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THE DEVELOPMENT OF A MATHEMATICAL PHANTOM, REPRESENTING A 10-YEAR OLD FOR USE IN INTERNAL DOSIMETRY CALCULATIONS

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THE DEVELOPMENT OF A MATHEMATICAL PHANTOM REPRESENTING A 10 YEAR OLD FOR USE IN INTERNAL DOSIMETRY CALCULATIONS[1]

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ABSTRACT

With the increasing growth of nuclear energy generating facilities estimates of absorbed dose to population groups (e.g. children) are required. In addition children are being exposed to many nuclear medicine procedures and accurate dose estimates are needed. The main purpose of this research is to design a mathematical phantom representing as closely as possible a 10-year old child

The phantom was similar in shape to the adult phantom of Snyder and Fisher but several changes were made in the design to make the phantom more realistic. These changes included the addition of neck and feet, placing the arms outside the trunk section changing the shape of the trunk region and a redesign of the male genitalia region. Several modifications were made to the idealized skeleton For example the skull ribs pelvis spine scapulae and clavicles were redesigned to approximate more closely the true anatomical shapes Some internal organs were modified as a result of the above changes. These organs included the brain lungs liver and the large and small intestines. However in all cases an attempt was made to modify the shapes and locations in a manner such that they were more representative of those of the 10-year old child.

A description of the phantom and its utility will be presented. Estimates of absorbed dose obtained with this phantom are expected to be significantly different from those estimates derived through the use of simpler models These differences and their significance will be also discussed.

INTRODUCTION

With the increasing growth of nuclear energy generating facilities, estimates of absorbed dose to other population groups (e.g., children) are required In addition, children are being exposed to many nuclear medicine procedures and accurate dose estimates are needed. Snyder and Fisher recognized this need and reported on the design of six phantoms for use in dosimetry calculations[4] The phantoms corresponded to the ages 0 (newborn), 1, 5-, 10-, 15-, and 20-years (adult) In actuality, the phantoms of ages younger than the adult were obtained by reducing each of the three regions of the adult phantom (head, trunk, and legs) by factors chosen to be representative of the particular age. All organs, etc., within each region were "shrunk" by the same factors and changes in organ shape, location, etc., were ignored.

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The physiological geometry of a child is different from that of an adult. For example[4] the weight of the head with respect to total body weight is greater for a child than an adult[6] the trunk of a child is more cylindrical than the adult trunk (which is best represented by an elliptical cylinder) and[8] some internal organs, such as the thymus gland are larger with respect to other major organs in the child. Such factors as these may lead to gross uncertainties in calculated dose estimates for children

The purpose of this research was to develop a phantom representing a 10-year old child and to use this phantom as the basis for dosimetric studies similar to the adult. Phantoms representing children of ages 0 (newborn) 1, 5- and 15-years have been designed recently[6,8] This phantom the 10-year old' represents the last of a sequence of phantoms considered necessary for dose estimation purposes[9] An initial literature survey was made to determine organ mass shape and location in a normal 10-year old child These data were used to construct a mathematical representation of the child for use in computer calculations of absorbed dose for typical exposure situations Although the design is not yet finalized this papers is intended to report recent progress and to point to a design which may represent the first in a new generation of phantoms for pediatric dosimetry

DESCRIPTION OF THE PHANTOM

In the design of a phantom representing a 10-year old many anatomical factors were considered The other phantoms in this group were designed in a manner similar to the adult phantom of Snyder and Fisher[3] However for the 10-year old the objective was to make the phantom as realistic as possible Thus the new design has several features not included in any of the previous phantoms. For example the neck region was more realistically designed the arms were taken out of the trunk, and the trunk was redesigned to allow for the appropriate thickness of soft tissue between the outer surface of the phantom and the spine and sternum In addition the genitalia region was modified (defined as one quarter of an ellipsoid) and a region representing the feet was added These new features are apparent in Figures 1 and 2 Similar changes were made in the design of many of the internal organs.

Skeleton

The head region was completely redesigned to be much more realistic A mandible was clearly defined and a region representing the teeth was added This modification was necessary in order to make the phantom useful in the evaluation of dental x ray exposures.

The shape of the cranium was represented by an ellipsoid cut by a plane The cranium also contains the brain which has the same general shape as the inside of the cranium In addition there are openings in the skull to represent the eye sockets and the nasal region These features are shown more clearly in Figure 3

In the trunk region the rib cage (ribs and sternum) were completely redesigned. In previous designs the ribs were parallel to the XY plane and each rib had the same dimensions and mass. Previously, no provision was made for a region representing the sternum The new rib cage was described as the region between parts of two concentric ellipsoids. Figure 3 shows the new design clearly

In order to be compatible with the newly designed rib cage the spine was designed to have an "S" shape. The spine has an elliptical cross section with the axis increasing from the thoracic region to the lumbar region. As can be seen from Figure 3 the pelvis was redesigned keeping in mind the relationship between the superior aperture (or inlet) and the inferior aperture (or outlet) The illium was defined as a region between two concentric ellipsoids while the anterior part of the pelvis (the os pubis and ischium) are defined as being located between the halves of two concentric circular cylinders.

The total mass of the skeleton was 4 573 g The mass of the bone was 3 413 g red marrow had a mass of 600 g and yellow marrow was assigned a mass of 560 g The masses

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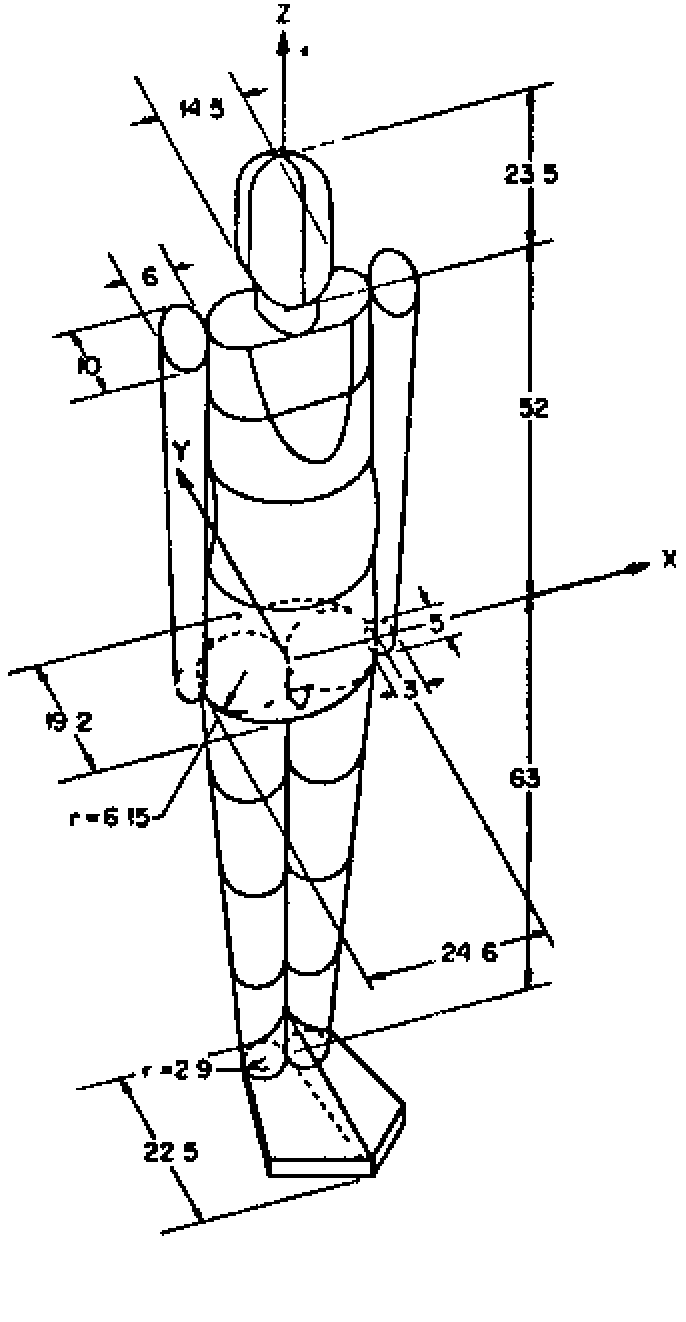

Figure 1 – Ten-year-old phantom (All measures are in centimeters)

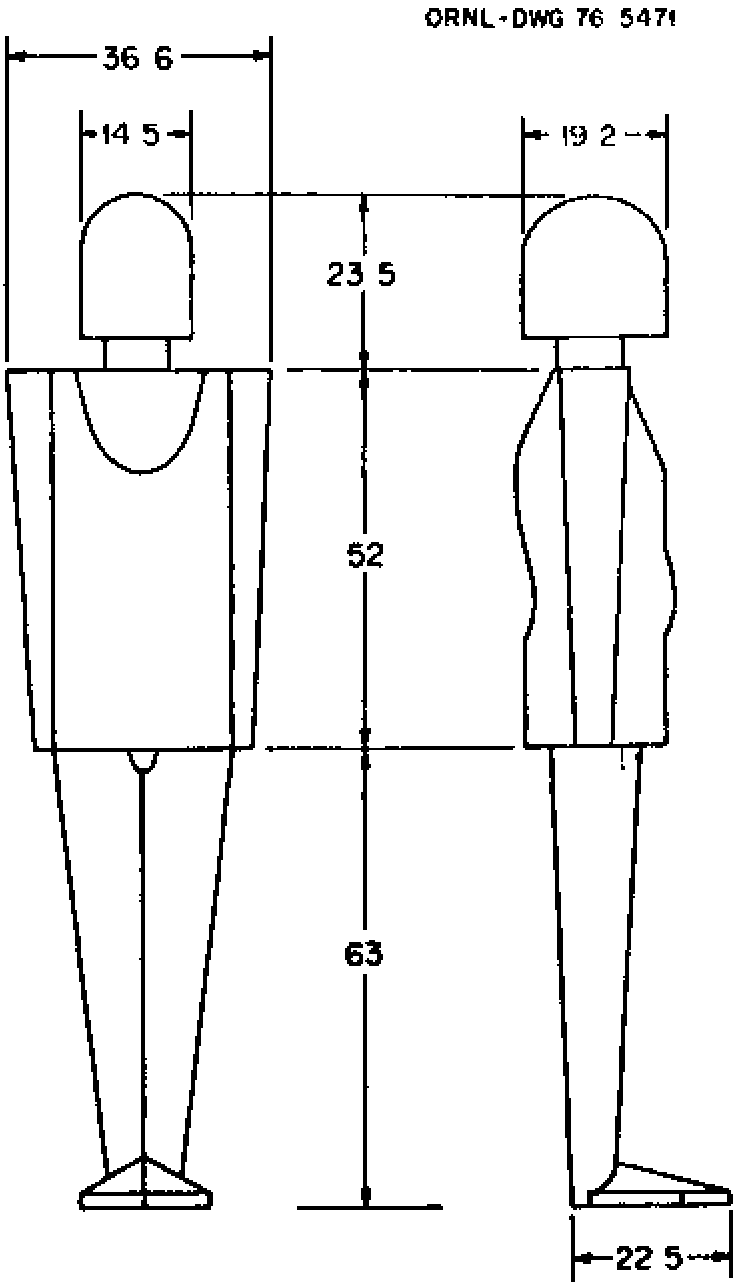

Figure 2 – Front and side view of ten year-old phantom (All measures are in centimeters)

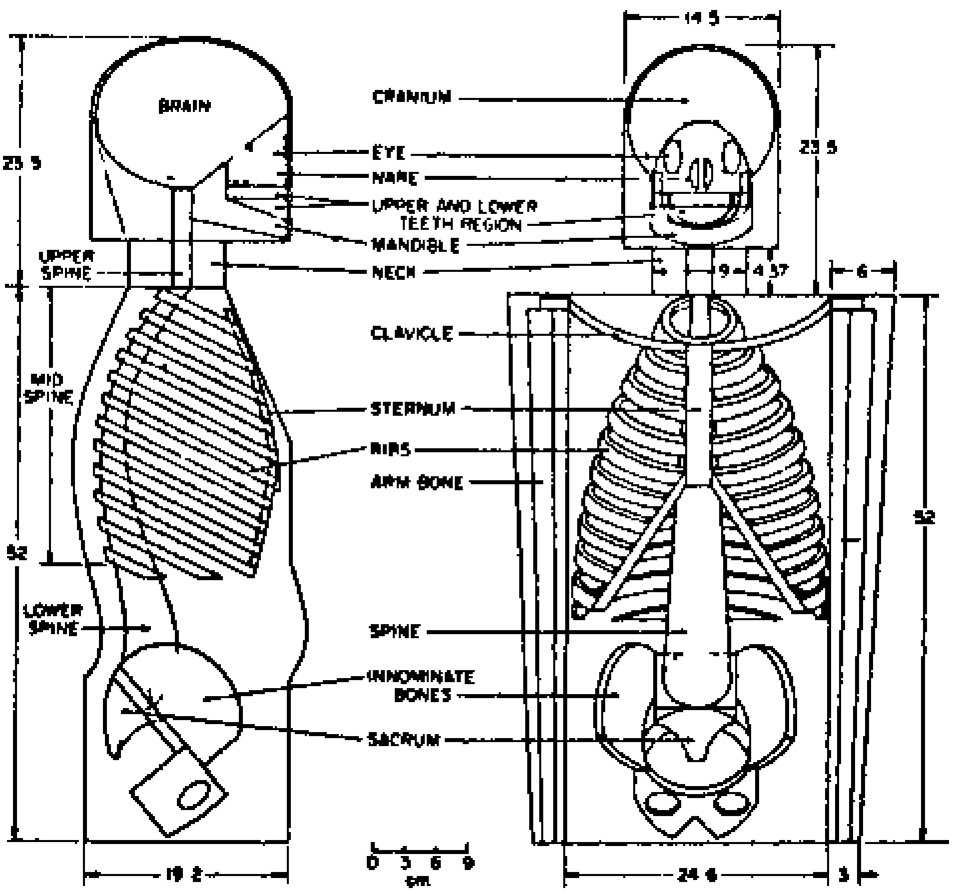

Figure 3 – Idealized ten year-old human skeleton (All measures are in centimeters)

of the red and yellow marrow in the individual bones as well as the bone masses are shown in Table I.

Table I

Masses of Red and Yellow Marrow and Bone in the Phantom

Bone Region	Red Marrow (g)	Bone (g)	Yellow Marrow (g)
Arms			
Upper	25.3	116.9	24.3
Lower	29.4	203.9	41.6
Clavicles	6.7	25.6	2.0
Legs			
Upper	83.4	421.8	92.5
Lower	56.6	330.8	80.0
Ankles and feet	44.1	195.4	62.3
Innominates	89.5	323.0	44.3
Ribs and Sternum	55.8	254.2	43.5
Scapulae	25.2	127.9	1.9
Skull			
Cranium	43.9	737.2	77.7
Mandible	4.1	75.8	7.4
Spine and Sacrum	136.0	600.5	82.5
Total	**600.0**	**3413.0**	**560.0**

Internal Organs

Many organs were redesigned in order that the organs fit into the new shape of the trunk and the skeleton. In some cases, however, a shape similar to those of Snyder and Fisher[3] was used. Space does not permit the listing of the detailed equations, etc. here. Table II shows the organ masses for many of the internal organs. In addition, these data are compared to the data of Wellman et al[14] who attributed most of the data to Spector[13]. Our analysis of Spector's data did not produce the same values as reported by these authors. However, the differences can not be considered significant. In general, for the phantom proposed here, organ masses are slightly lower than those proposed ten to twenty years ago.

Table II

Summary of Organ Weights for the 10-Year Old

Organ	ORNL (g)	Wellman et al (g)
Brain	1 355	1 313
Bladder Wall	22	–
Intestines	–	820
Kidneys	178	187
Liver	896	918
Lungs	426	523
Red Marrow	600	–
Yellow Marrow	560	–
Ovaries	3.2	3.5
Pancreas	27	30
Skeleton	4 573	–
Spleen	80	101
Stomach	88	90
Testes	1.9	2.0
Thyroid	8.8	8.0
Total Body	32,000	33,500

UTILITY OF THE PHANTOM

The phantom described briefly in this paper represents another step toward realistic models for use in dose estimation. This design will be incorporated into Monte Carlo dosimetry codes and estimates of absorbed dose will be obtained for many exposure situations. However, it is difficult to predict accurately the effect this more realistic design will have on the field. It is well known that children are being exposed in diagnostic radiology and nuclear medical procedures. And further, it is important that accurate dose estimates be made available so that benefit risk evaluations can be made.[10] Preliminary estimates indicate large discrepancies (for some organs) between the dose estimates obtained from the similitude phantom technique and the newer pediatric phantoms.

It is anticipated that this phantom and the Monte Carlo dose code will find applicability in pediatric radiology and pedriatic nuclear medicine. More reliable dose estimates for certain medical procedures can focus the attention of the medical physicist on the necessity of optimizing the exposure while providing the best clinical information Evaluation of the exposure of population groups such as children to the effluents of nuclear power reactors fuel processing plants etc in another obvious application of this development

DISCUSSION

SYED I have two questions What is the difference between the newer model and the old model and how much difference is there in absorbed dose estimates? The second question is how did you get the different values for the marrow and the bone for a 10-year old child? If from autopsy data how you get the marrow out of the bone?

DEUS In the MIRD No 5 model, the head neck and the trunk were cylinders and didn t have a plane cutting in front and the back was not curved

SYED If I don t use your refined model how much error will I make in estimating the radiation dose?

DEUS Well we can t say that would be the difference in absorbed dose at this point. We would be able to answer your question only after we finish

SYED The second question was about the marrow and the bones of a 10-year old child

DEUS It s a good question and it was very difficult to get the mass of those bones We used Borisov and Marei for the percentages of each bone with respect to the whole body skeleton A factor was used from Bardeen correcting the size of the head and other bones of an adult to the 10-year-old The values for the marrow were taken from Bernard Schleien who gives the percentage of read marrow in each bone and from the Reference Man report we have the total red and yellow marrow as a function of age This is what we used and the references are included in the proceedings with the paper

RESUMO

Com o aumento do numero de equipamentos de geração de energia nuclear uma estimativa precisa da dose de radiação absorvida pela parte da população não ligada a trabalhos com radiação se faz necessária. Especialmente importante é a determinação da dose absorvida nos órgãos dos individuos da parte da população representada pelas crianças O principal objetivo deste trabalho é o desenvolvimento de um fantasma matemático representando da maneira mais próxima possível uma criança de 10 anos de idade

O fantasma era similar na forma ao fantasma adulto de Snyder e Fisher porém diversas mudanças foram feitas no projeto para torná-lo mais realístico. Essas mudanças incluíram a adição de um pescoço colocação dos braços fora da região do tronco, modificação na forma do tronco e dos órgãos genitais Diversas modificações foram feitas no esqueleto. Por exemplo os ossos da cabeça costelas pelvis coluna vertebral escápulas e clavículas foram redesenhados a fim de aproximarem ainda mais das formas anatômicas reais Alguns órgãos internos como o cérebro pulmões fígado intestino delgado e intestino grosso foram também modificados em consequência das mudanças acima. Em todos esses casos as modificações foram feitas não só nas formas mas também nas posições dos órgãos e ossos de maneira tal que eles fossem mais representativos da criança de 10 anos de idade

Uma descrição do fantasma e sua utilidade será apresentada Estimativas da dose absorvida obtida com este fantasma poderão ser significantemente diferentes das estimativas feitas usando modelos mais simples Essas diferenças e seus significados serão também discutidas

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