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The Spintharicon:
A New Approach to Radiation Imaging

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The determination of the spatial distribution of radioisotope concentrations is now one of the most intensely active areas of investigation in the field of nuclear medicine. These distribution patterns may provide information related to location, shape, and function of the organs. The technique of scanning was first described by Cassen *et al* (1) in 1951. Since that time the process has been refined by means of larger crystals, better collimation, and pulse height analysis. The data print-out for the scanner has been improved by the application of Teledeltos recording by Jacobs *et al* (2) and photorecording by Horwitz and Lofstrom (3). When carefully used, the scanner is capable of producing images of remarkable quality.

There are, however, several serious disadvantages in the line scanning instrument. The most significant are:

1. The relatively long time required to perform the imaging process.
2. The temporal lag in data acquisition for areas scanned at the beginning and end of the process. The line scanner handles data in a serial manner.
3. The line scanner utilizes only the radiation within its limited field of view at any particular time. It must not respond to radiation originating from without the field of view.

The mechanical scanner is a hybrid of very sophisticated electronics and a relatively crude mechanical scanning system. An imaging system which is entirely electronic is most appealing. Anger (4) in 1958 described his very ingenious gamma-ray camera. This instrument was the first all electronic, direct viewing imaging device. This camera electronically locates the site of a gamma ray interaction by the comparison of the pulses produced by an array of photomultiplier tubes which look at a scintillator. This camera collects data in parallel fashion in that it may accept information from all areas of the source on a time sharing basis.

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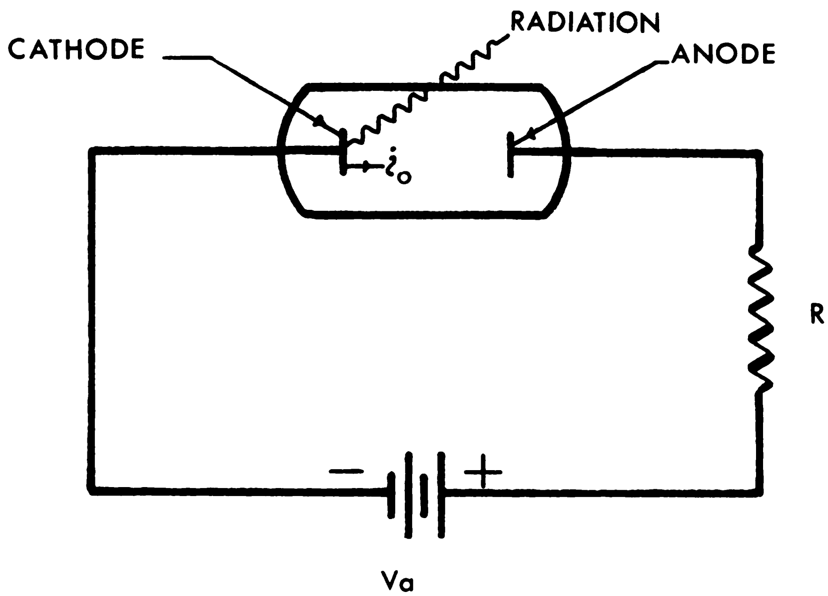

Fig. 1. Schematic representation of a basic discharge tube circuit.

A modification of the Anger camera is the Autofluoroscope of Bender and Blau (5). Here the single scintillator is replaced by a mosaic of several hundred scintillator cells for the purpose of increasing sensitivity and resolution.

Recently, Ter-Pegossian (6) has described a camera which uses a specially designed image amplifier tube. This instrument is designed for use with low photon energies.

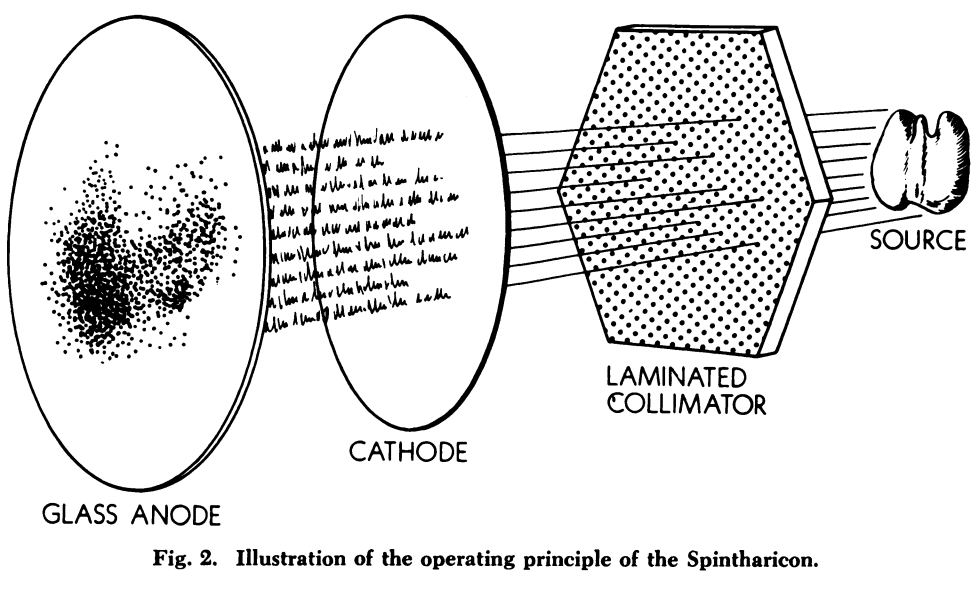

Fig. 2. Illustration of the operating principle of the Spintharicon.

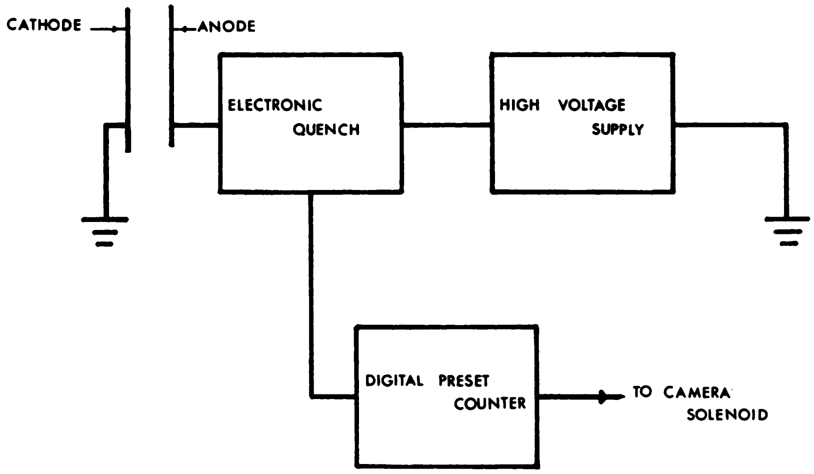

Fig. 3. Block diagram of the electrical circuitry.

In the cameras described above, an intermediate process is required to translate the initial interaction of the photon into a dot in the image. If the initial photon interaction could trigger a process which is immediately observable by a camera a highly simplified instrument could result. The spark discharge mechanism offers this possibility. Under the proper conditions, a gamma ray photon may be made to trigger a spark discharge which is accompanied by sufficient luminosity to be directly photographed. It will be the purpose of this paper to describe an imaging device based on this principle.

THE SPARK DISCHARGE

The electrical discharges which may occur in gases may be divided into two distinct groups, those which are not self-sustaining and those which are self-sustaining. The phenomenon of sparking occurs in the transition between the

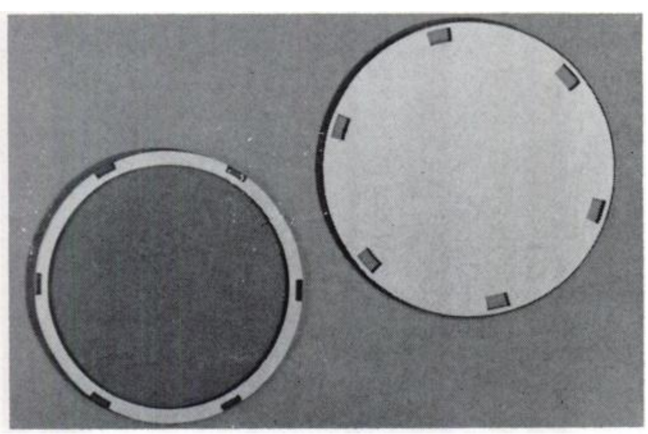

Fig. 4. Photograph of prepared anode (left) and cathode. Masked areas in the silver coating are provided for the spacers.

former and the latter state. Consider the discharge tube shown schematically in Figure 1.

The tube consists of two electrodes in a gas filled envelope. A ballast resistor R in series with the electrodes limits the current. Free electrons may be produced by the interaction of radiation with the cathode or the filling gas. Let us assume that this interaction occurs only at the cathode. If a current i_0 leaves the cathode, the current arriving at the anode is represented to a fair approximation by:

$$i = i_0 \exp(\eta V_a),$$

where V_a is the potential applied across the electrodes and η is a coefficient defined such that ηdV is the average number of ionizing collisions produced by an electron in falling through a potential difference dV in the direction of the electric field.

The positive ions produced in the above process may produce electrons in excess of the number required for neutralization. These excess electrons may then produce a second avalanche as described above. If the probability of producing a secondary electron which does not diffuse back to the cathode is γ, then the following equation gives the total electron current arriving at the anode:

$$i = i_0 \frac{\exp(\eta V_a)}{1 - \gamma\,[\exp(\eta V_a) - 1]}.$$

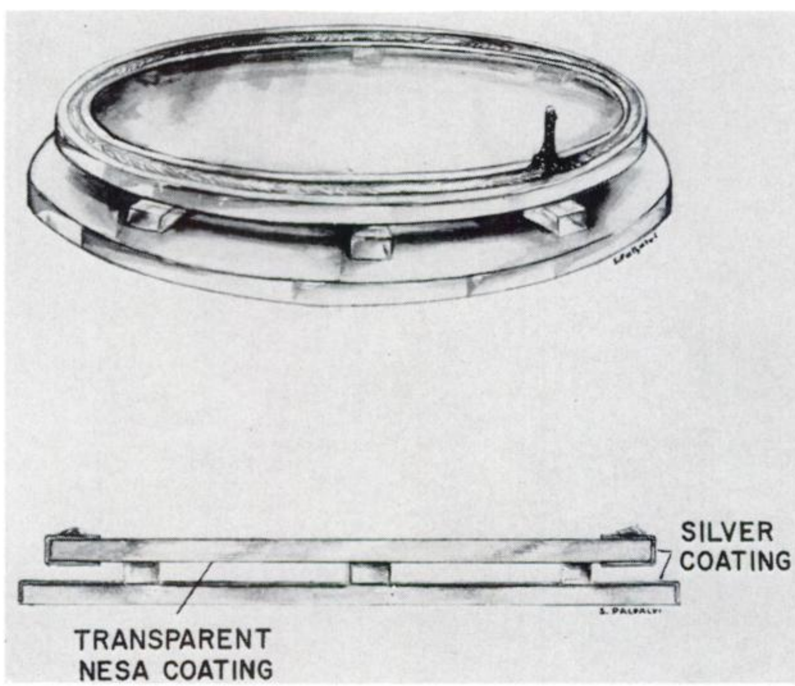

Fig. 5. Illustration of the assembled electrodes. A silver film provides electrical contact to the anode (top plate). A fine metallic braid is soldered to the silver. The electrodes and the spacers are epoxied together.

This equation predicts that $i \rightarrow \infty$ as $V_a \rightarrow V_s$ for the situation where $\gamma\,[\exp(\eta V_a) - 1] = 1$. The voltage V_s at which this transition takes place is called the *sparking potential.* This is, for a given gas, a function of the separation of the plates, the pressure in the chamber, and to a certain extent the physical properties of the cathode (7, 8).

The time required for the development of the spark is extremely short, typically 10^{-7} seconds. The ballast resistor (10-100 megohms) in series with the chamber capacity frequently provides RC time constants of the order of ten milliseconds and hence the recovery time of these chambers is quite long.

Several properties of these spark discharges are very useful in their application to radiation imaging.

1. The spark discharge may be triggered by the secondary electrons produced by gamma-ray interactions.
2. The spark discharge is highly localized to the site of the gamma-ray interaction.
3. The spark is accompanied by sufficient luminosity to permit visual and photographic localization of the interaction site.

The use of the spark discharge to delineate the tracks of ionizing radiation has been used in the so-called spark chamber since 1949 (9). In this application several parallel plate chambers are stacked together and the path of the particle is defined by the sequence of sparks occurring in adjacent units.

The track delineating chamber of Fukui and Miyamoto (10) consists of a glass box with two opposite faces fabricated from electrically conducting glass. They found that when an electric field was applied immediately after the passage of an ionizing particle tiny luminous discharges were produced along the trajectory of the particle.

Lion and Vanderschmidt (11) showed that a photographic emulsion coated on the anode could be exposed by the sparks occurring in a discharge chamber. An array of needles was used for the cathode.

Fig. 6. A 7 inch diameter chamber is shown on the left and the 5 inch "thyroid" chamber on the right. The electrodes have not been sealed into these chambers.

Recently, Kellershohn *et al* (12) reported on a parallel plate spark chamber which employs fine metallic mesh for the anode elements. By the clever use of a grid at an intermediate potential this chamber can discriminate against undesired events.

The authors have been independently working on a spark chamber, but from a slightly different approach. This device has now been developed to the point where the sensitivity and resolution permit its use as a clinical instrument.

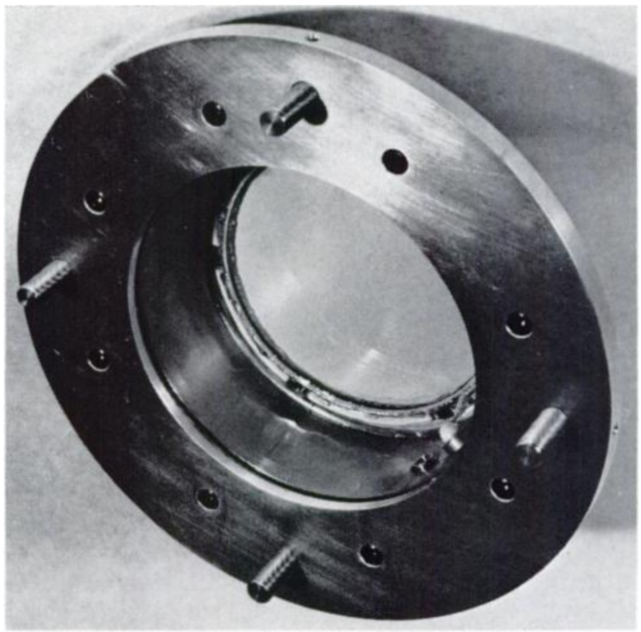

Fig. 7. View looking through the window of the chamber. In the lower right corner appears the high voltage connection. The protruding screws on the front flange are used in mounting on the camera.

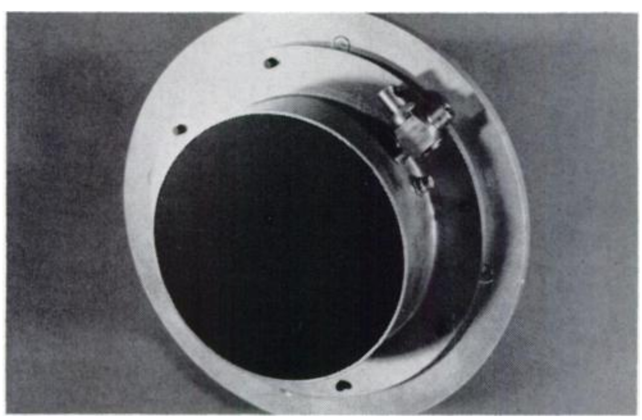

Fig. 8. View of electrode end of chamber. The electrode system is sealed, vacuum tight, to the housing. The glass is painted dull black to prevent room light from entering the chamber.

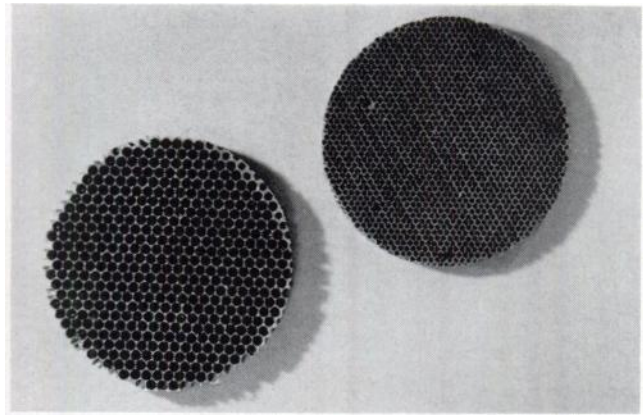

Fig. 9. Photograph of typical collimators.
Left: 8 sheets, 84 per cent open area, 488 holes of 0.209 inch diameter, septa 0.015 inch.
Right: 6 sheets, 75 per cent open area, 1540 holes of 0.110 inch diameter, septa 0.015 inch.

THE SPINTHARICON CHAMBER

The operating principle of this instrument is illustrated schematically in Figure 2. The electrode assembly consists of a thin cathode and a transparent anode. The anode is fabricated from electrically conducting glass.[2] The space between the electrodes is occupied by a noble gas or a mixture of noble gases as is described below. A potential slightly above the sparking potential of the gas is applied to the electrodes.

If a photon from the source passes through the collimator and interacts in the cathode, a secondary electron will be projected into the gas. This will trigger an avalanche which will culminate in a spark. This columnar discharge when viewed end-on by the camera appears as a luminous dot. This spark will quickly extinguish and the chamber will then be ready for another event. A camera set on time exposure integrates the individual sparks into a distribution pattern. This system thus amplifies the photon interaction sufficiently in a single stage to provide data which may be immediately recorded by the camera. A schematic diagram of the electrical circuit is shown in Figure 3. The chamber operates satisfactorily without the electronic quench circuit but we have found that it is possible to increase the count rate by about 15 percent when the voltage is restored to the sparking potential very quickly by electronic means. When used without electronic quench ballast resistances of 20 to 70, megohms are employed. Although the operating principle is quite simple, great care is required in the construction if a chamber of good sensitivity, high resolution, and long useful life is to be prepared.

[2]The glass used is sold under the name NESA and is manufactured by the Pittsburgh Plate Glass Company, Pittsburgh, Pa.

a. *The Electrode System*

The cathode found to be most suitable at this stage of development is constructed from 1/16 inch Pyrex plate glass. This glass is selected by means of interference measurements to be flat on one side to within 0.001 inch. This surface is then coated with a silver electrically conducting preparation.[3] This preparation is silk screened on to assure uniform coverage and thickness. The coated glass is then fired at 1000° F. The fired silver layer is about 0.0006 inch thick. The firing process does not distort the glass. A typical cathode is shown in Figure 4. Notice that the silver film has six open areas which were masked off by the silk screen. These open areas are used to position the glass spacers to be discussed below.

The anode is constructed from NESA glass. This glass is available in a wide range of resistivities. Glass with a resistance of about 200 ohms per square is now being used. Electrical contact is made to the NESA surface (the glass is coated on one side only) by silk screening on the same

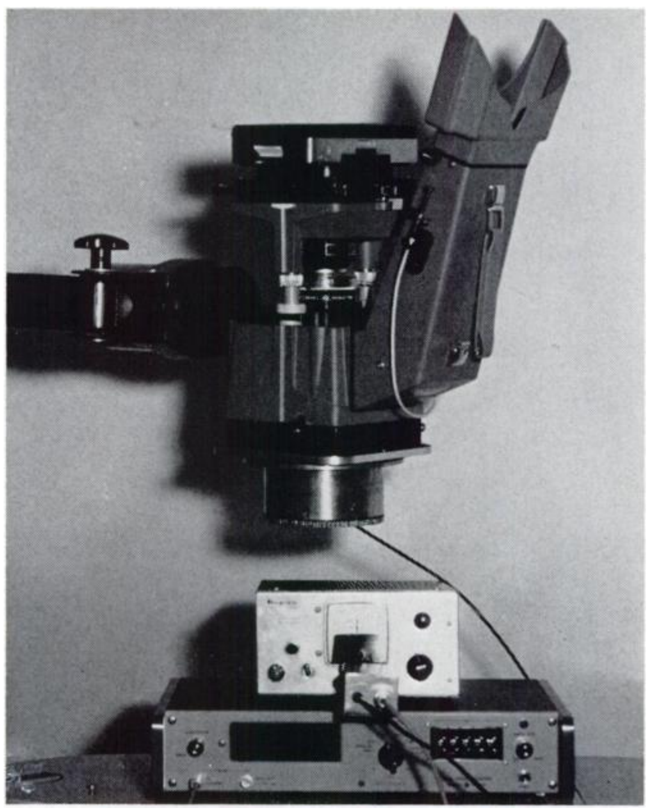

Fig. 10. Photograph of complete imaging system. Chamber with collimator is shown mounted on commercial oscilloscope camera. The high voltage supply and preset digital counter are shown below the imaging system.

[3]DuPont Silver Preparation Type 7713, E.I. DuPont DeNemours, Wilmington, Del.

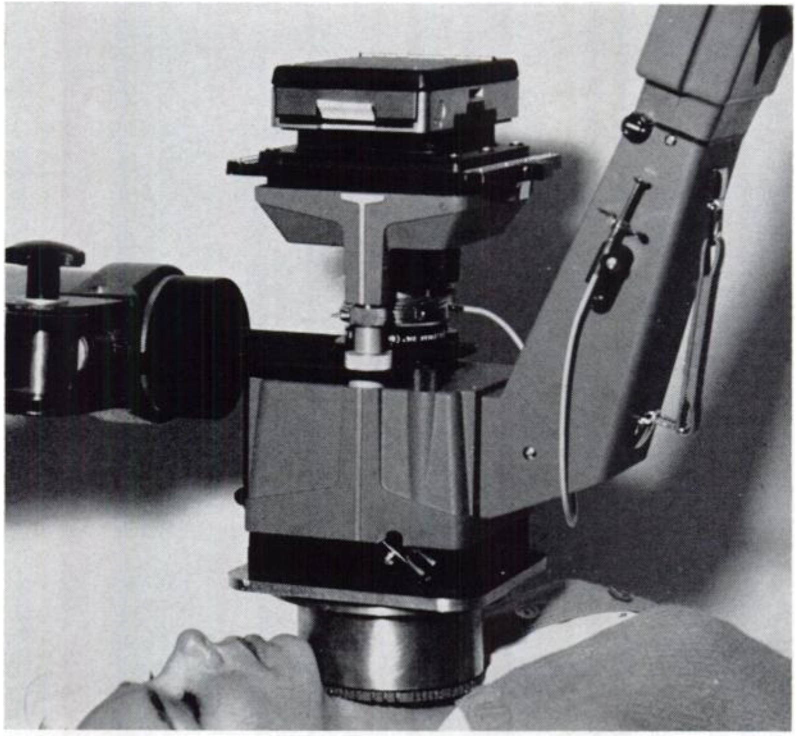

Fig. 11. Spintharicon is shown positioned for thyroid imaging. The chamber is small enough to comfortably fit against the patient's neck.

conducting material used on the cathode. In Figure 4 is shown a partially completed anode. The open notched areas mate with the open areas on the cathode. The silver preparation is painted over the edge and this is continued around the periphery of the nonconducting side to form a band about ¼ inch wide. A very light gauge metallic braid is soldered to this band to assure uniform electrical connection to the NESA surface below.

The cathode and anode are then cemented together. To assure uniform spacing pieces of optically ground glass were used. These spacers are nominally 0.120 inch thick but the tolerance for all six is plus or minus 0.0001 inch. The cement used to hold the electrodes and spacers together must be strong, resistant to alcohol vapor, and it must have a very low vapor pressure. Some of the epoxies have these properties. We have used successfully Armstrong type A-271.[4] The conduction strip on the NESA surface must be well coated with the epoxy to prevent spurious sparking from occurring in this region. When the cement is cured, the spacing is checked for uniformity. If the deviation in spacing is anywhere greater than 0.001 inch the assembly must be rejected. Uniform sensitivity and high resolution can be obtained only with precise spacing. Figure 5 is an illustration of the assembled electrode system.

[4]Armstrong Products Company, Warsaw, Indiana.

b. *The Chamber Assembly*

Photographs of the chamber assembly are shown in Figures 6, 7 and 8. The chamber consists essentially of a tube fitted with an "O"-ringed flange to seal the window on one end and a recess on the other end to accept the electrode assembly. A small high vacuum valve is provided to permit pumping and back-filling with gas. A miniature hermetically sealed coaxial connector is soldered in to provide electrical connection to the anode.

The electrode assembly is sealed to the chamber with Armstrong A-271 epoxy cement. The cathode must be in good electrical contact with the wall of the chamber and the resultant seal must be vacuum tight.

c. *Preparation of the Chamber*

The chamber must be carefully cleaned prior to assembly. Before the window is placed in position all dust and lint must be removed from within the chamber. The presence of foreign material will result in spurious counting and possibly in permanent damage to the electrodes.

The chamber is then pumped down to a pressure of at least 1 micron and preferably lower. This is necessary to remove traces of oxygen and water vapor which form negative ions in the discharge process. It is necessary to pump on the outside of the cathode simultaneously so that there is never sufficient pressure differential to destroy the thin glass cathode. This is accomplished by fitting a cap over the cathode end of the chamber. A separate pump is used to evacuate this cap. Valves are used on both pumping systems to slowly bring the pressures down.

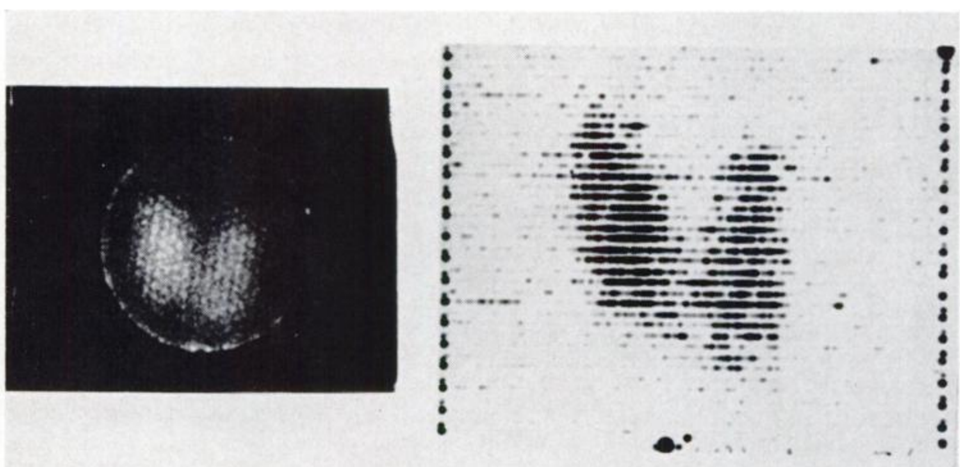

Fig. 12. Early clinical results obtained with Spintharicon. Spark image of thyroid gland (left) is compared with image of same gland produced by scintillation scanner. Approximately 14μc ^{125}I in gland.

Exposure time: 13 min.
Total sparks: 20,000

Collimator: 30 per cent open area
Camera stop: f/2.8

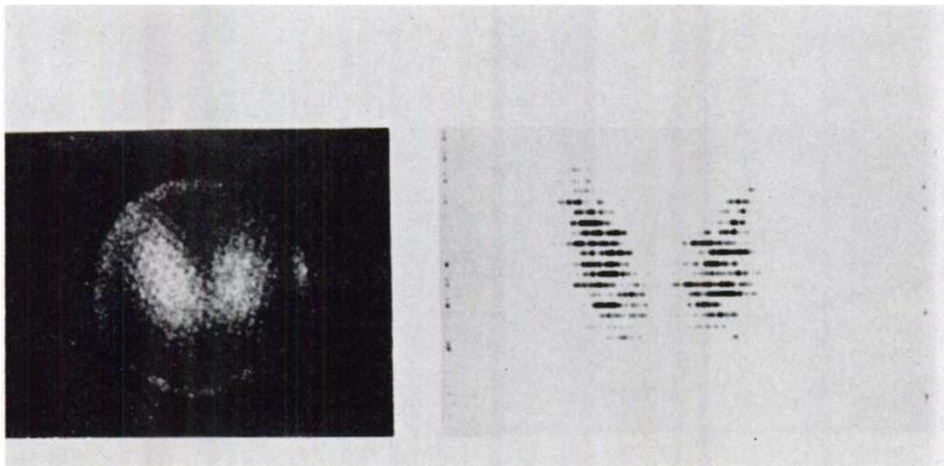

Fig. 13. Early clinical results obtained with Spintharicon. Spark image of thyroid gland (left) is compared with image of same gland produced by scintillation scanner. Approximately 25 μc ^{125}I in gland.

Exposure time: 13 min. **Collimator: 65 per cent open area**
Total sparks: 15,000 **Camera stop: f/3.5**

The chamber is back-filled with the gas and quenching agents. Argon and neon have both been used successfully. The lower sparking potential of neon permits operation at about 1500 V for the chamber parameters described here. Argon produces sparks at about 2000 V under these conditions. The sparks in argon are more easily photographed. The Polaroid ASA 3000 film, which is used, is more sensitive to blue argon sparks than the red neon sparks. The higher voltages required with argon increase the insulation requirements within the chamber.

Ethyl and methyl alcohol have both been used as quenching agents. Sufficient alcohol is added to provide about 6 per cent vapor by volume. The addition of iodine vapor to the gas has been shown to greatly decrease the occurrence of spurious discharges and "hang-up" of sparks. The iodine is added by dissolving the crystals in the alcohol which is to be admitted to the chamber.

d. *The Collimator*

The parallel hole collimators which are used between the cathode and the source of radiation are fabricated from perforated lead sheet. The stock is one-sixteenth inch thick, 6 per cent antimonial lead. The perforator can provide round holes as small as one-sixteenth of an inch in diameter in a staggered array to give septa one-sixteenth of an inch thick. The perforations must be accurate enough to permit stacking of many pieces to provide the required collimator thickness. The cut laminations are aligned with tapered pins to obtain the best possible register. These laminations are then epoxied together. The holes may then be enlarged by drilling on a drill press with successively larger drills. This operation proceeds with surprising ease. The epoxy seems to provide sufficient rigidity to the assembly to prevent creep of the lead. Collimators with septa as small as 0.010 inch have been made in less than two hours by this method. Figure 9 shows several such collimators.

THE CLINICAL INSTRUMENT

To evaluate the clinical usefulness of this imaging principle, a compact instrument was designed which has the camera integral with the chamber. This is shown in Figure 10. The chamber is shown mounted on a commercial

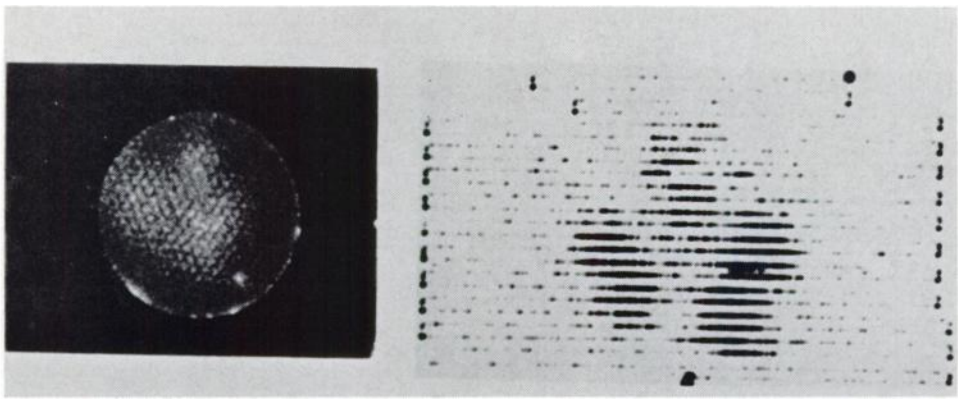

Fig. 14. Early clinical results obtained with Spintharicon. Spark image of thyroid gland (left) is compared with image of same gland produced by scintillation scanner. Approximately 16 μc ^{125}I in gland.

Exposure time: 11 min.
Total sparks: 20,000

Collimator: 65 per cent open area
Camera stop: f/2.8.

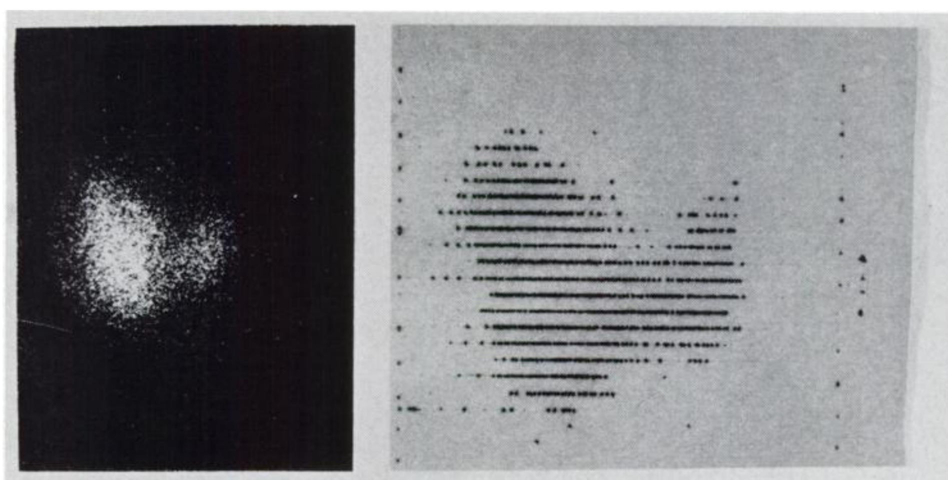

Fig. 15. Recent clinical results obtained with Spintharicon. Spark image of thyroid gland (left) is compared with image of same gland produced by scintillation scanner. Approximately 70μc ^{125}I in gland.

Exposure time: 5 min.
Total sparks: 7,500

Collimator: 75 per cent open area
Camera stop: f/2.8

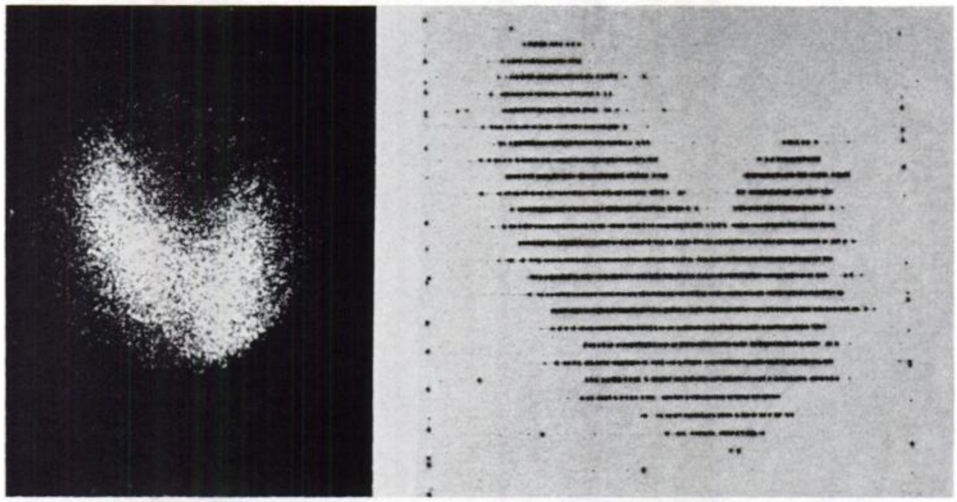

Fig. 16. Recent clinical results obtained with Spintharicon. Spark image of thyroid gland (left) is compared with image of same gland produced by scintillation scanner. Approximately 64 μc ^{125}I in gland.

Exposure time: 10 min.
Total sparks: 15,000
Collimator: 75 per cent open area
Camera stop: f/2.8

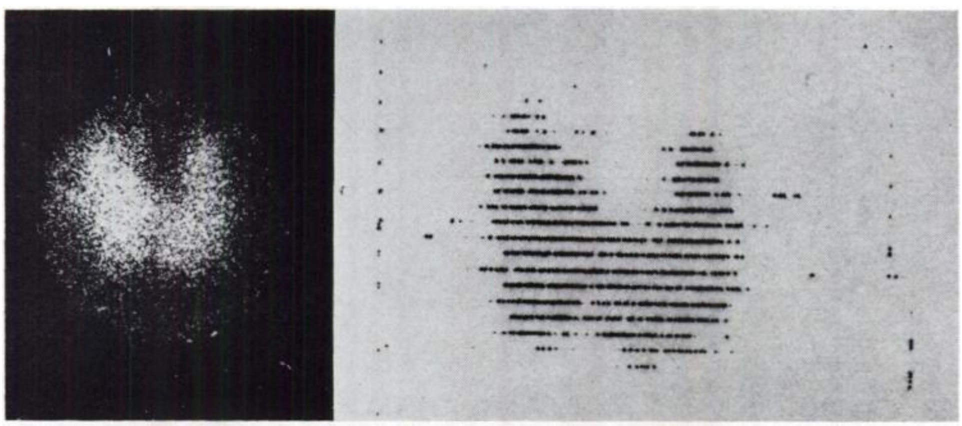

Fig. 17. Recent clinical results obtained with Spintharicon. Spark image of thyroid gland (left) is compared with image of same gland produced by scintillation scanner. Approximately 44 μc ^{125}I in gland.

Exposure time: 15 min.
Total sparks: 12,000
Collimator: 75 per cent open area
Camera stop: f/2.8

oscilloscope camera.[5] This camera which is equipped with a Polaroid pack back permits the observation of the sparks during the exposure period.

The chamber shown in this photograph was designed for thyroid imaging. The 5 inch diameter of the chamber permits positioning of the collimator against the patient's neck. Figure 11 shows the camera positioned for such imaging. It

[5]Tektronix Model C-12, Tektronix Incorporated, Beaverton, Oregon.

has been found convenient to use a digital preset counter to obtain the count rate and to terminate the exposure after the requisite number of counts have been collected. A picture containing about 15,000 sparks usually has excellent resolution. The camera is mounted on a conventional scintillation probe stand. The total weight of the camera assembly is no greater than a shielded scintillation probe and, hence, no modification is necessary in the counterweight.

PERFORMANCE

In its present state of development this imaging device is limited to use with low energy gamma rays. The efficiency of the cathode for the production of secondary electrons increases as the photon energy decreases. It follows that when high energy photons are used the chamber will be more sensitive to the secondary photons generated in the collimator than to the primary photons which traverse the collimator hole. This results in a smearing out of the primary image by the scattered radiation. Excellent images have been obtained with ^{125}I, ^{197}Hg and ^{131}Cs. Fair images have been obtained with ^{141}Ce (gamma energy 0.145 MeV).

Figures 12, 13 and 14 are representative of the early clinical results. The pattern of the collimator is evident due to the relatively thick septa in the early collimators.

Figures 15-18 show the results obtainable with high efficiency collimation and a carefully constructed electrode assembly. Figure 19 demonstrates the existence of an artifact in the line scan. The "cold spot" in the left lobe does not appear on the Spintharicon image. On closer examination of the scan it becomes evident that the patient moved during the interval in which the broken line was

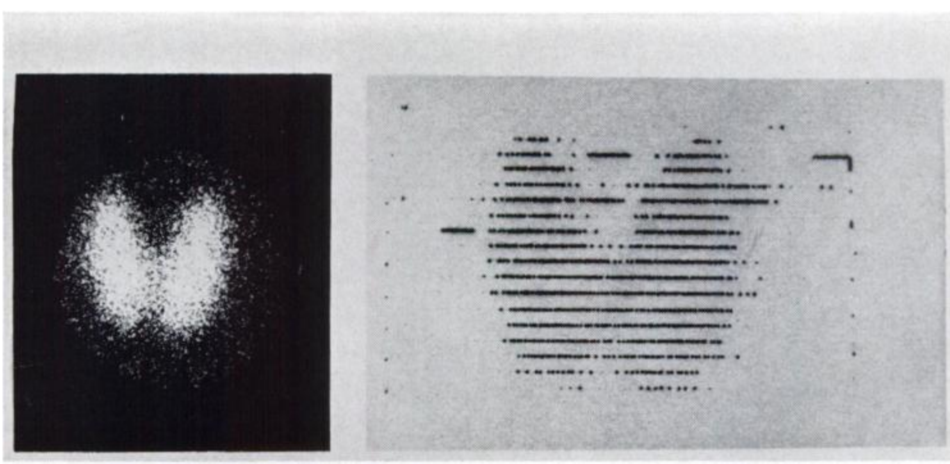

Fig. 18. Recent clinical results obtained with Spintharicon. Spark image of thyroid gland (left) is compared with image of same gland produced by scintillation scanner. Approximately 55 μc ^{125}I.

Exposure time: 10 min.
Total sparks: 15,000

Collimator: 75 per cent open area
Camera stop: f/2.8

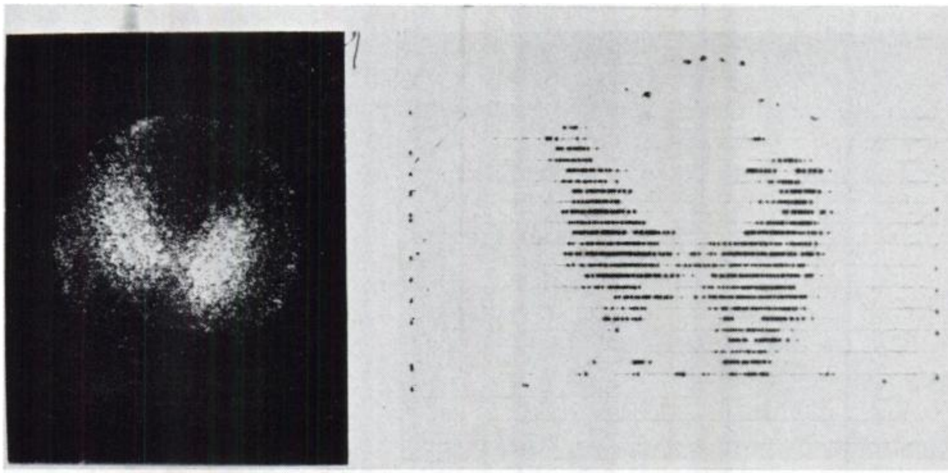

Fig. 19. Recent clinical results obtained with Spintharicon. Spark image of thyroid gland (left) is compared with image of same gland produced by scintillation scanner. Approximately 34 μc ^{125}I in gland.

Exposure time: 6.5 min.	**Collimator: 75 per cent open area**
Total Sparks: 15,000	**Camera stop: f/2.8**

scanned. Although those skilled in the art of scanning would question that a single broken line represented a cold spot, this does point out a serious disadvantage in line scanning: The moving probe in a line scanner "looks" at a particular area for one brief period only. If the patient moves, or if noise is injected into the electronic system during this period, this erroneous information will be stored with no possibility of further sampling. In the case of direct viewing cameras, however, all areas are continuously monitored and although small movements of the source reduce resolution, there is no discontinuous change in image buildup.

The small chamber has been applied to the visualization of organs in animals. The kidney has been clearly imaged in rats and rabbits using ^{197}Hg Neohydrin. Under construction is a 7 inch diameter chamber which will be applied to kidney and brain imaging in humans.

SUMMARY

The spark discharge method of imaging has been found to be a simple and relatively inexpensive method of obtaining radioisitope distribution patterns. The images are of high resolution and are obtained in about one half the time required for a conventional scintillation scan.

As the development of this principle continues it is expected that an increased sensitivity will permit time-lapse imaging.

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