permits one to make any significant measurement of effective integrated thermal neutron infiltration.

In developing these and other studies the operational routine of the reactor will be markedly varied. It is hoped that it may be used for very large neutron burst pulses as well as more usual continuous operation. Thus far the maximum power level reached is 3 megawatts; the reactor design permits continuous operation at this power.

Brookhaven National Laboratory

While the reactor has been described largely in terms of its development of Brookhaven's medical program, it must be made clear that it is one dramatic representative product of the interplay between various scientific and engineering disciplines represented on Brookhaven's staff. In this environment the staff of the Medical Research Center is composed not only of medical department members but also of colleagues working daily within their own specialties, who come from the reactor operations, nuclear engineering, chemistry, physics, instrumentation, and health physics departments of the laboratory.

Brookhaven National Laboratory is a civilian academic establishment, operated under the guidance of nine major private universities of the Northeast area. They supervise its administration through a corporate entity, Associated Universities, Inc., chartered under the education laws of New York State. Supporting funds are obtained by the corporation from the U.S. Atomic Energy Commission under terms of a specific contract (*4*).

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X-ray Emission from Television Sets

The gonad dose to the population is evaluated on the basis of laboratory and field measurements.

Carl B. Braestrup and Richard T. Mooney

It has long been realized that any electronic tube operating at a potential above a few thousand volts may be a source of x-radiation. The need for eliminating any resulting hazards received official recognition by the American Standards Association in 1946 (*1*). It was specified that the radiation level at any accessible region "shall not exceed 12.5 mr/hr"—that is, 100 milliroentgens per 8 hour day, the then-prevailing maximum permissible dose (MPD). The purpose of this requirement was to prevent radiation injury to the individual; no consideration was given to genetic effects at that time. The maximum permissible dose has since been progressively reduced; the present limit for radiation workers is an average of 100 mr per week.

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Since the publication of the reports of the International Commission on Radiological Protection (*2*), the National Academy of Sciences (*3*), and the British Medical Research Council (*4*), attention has been focused on the genetic effects of ionizing radiation. It is now agreed that the dose to the gonads should be kept as low as possible without sacrificing the many benefits associated with the use of radiation. For this reason, a further reduction has been made in the maximum permissible dose for persons not occupationally exposed. For individuals in the environs of radiation areas, the National Committee on Radiation Protection (*5*) has set the maximum permissible dose at 0.5 rem per year. An additional limit has been recommended for the exposure of large population groups. The National Academy of Sciences has proposed that the average exposure of the population's reproductive cells to radiation above the natural background, but including the contribution from medical exposure, should be limited to 10 r from conception to age 30. The International Commission on Radiological Protection has recommended that the genetic dose to the whole population from all sources, additional to the natural background, should not exceed 5 rems plus the lowest practicable contribution from medical exposure (*6*). Consequently, even sources of minute radiation are of interest if they affect a large percentage of the population. Yet there have been very few scientific publications concerning sources of nonuseful x-rays such as cathode-ray tubes, oscillographs, electron microscopes, and television and other electron tubes (*7*). Of these, home television is of particular genetic interest because a high percentage of the population is involved.

The present study includes an estimate of the average per capita dose to the gonads from home television sets, based on radiation measurements on representative types of television tubes and the results of laboratory depth dose measurements required to determine the actual dose to the gonads.

Instrumentation

Highly sensitive instruments are required to measure the low level of radiation. Scintillation and thin-window Geiger-Müller counters have the required sensitivity (*8*) but are quite dependent on wavelength. For quantita-

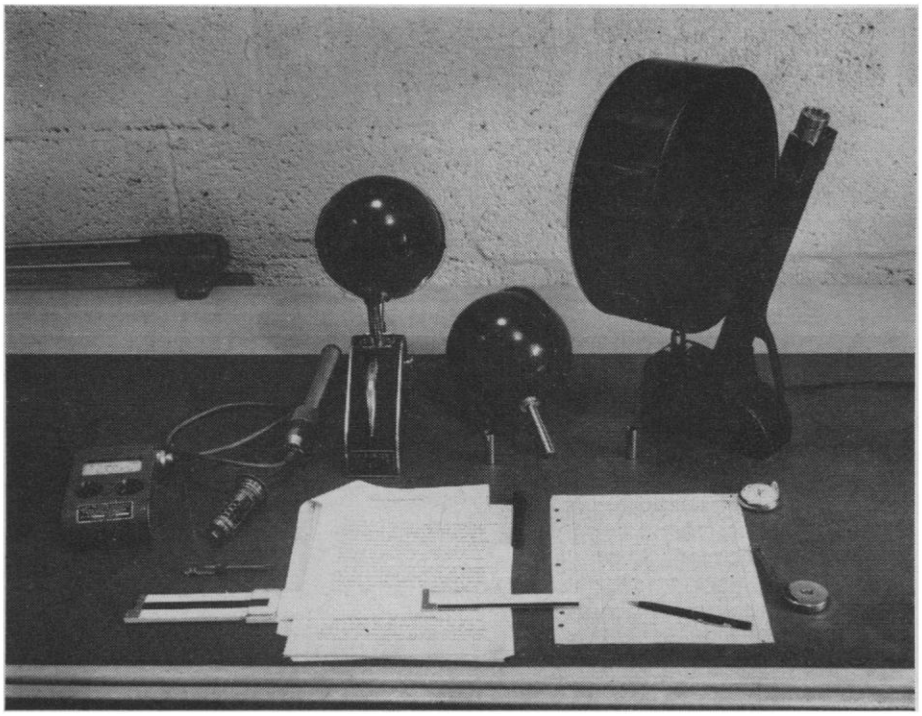

Fig. 1. Some of the chambers and electrometers used in this investigation.

tive measurements, use of condenser ionization chambers in conjunction with a sensitive electrometer was found to be most satisfactory. The condenser chamber has the advantage that the ionization can be integrated over a suitable period of time. The initial chamber, constructed in 1947 for television measurements, had three flat parallel electrodes, the center one consisting of a fine-mesh nylon gauze coated with aquadag to make it conductive. This design insured a relatively uniform electric field in the chamber, but by replacing the flat center electrode with an aluminum collector rod, the capacitance was decreased with a resultant increase in the sensitivity of the chamber. This type of chamber does not have a uniform electric field, but the interelectrode potential was found ample to prevent ion recombination in the low-level radiation fields of interest.

The potential across most home television picture tubes is relatively low, from 10 to 25 kv. The emitted radiation is essentially monochromatic, because of the high filtration effect of the heavy tube wall. Thus, the energy of the *emitted* radiation in thousands of electron volts corresponds to the accelerating potential in thousands of volts. It is still necessary, however, to use an ionization chamber with a thin window, for the x-rays are produced over a large area of the screen and enter the ionization chamber at different angles; with a thick-walled chamber, the resultant oblique filtration would cause significant dependence on energy which cannot be corrected for in its calibration against a standard open-air chamber using a nearly parallel beam from a very small target. The chambers used in this investigation had windows of polystyrene with a thickness of 0.5 mm, or less.

In addition to the chamber described above, spherical and cylindrical chambers were used when it was desirable to have minimum directional variation in sensitivity. Figure 1 illustrates some of the chambers and electrometers used in this investigation.

Tube Potential and Panel Distance

A beryllium window x-ray tube (AEG-50) was used to determine the attenuation of various types of viewing panels and samples of flat glass cut from such panels. The density of the samples (2.6 gm/cm^3) was slightly greater than that of clear plate glass (2.5 gm/cm^3) due to the presence of materials of higher atomic number. The x-ray tube was operated at constant potential of 15, 20 or 25 kv; the current was 20 ma. The x-ray tube was used also to determine the quality of the transmitted radiation and the percentage depth dose at the levels of the gonads.

The x-ray tube potential was determined by means of a milliammeter and a 125-megohm Taylor-type resistor. A Variac provided vernier control of the tube potential under load, while line fluctuations were minimized by means of a 2-kva voltage stabilizer. These precautions were necessary because of the great dependence of exposure rate on the tube voltage, as is illustrated in Fig. 2. As indicated, a similar relationship was obtained on a conventional 21-inch television tube. For the voltage range generally used on television sets, the x-ray emission varies approximately as the 20th power of the tube potential. Radiation measurements on television sets, therefore, have very little meaning unless the tube voltage has been very accurately established and maintained.

Most of the field measurements were made very close to the panel of the tube in order to secure sufficiently high readings and to minimize errors due to normal variations in background radiation. It was necessary, therefore, to establish the relationship between the radiation level at the panel and the level at the usual viewing distance, which is essentially equal to the gonad distance. A special television tube with a thin glass panel was used in order to obtain high readings at even greater distances. The thickness of the panel, however, was ample to insure nearly monochromatic radiation similar in quality to that obtained from a conventional television tube. Figure 3 shows the results of these measurements. It will be noted that there is no significant variation in the radiation level for distances within 8 cm of the surface. This might be expected, because of the large area of the radiation source. Between 8 and 100 cm, the reduction is considerably less than is indicated by the inverse square law. The relative radiation levels at various distances from the panel depend on the raster size and tube potential. Since the measurements were made with a large raster and high voltage, there is a maximum deviation from the inverse square law, and this graph, therefore, represents the worst condition that might be expected. It is obvious that this relationship is of primary importance in utilizing the results of measurements made at close distances.

Quality Determinations

Figure 4 shows the results of transmission measurements made at usual operating voltages with various thicknesses of flat samples of panel glass. It

Table 1. Half-value layers and corresponding energies.

Tube potential (kv)	Half-value layer Glass (mm)	Half-value layer Al (mm)	Energy (kev)
15	0.17	0.30	14
20	0.34	0.60	19
25	0.60	1.10	24

will be observed that the transmission curves become straight lines for relatively thin samples of glass. Measurements were also made on actual panels 7 to 11 mm thick; their transmission curves were found to be linear extensions of those shown for the samples. Thus, the radiation emitted from television tubes is, as stated, essentially monochromatic. In addition, the curves indicate that only a minute fraction of the emitted radiation is transmitted through the glass panel. Even at an operating voltage of 20 kv, which is higher than that used on most black-and-white sets, the thinnest panel glass attenuated the radiation by a factor of more than 100 million. The attenuation coefficient at higher voltages is obviously less. This, however, is partially compensated for by the increased panel thickness, higher voltages being used mainly with larger-sized screens where the panel thickness has to be greater to insure adequate mechanical strength.

Even minute variations in the amount of materials of high atomic number present in the glass cause great changes in the attenuation coefficient (*9*). It is desirable, therefore, to establish the equivalence of glass in a pure material

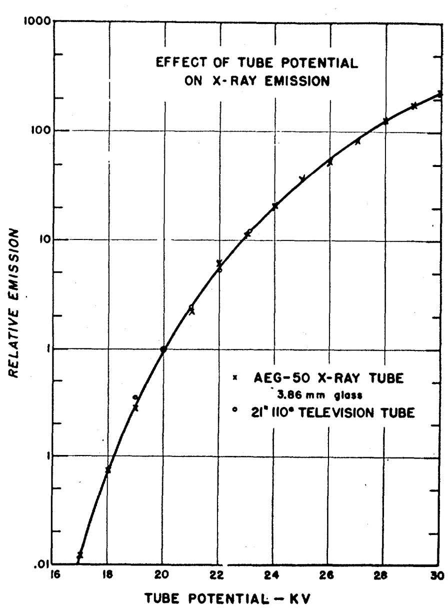

Fig. 2. Relative x-ray emission as a function of tube potential.

for production control. Aluminum was selected as the base for comparison because it is readily available and its absorption coefficient is not very different from that of glass.

Figure 5 shows the transmission curves in aluminum. These curves also serve to determine the quality of the radiation transmitted by the panel. Table 1 shows the half-value layers and corresponding energies. These values are essentially the same for all television tubes irrespective of the variations in thickness and composition of the glass. As is indicated, the half-value layer at 25 kv is approximately 1 mm of aluminum, a value frequently used in superficial therapy. Therapy depth dose tables, however, are of limited value in estimating the dose to the gonads from television sets because the radiation is more homogeneous and the source-skin distance is very much greater.

Depth Dose Measurements

Due to the low exposure rate from television tubes at the usual viewing distance, the depth dose measurements were made with a regular x-ray tube operating at 25 kv and 20 ma. The filtration was adjusted to give maximum exposure rate for the same quality of radiation as that obtained from a television tube. A target-skin distance of 100 cm was chosen, although adults, as a rule, view high-voltage, large-screen sets from a greater distance. The 100 cm allows for the tendency among children to view even large screens at short distances. This is an important consideration since the exposure of children is genetically more significant than the exposure of adults, many of whom have passed their reproductive age.

Measurements were made in a water phantom at 1 and 5 cm, the average depths of the testes and ovaries. The depth dose at 1 cm was found to be 75 percent, and at 5 cm, 10.8 percent, of the air exposure dose. Phantom measurements were not made at lower voltages because of the minute exposure rates and much higher absorption coefficients. However, attenuation measurements made at lower voltages indicate depth doses at 5 cm of the order of 0.01 percent for 15 kv and 2 percent for 20 kv. It is obvious, therefore, that the tube voltage has the most influence on the magnitude of the dose to the

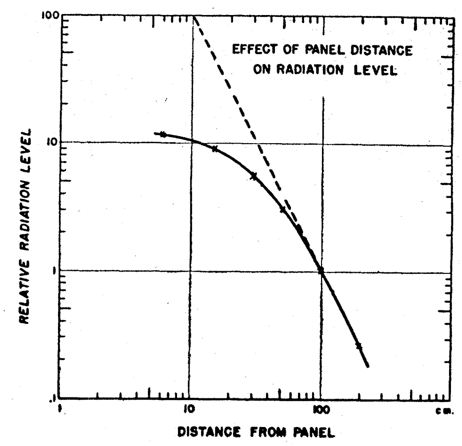

Fig. 3. Effect of panel distance on radiation level.

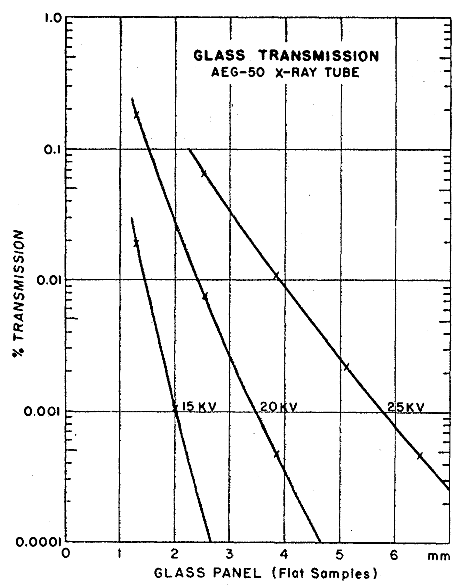

Fig. 4. Glass panel transmission curves.

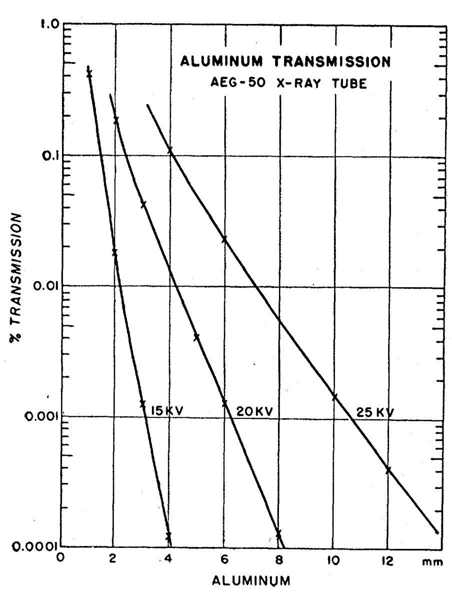

Fig. 5. Aluminum transmission curves.

gonads. For the usual operating voltages, a variation of just 1 kv may vary the dose to the ovaries by a factor of 6; it is not merely the percentage depth dose but also the exposure rate which is affected.

Population Gonad Dose

The estimate of the television contribution to the gonad dose requires, in addition to the data already presented, information concerning the viewing habits of the population. According to estimates obtained from the industry and other sources, approximately 55 million homes in the United States have television sets; the average viewing time is 5 hours per day, and the number of viewers 2.2 persons. On this basis, and assuming a population of 180 million, the average number of viewing hours per person per year is approximately 1000.

The International Commission on Radiological Protection recommended that the emission of x-rays should not exceed 2.1 mr per hour at any accessible surface on home television sets (*2*). Consideration has since been given to lowering this value to 0.5 mr per hour at 5 cm from any accessible surface of the set. Table 2 shows the calculation of the gonad dose for this value. The dose is given for viewing distances of 100 and 200 cm. However, most sets operating at 25 kv have large screens for which the optimum viewing distance is at least 200 cm; the resulting yearly average gonad dose is less than 5 mrad. The gonad dose due to natural background radiation is of the order of 100 mrad per year (*10*); thus the television contribution for the above conditions is less than 5 percent.

Field measurements of some 200 television sets show a progressive reduction in the x-ray emission over the last 12 years even though the trend has been toward use of higher voltage. This reduction may be ascribed to the increasing attention given to the need for radiation protection. In general, television tubes are not marketed today until measurements on pilot models indicate acceptable radiation levels. Although at present there are no national recommendations specifying the maximum permissible x-ray emission from television sets, television tubes, in general, are designed so that the maximum emission at a distance of 5 cm from the tube surface is less than 0.5 mr per hour.

Most sets have a safety glass in front of the screen to provide protection in case of implosion. This glass reduces the radiation transmitted by the panel to a few percent. As a result, the average gonad dose from home television sets is much less than 1 percent of that due to normal background radiation.

Table 2. Calculation of per capita gonad dose.

Average yearly viewing time	1000 hr /person	
Operating potential	25 kv	
Radiation level 5 cm from screen	0.5 mr /hr	
Viewing distance	100 cm	200 cm
Correction factor for distance (see Fig. 3)	0.08	0.02
Depth dose:		
at 1 cm (male)	75%	75%
at 5 cm (female)	10.8%	11.3%
Yearly gonad dose:		
Male	30 mrad	7.5 mrad
Female	4.4 mrad	1.1 mrad
Average	17.2 mrad	4.3 mrad

Other Sources of Nonuseful X-rays

So far, only the radiation transmitted by the panel of the television tube has been considered. The radiation transmitted by the funnel and other parts of the tube may actually be greater; in addition, the high-voltage rectifier may serve as a source of radiation. Usually, only the radiation transmitted by the panel is directed toward the viewer; the other sources of radiation are, therefore, of little genetic significance. However, the possibility of somatic injuries to personnel during testing and servicing should not be overlooked.

Consideration should also be given to possible somatic injury to personnel operating and servicing theater-projection-type television tubes, closed circuit television, cathode ray oscilloscopes, klystrons, electron microscopes, and devices incorporating high-voltage rectifiers. Measurements have indicated radiation levels as high as 1 r per hour in the vicinity of some of these, indicating that none should be considered safe until so established by dependable radiation measurements.

Conclusion

The results of this study indicate clearly that the possibility of somatic radiation injuries to the viewer from conventional television sets is extremely remote. From a genetic point of view, a permissible radiation level of 0.5 mr per hour 5 cm from any accessible surface of the equipment appears reasonable and will not require any changes in most existing sets. Even if all sets emitted radiation at this rate the contribution to the gonad dose at usual viewing distances would still be less than 5 percent of that due to the average natural background radiation. Furthermore, since sets meeting the above requirement must be so constructed that the x-ray emission does not exceed 0.5 mr per hour at the maximum operating voltage, the exposure dose rate under average conditions will be much lower. For instance, lowering the voltage from 25 to 20 kv will reduce the radiation level by a factor of 36 and the average gonad dose by a factor of 124. Thus, for actual viewing conditions the television contribution to the gonad dose will be insignificant compared with the differences in natural background radiation between various localities.

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