Anatomical Data

Matthew Mille, Andrew Novick, X. George Xu[1]
[1]Rensselaer Polytechnic Institute, Troy, NY

October 8, 2008

Introduction

- Despite safety efforts, radiation accidents do happen!
- Radionuclides such as ^{241}Am & ^{238}Pu can enter the lungs
- To assess radioactive burden, must first identify and quantify radioactivity in the lungs
- Lung counting is most direct method

Efficiency Calibration

Detector Response ⟷ ***Retained Activity***

Physical Lung Phantoms

- **Lung counter calibrations performed using physical phantoms with removable lungs that are spiked with known activity.**
- **Existing phantoms have not been revised for decades.**
- **This research focuses on the adoption of modern rapid prototyping methods to revolutionize phantom design by using patient specific images.**

LLNL

JAERI

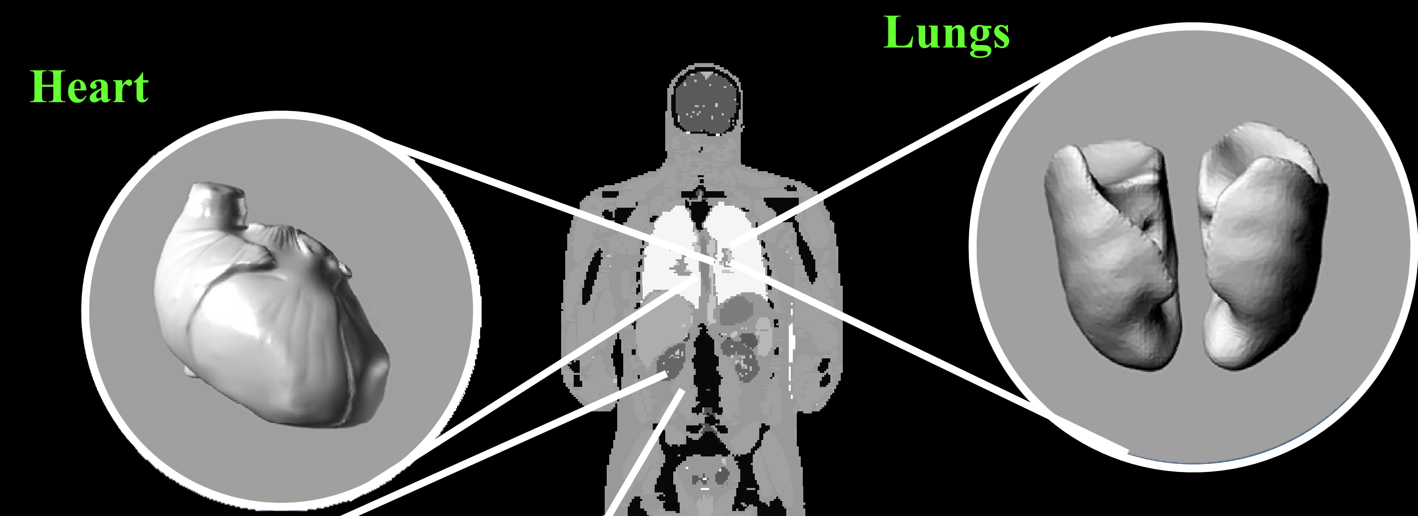
The RP Process

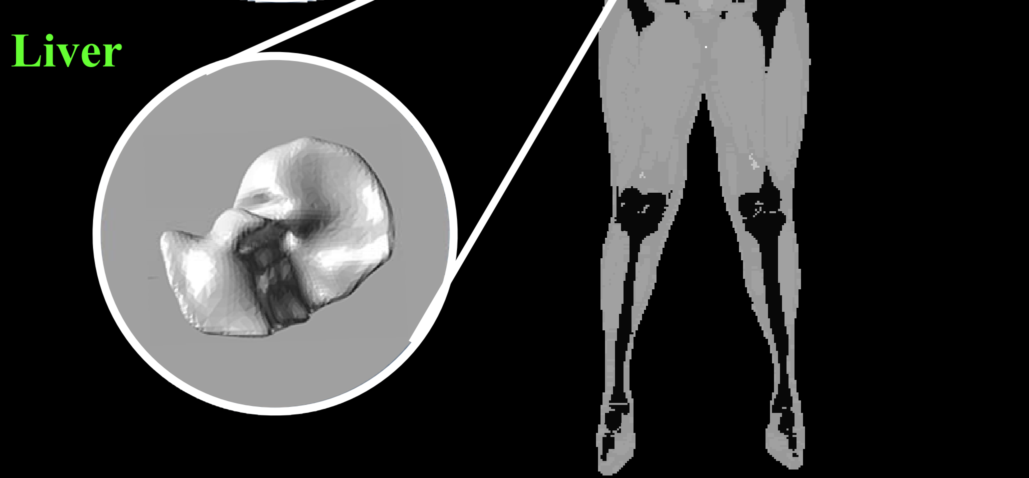
Rapid Prototyping (RP):

A group of technologies in which parts are quickly produced from 3d-data using an additive approach.

1. **Create a CAD model of the design.**
2. **Convert the CAD model to STL format**
3. **Slice the STL geometry into thin cross-sectional layers**
4. **Construct the model one layer atop another.**
5. **Clean and finish the model.**

Generating Organ Geometries





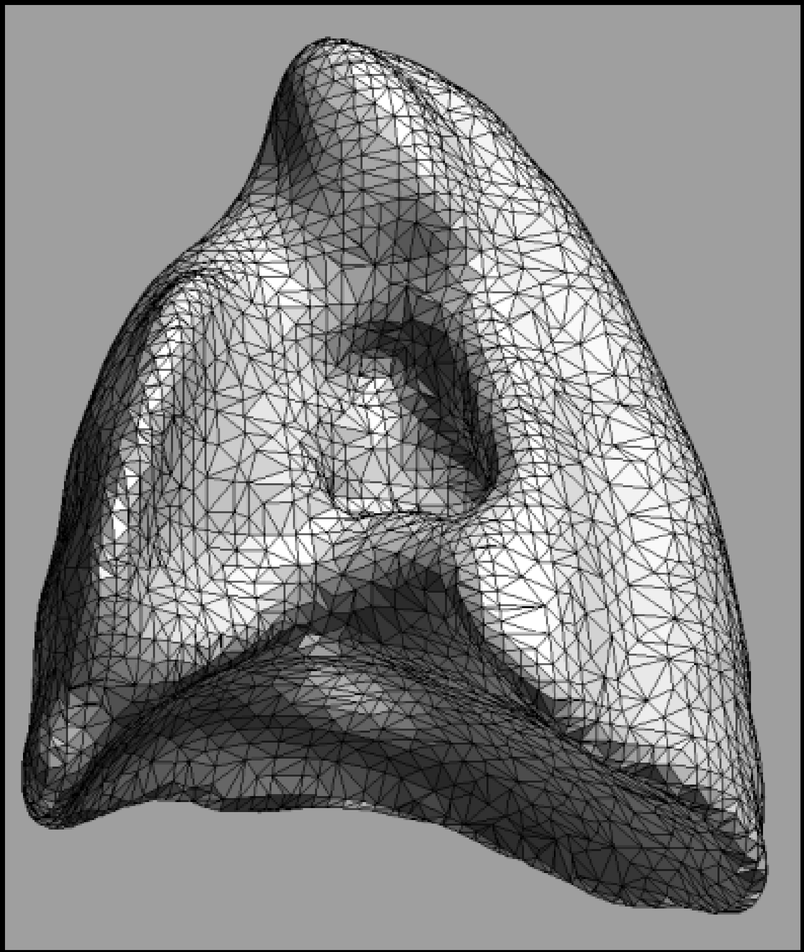
VIP-Man Voxel Phantom

High Resolution Photographs from the Visible Human dataset

(Xu et al. 2000)

- **Any anatomical dataset (CT, MRI, photos, etc.)**
- **Capture organ surface data & convert to triangular polygon mesh (STL format).**
- **Useful software: VTK, 3D-Doctor, Rhinoceros 4.0**

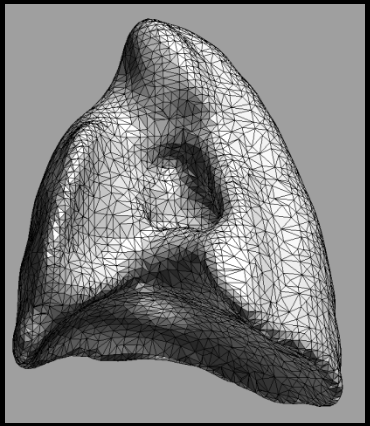
Triangular Mesh File of a Lung



- STL file lists the triangular facet data for the lung surface.
- Each face uniquely defined by three vertices and a unit normal vector.
- STL files use planar faces, thus cannot describe curved shapes exactly.
- Smaller triangles → better approximation

Rapid Prototyping A Lung

- STL file of lung ported into Z-Corp 402 3D printer (RPI's Advanced Manufacturing Laboratory)
- STL file sliced into many thin layers (0.004 inches).
- Layers printed using a plaster powder-binder process
- Cost = $3/inch^3
- Total print time = 3 hours

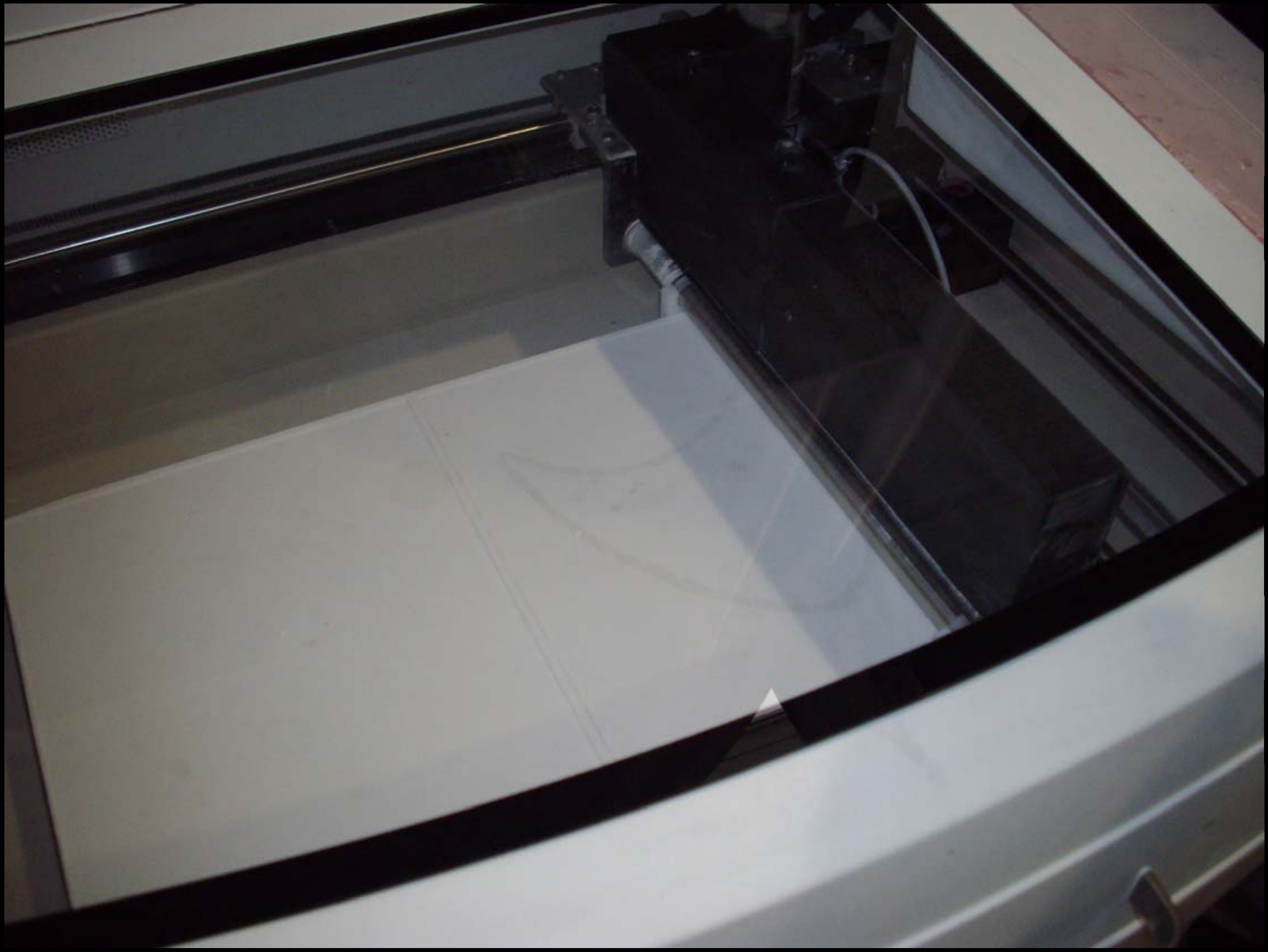


Virtual Lung

3D Printer

Physical Lung

Rapid Prototyping In Action



Producing A Lung Mold

- Plaster lung model is not tissue-equivalent
- Mold created for casting tissue-equivalent copies.
- Two-part , RTV silicone rubber block mold
- Dividing line chosen carefully to prevent locking
- Pour hole and rubber stopper.

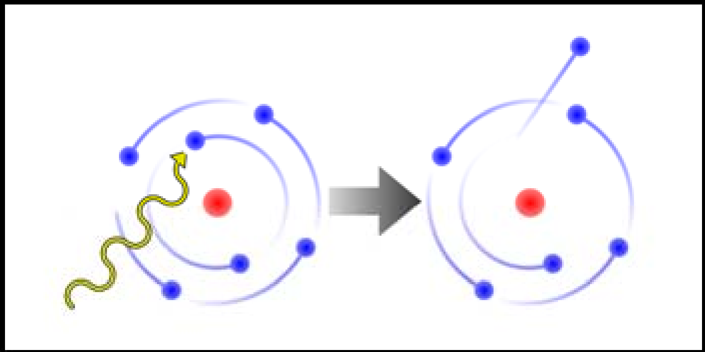
Physical Lung

Lung Mold

Designing A Lung Substitute Material

- **Objective: Find or create a material which mimics the mass attenuation (μ/ρ) of lung tissue for low energy photons.**

- **Low energy → photoelectric effect is dominant (electron density)**



- **Thus, critical the parameters for a lung substitute (ICRP 89) are:**

  1) *Density*, ρ = 0.26 g/cm³

  2) *Effective Atomic Number*, $Z_{eff} \approx 7.49$

$$Z_{eff} = \left(\sum_n f_n Z_n^{\xi} \right)^{1/\xi}$$

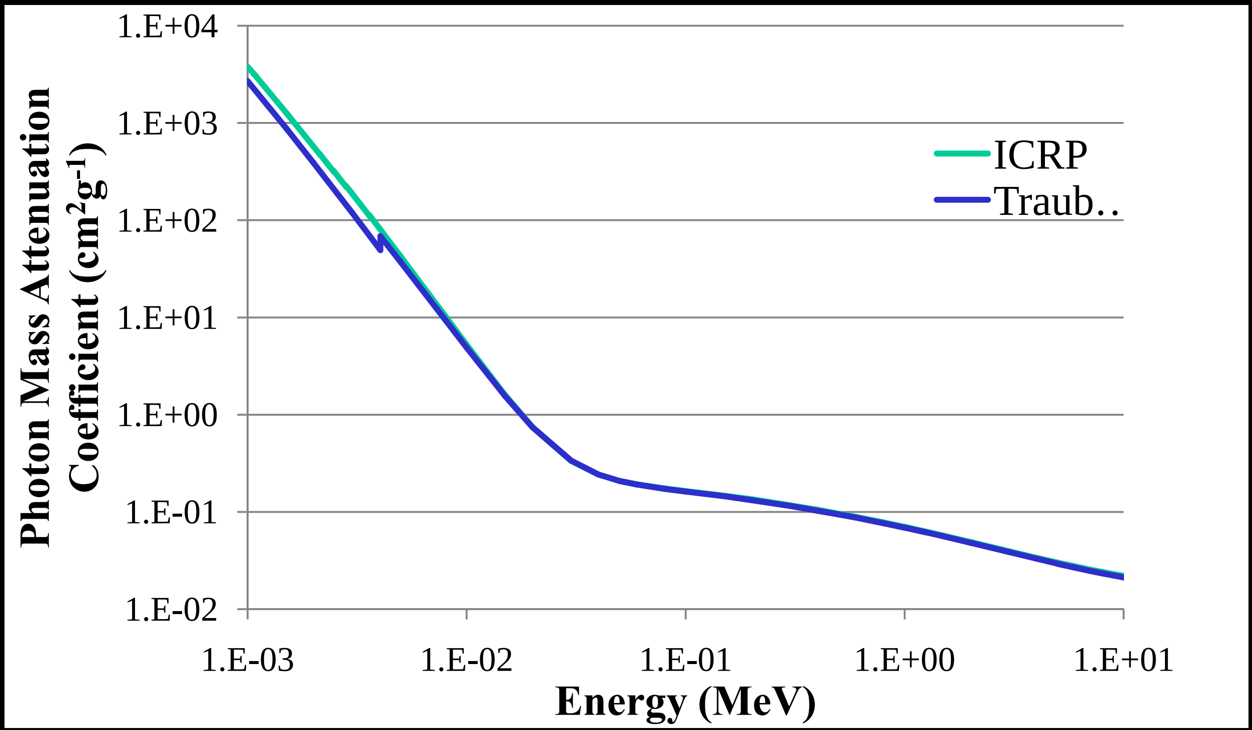
$$\xi \sim 2.94$$

(Traub et al 2006)

Rensselaer
why not change the world?℠

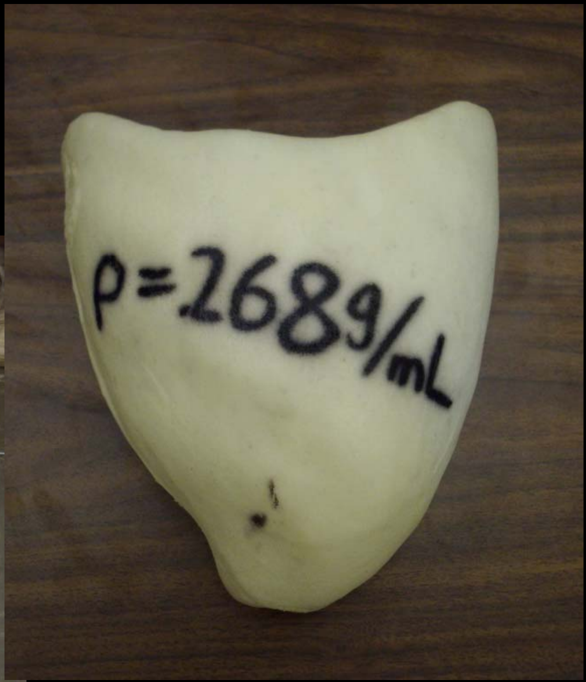
Lung Substitute Materials

- Many described in literature -- all begin with a candidate material which is then adjusted to meet specific needs.
- Two-part polyurethane foams with added 5.25% + $CaCO_3$ (Traub et al 2006)



Casting Lung Phantoms

- Density controlled by the amount of material poured into the mold.
- Volume of mold is known from the CAD model.
- Mold is clamped tightly because of the expanding force of foam.



Conclusions

- A lung phantom was created with similar geometry, density, and Zeff to real human lung.
- The process described is completely generalizable to different organs (e.g. lungs, heart, skeleton etc.)
- Rapid prototyping is a promising tool for allowing the creation of phantoms with patient-specific geometries.
- But, the prototyping materials generally cannot be used to fabricate tissue-equivalent phantoms directly.

Future

- **Addition of radioactivity to the polyurethane foam**
- **Experimentally verify the attenuation coefficients**
- **Generate new tissue substitutes.**
- **Investigation of different rapid manufacturing techniques and the possibility of customization of materials.**

Acknowledgements

- Dr. Richard Traub of PNNL
- Dr. Ken Inn, Dr. Brian Zimmerman, and Svetlana Nour of NIST
- CIRMS
- This project supported in part by:

  -U.S. Department of Commerce National Institute of Standards and Technology (70NANB7H6124)

NIST
National Institute of Standards and Technology

References

[1] Traub R. J., Olsen P.C., McDonald J.C., The radiological properties of a novel lung tissue substitute, *Radiat. Prot. Dosim.* 121(2):202-207, 2006.

[2] Xu X.G. , Chao T.C., and Bozkurt A., VIP-Man: An image-based whole-body adult male model constructed from color photographs of the visible human project for multi-particle Monte Carlo calculations, *Health Phys.*, 78(5) :476-86, 2000.