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LAWRENCE LIVERMORE LABORATORY
University of California/Livermore, California/94550

UCRL-50007-76-2

HAZARDS CONTROL PROGRESS REPORT NO. 53
July through December 1976

MS. date: February 15, 1977

Progress Reports

RADIATION PROTECTION

Continued Realistic Phantom Development

Introduction. Continued construction of the realistic phantom for calibration of transuranic isotope lung counters[1,2,3] is discussed in this progress report. Current work includes final shaping of the torso cast, development of a technique for making foamed plastic lungs loaded with transuranic isotopes, casting of tissue-equivalent (T.E.) organs, and acquisition of rib cages for the second and third phantoms.

Torso Cast. In the previous progress report[3] we noted that an important criterion of phantom construction is that the torso shell will have a thickness which simulates the x-ray attenuation of the chest wall of a very thin individual. Specifically, this means that the average transmission of plutonium x rays through the T.E. material overlying the lungs is equivalent to transmission through approximately 16 mm of lean soft tissue. The torso cast made from the cadaver which was the source of our first rib cage has now been altered to the necessary shape (Fig. 1). We made the alteration by vacuum forming a thin plastic replica of the torso contour. With the plastic shell in position over the plaster organ cavity cast, we mapped the space between. The difference between this space and the required "chest wall" thickness was removed from the torso cast to yield the final torso. "Chest plates" will now be made of T.E. material to overlay the phantom to simulate differences in human stature.

Lung Casting and Loading. Our Plastics Shop has prepared a formulation of commercially available polyurethane which will give us a density of 0.25 g/cm^3 which is equivalent to the nominal density of human lung. The material we use is polyurethane foam 1940D (Black) available from the CPR Division of Upjohn Corp. The recommended formulation has been altered by our Plastics Shop personnel to yield the desired density (30.0% 1940D component A, 68.4% 1940D component B, 0.15% water, and 1.45% acetone lanthanum nitrate solution). Our recent experience is that there is batch-to-batch variation in the foaming properties of the material, so specific tests must be made before use. Figure 2 shows a cast lung and silicone mold. We coat the finished lungs with a thin skin of unit density polyurethane to avoid contamination by radioactively loaded lungs.

One major concern over the foamed lungs and other polyurethane organs, for that matter, is the ability to introduce transuranic isotopes uniformly through finished organs. We now believe that can be done by dissolving the isotope in nitrate form in dry acetone, using lanthanum nitrate as a carrier. Dry acetone is important because unwanted water accelerates the polyurethane foaming process and alters the finished product. At present we are using 3 to 10 ml of acetone with up to 10% lanthanum nitrate in each lung section.

Of course, a key to the loading process is knowing that the radioactive material (essentially lanthanum) will be uniformly mixed through the lung volume. To test loading uniformity, we made a lung loaded only with lanthanum (no radioactive material). The lung was sliced along the plane having the largest cross-sectional area. Then, using a system which measures elemental

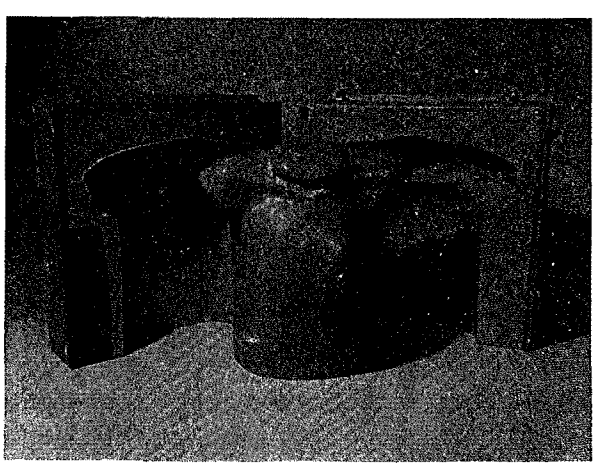

Fig. 1. Plaster torso model with silicone molds.

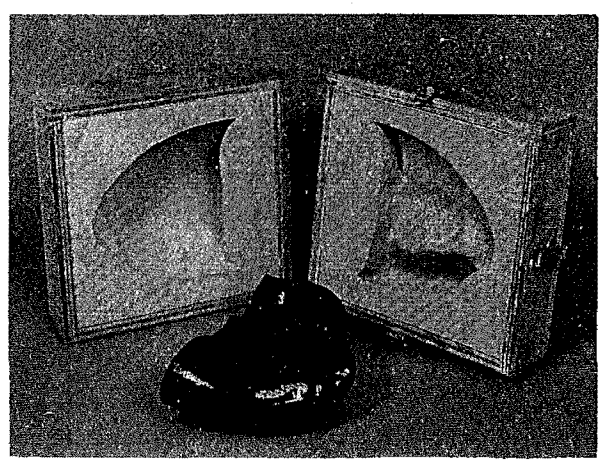

Fig. 2. Foamed polyurethane "lung" with silicone molds.

concentration by x-ray fluorescence, we mapped the relative concentration of lanthanum in the lung. The result is shown in Fig. 3. The measured variation in concentration of lanthanum through the organ volume is certainly acceptable for our requirements.

Organ Casts. Fabrication of the silicone molds of other major organs has been reported before.[3] We have now cast replicas using our T.E. plastic formulation (4.3% calcium carbonate, 95.7% polyurethane). Figure 4 shows the T.E. heart, kidneys and liver together with the actual organs.

New Rib Cages. We plan to build three phantoms in order to meet the needs of the transuranic measurements intercomparison program.[1] We have now obtained rib cages for use in phantoms 2 and 3. Although there are some differences, the new rib cages appear to fit well on the existing organ cavity mold. The second rib cage does present an interesting example of human anatomical variability. There is a bifurcation of the cartilage that connects the third rib on the left side to the sternum (Fig. 5). As a result, the rib itself is unusually wide at the point of cartilage attachment. This kind of aberration is not uncommon, and occurs during embryotic development. To maintain uniformity of the three phantoms, the rib will be trimmed before construction, and a normal plastic cartilage replacement will be used.

Work Remaining. Before casting the first torso, we must make cartilage-equivalent segments and attach them to the ribs and sternum. After casting a torso without ribs to test the molding process, we will make the first phantom torso. We must also make T.E. organ cavity filler for space not occupied by major organs. This will include provision for tracheal lymph nodes.

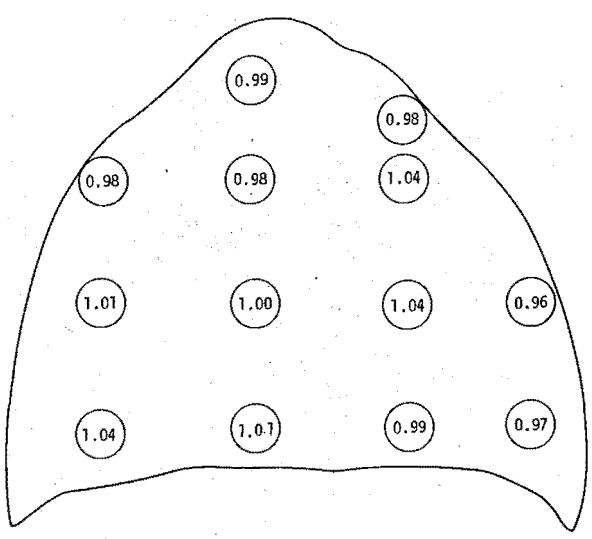

Fig. 3. Cross section of lung with map of relative lanthanum content.

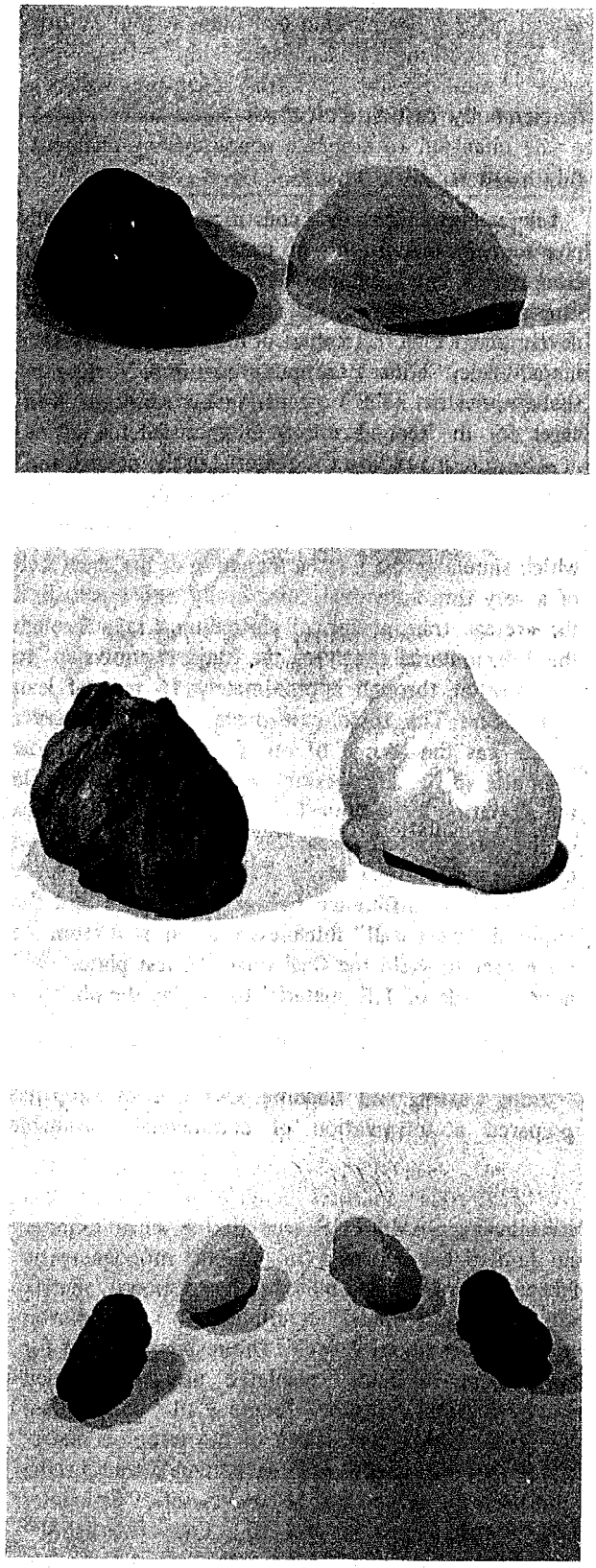

Fig. 4. Tissue-equivalent organs shown with human counterparts.
(a) Liver,
(b) heart, and
(c) kidneys.

We will make a set of unloaded lungs as well as lung sets, liver, and lymph nodes loaded with ^{238}Pu, ^{239}Pu and ^{241}Am. Finally the first phantom will be completed by casting T.E. chest plates to be placed on the phantom to simulate people having different body statures.

Acknowledgments. As usual, a number of people have contributed to this project. We would like to thank Norm Boyer, Robert Taylor, and the Plastics Shop personnel for their help and interest in all phases of the plastics work, Robert Jones at the University of California, Berkeley Campus, Museum of Vertebrate Zoology, for his help in preparing the rib cages, Ken Hulet of our Radiochemistry Division for his advice on incorporating radioactive material in the organs, and Sexton Sutherland and Jerry Ritchie at the University of California Medical Center, San Francisco, for their help in obtaining the rib cages.

Calculated Response Matrix for a Collimated 2 × 2 NaI(Tl) Gamma Ray Detector

Several small NaI(Tl) detectors are now being used at LLL to measure gamma-ray energy spectra for the purpose of determining dose rates, and to verify transport calculations. The gamma-ray continuum is of particular interest here since only a small portion of the total dose rate is due to unscattered photons. Consequently, a simple photopeak integration is inadequate for our purpose. Instead, the pulse-height response of the detectors to monoenergetic photons must be determined and unfolded from the pulse-height data to provide the full gamma-ray energy spectrum.

A code called GAMREDUX is currently under development at LLL for the purpose of unfolding gamma-ray pulse-height data. It is a successor to the GAMSPEC code[4] and uses the unfolding strategy from Mollenauer's GAMSPEC.[5] Due to the small number and limited energy range of available monoenergetic photon sources, the pulse-height response matrix cannot be determined experimentally for photon energies above about 1 MeV. The response matrix for our system is being calculated using a coupled photon-electron transport Monte Carlo code called SANDYL.[6] Upon completion of the response matrix calculation, the results will be parameterized in the form used by Berger and Selzer.[7] A set of parameter data is then used by the LLL code GAMRESP[8] (described elsewhere in this report) where a smoothed and rebinned matrix is produced for input to the GAMREDUX unfolding code.

Pulse-height response of the NaI(Tl) detector is described, using the definitions from Ref. 7. First, the response function $R(E_\gamma,h)$ is given by Eq. (1) below:

$$R(E_\gamma,h) = \eta(E_\gamma) \int_0^\infty D(E_\gamma,E_d)\, G(E_d,h)\, dE_d \tag{1}$$

where

$R(E_\gamma,h)dh$ = probability that a gamma-ray incident on the detector with energy E_γ will produce a pulse with height between h and h + dh.

$\eta(E_\gamma)$ = probability that an incident gamma ray at energy E_γ will interact at least once in the detector.

$D(E_\gamma,E_d)dE_d$ = probability that the gamma ray, if it interacts in the detector at all, will deposit an amount of energy E_d between E_d and $E_d + dE_d$.

$G(E_d,h)dh$ = the probability that the deposition of energy E_d will give rise to a pulse with height between h and h + dh.

Then the pulse-height distribution P(h) is given by Eq. (2) below for a gamma-ray differential flux, $\theta(E)$ photons/cm^2-s-MeV:

$$P(h) = A\,T \int_0^\infty R(E_\gamma,h)\, \phi(E_\gamma)\, dE_\gamma \tag{2}$$

where

T = length of data acquisition (s)

A = effective cross-sectional area of detector (cm^2).

Fig. 5. Close-up of human ribcage showing bifurcation in cartilage and rib.

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