DEPARTMENT OF TECHNIQUE

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HISTORY OF DIAPHRAGMING ROENTGEN RAYS BY USE OF THE BUCKY PRINCIPLE*

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THE step by step evolution of the present forms of grid diaphragm apparatus has never been set forth in a manner that gives the young roentgenologist of today a good idea of the difficulties encountered by the older workers before the days of the Coolidge tube, the duplitized film and the intensifying screen. Up to the time of Bucky's article in 1913, all workers recognized and hated the dire effects of scattered rays but uniformly attributed them to some peculiarity in action of the roentgen-ray tube. As a background for succeeding articles in this Journal and for the information of persons in Germany who are now trying in every way to discredit the original work of Bucky, such a historical sketch seems justified.

While physicists at that time were aware of the presence, the direction, and the characteristics of scattered rays within materials, roentgenologists insisted that their plate fog had its origin in the tube as "extra-focal rays," "glass-wall rays," "inverse currents," etc. It is interesting in passing to note the devices intended to reduce these obnoxious rays to a minimum.

1. Circular, square and other simple diaphragms, placed below the tube, later combined with lead-lined cones as developed by Albers-Schönberg who also compressed the part to immobilize it and make it thinner. Hickey and others devised special forms of cone to further increase their efficiency.

2. The "Moving Slot" diaphragm of Pirie,[3] described in this Journal in September, 1913. Here a piece of flat lead containing a transverse slot was moved beneath the tube so that a narrow beam of x-light exposed a film from top to bottom in successive strips during the motion.

3. The "Double Slot" method of Cole, in which a second piece of flat metal containing a larger transverse slot was placed beneath the patient and moved with the upper slot of Pirie so as to protect the plate wherever not exposed to direct rays.

4. The writer's moving grid complex oscillating beneath the tube, shown at the Detroit meeting in the Winter of 1915.[4]

5. The "Hooded Target" of Coolidge. Here by a metal shield about the focal spot the number of extra-focal rays were reduced so that the tube efficiency was said to be improved several per cent.

These devices for eliminating film fog were not without value but their effects were misinterpreted. It was not understood that any restriction in the size of the roentgen-ray beam reduces fog on the film mainly because it fails to excite the number of scattered rays within the body that are excited by a larger beam. An estimation of the quantitative value of diaphragming below the tube was first given out by Wilsey[10] in January, 1922. He shows for instance that a circular diaphragm allowing an image diameter of 1.5 inches has the same efficiency in removing scattered radiation as a grid diaphragm of slit ratio 1 to 5 placed beneath the patient. Under ordinary working conditions this circular opening would be scarcely larger than one-fourth inch in diameter.

The new explanation for film fog and scattered radiation assumed and then proved in the article of Gustav Bucky first

* This is the first of a series of articles by the same author on diaphragming roentgen rays. The title of the article for April is: "Principles underlying the Grid Diaphragm which Limit its Form and Efficiency."—ED.

published in English in the *Archives of the Roentgen Ray*, June, 1913, was revolutionary for the roentgenologist. His article was entitled "A Grating Diaphram to Cut off Secondary Rays from the Object." In the body of the article he called his device a "Gitter-Blende." His description follows:

This consists of a series of metallic strips from two to four centimetres in width, forming a sort of grating, and so arranged that the plane of each one is exactly parallel to the x-ray beam falling upon it. These strips, or fins, act as a screen, allowing the x-rays to pass, but cutting off all rays which are not parallel to the primary x-ray beam. On the photographic plate the shadow of the fins will be mere narrow lines, with an appearance as if a wire-netting had been stretched over the plate. Each mesh of this netting plays the part of a minute diaphragm cylinder, so short that it will not interfere to any great extent with the quality of the negative. I found this "grating-diaphragm" to be perfectly satisfactory, thus demonstrating the truth of my theory that the fogging is due to the secondary object-radiations.. I found that with the grating diaphragm, and the object four centimetres from the plate, I could obtain a negative much sharper than that obtainable without the diaphragm and with the plate and the object in absolute contact.

Again he says:

The network of white lines on the negative is of no disadvantage, but rather the contrary, since it may be used for the accurate measurement of the various organs, and further, it should be noted that with this diaphragm the time of exposure is increased by about 25 per-cent

In America roentgenologists have considered this article as the original announcement as to the rôle of scattered rays in roentgenography, first proved by their visible absorption within the metallic walls of the Bucky grating. I have been well in touch with the writings and the rumors throughout the development of grid diaphragms and know of nothing in America to precede the article by Bucky in 1913.

Bucky's grating, however, found no practical place in roentgenography. Here and there during the following years one could be found in the experimental junk heap of inquiring roentgenologists. Each and every test with his grating carried positive conviction as to the origin and possible suppression of the harmful vagabond rays but the shadow structure of the grating itself was too pronounced to be tolerated. In the Summer of 1914 Germany engaged in a war which was waged continuously to November, 1918. During this time Bucky and his grid were no more heard from on this side.

During the period from 1913 to 1917, I was one of several who designed and experimented with grid diaphragms in the

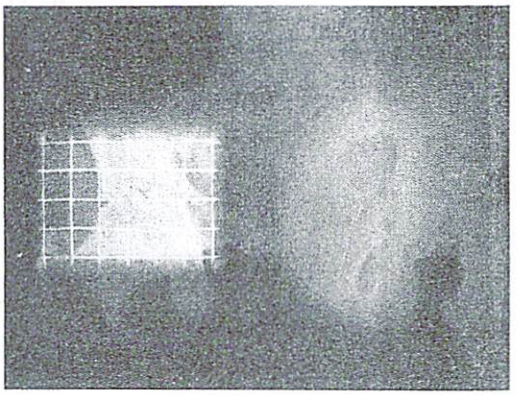

Fig. 1. From *Archives of the Roentgen Ray*, June, 1913.

hope of making the Bucky principle practical for routine use. Briefly the stages covered in my work were as follows:

At the Detroit meeting of the Central Section of the American Roentgen Ray Society, in February, 1915, there was shown a tubular grating of the Bucky type adapted for use below the tube and another below the patient. Both were arranged to move in a linear direction along or nearly along the diagonals of the squares. Moved in this manner the troublesome shadows of the metallic intersections were at a minimum. At the same time five general laws were laid down which must be satisfied in order that moving grids shall be rendered invisible on the roentgen plate. This article appeared in our Journal for March, 1916, "Diaphragming Roentgen Rays."[4]

In September, 1916, at the annual meeting of the American Roentgen Ray Society at Chicago, a second contribution was entitled, "The Bucky Diaphragm Adapted to Fluoroscopy."[5] This discussed a rotating circular disc grid with strips placed radially. Upon rotation between patient and screen at proper speeds the peripheral portion of this grid absorbed scattered radiation and the metallic strips were rendered less of a nuisance by motion.

In February, 1917, a mid-winter meeting of the Central Section was held in Cincinnati. By this time a long series of distressing experiments had caused me to abandon entirely for roentgenography all grid constructions which involved the crossing of metallic strips and to use only the parallel strips which fully satisfied the basic requirements for invisibility. A paper was read entitled "The Object Secondaries in Radiography—A Practical Working Method for Their Suppression."[6] The parallel strip curved grid apparatus such as is used today was shown, together with a dozen plates exposed through corpulent individuals. The following are paragraphs quoted from this paper, with introduction and other non-vital portions omitted:

The well-known Bucky grating consisting of numerous tubules of metal placed over the plate does this admirably. As pointed out previously the detracting shadows of the metal grating itself can be largely eliminated by a uniform motion along the diagonals of the squares. That the crossed type grating described by Bucky cannot completely neutralize its own shadows by motion was admitted for reasons set down under a formulated set of laws for invisibility of metal strips moving over plates during exposure. Since that time the author has been carrying on a series of experiments with other combinations of motion and construction to obtain, if possible, all the functions of the admirable grating of Bucky with a perfect and complete invisibility. This has been successfully accomplished.

By the general method shown at our last annual meeting by Dr. Shearer in which a photographic record of the scattered rays alone could be obtained under various conditions of absorption by metallic tubules, etc., I tested out some Bucky gratings against a series of filters made by not crossing the strips but running them parallel and closer together. It was surprising to find that the total amount of rays suppressed by the parallel system was about the same as in the Bucky crossed grating, and it is far easier to build them close together. It was also shown that when thin inch brass strips were spaced one-fourth inch apart, the filtering effect was practically as good as when spaced one-sixteenth inch apart. These results were considered very important from the standpoint of invisibility since they justified a parallel system of construction in which the strips could be assembled into the form of a portion of a cylindrical shell.

Accordingly an instrument was constructed of which a general idea can be obtained from figures A and B. The filter strips are mounted radially so as to form a portion of a cylindrical shell with the idea that the motion be along this same arc and across the strips. It is easily seen that with this construction there will result practically even illumination over a large area, that with a uniform motion the shadow of the strips will be neutralized and all requirements for invisibility satisfied in the simplest manner.

The motion must be a uniform one and does not need to be rapid . . . . The ratios were such that the filter unit moved half an inch a second for five inches . . . . The whole exposure should be made during one stroke.

Results: The results are highly gratifying for the demonstration of the lumbar spine, hip joints and pelvis and particularly for calculi. In several cases where small urinary calculi in portly individuals were difficult of demonstration the results obtained by the filter were so far superior as to justify almost any statement. In one case of intra-cranial bone tumor it aided materially in showing the spongy network within the tumor. Although at this writing no positive gall stone cases have been encountered the aid in this field cannot be doubted. With a suitably modified construction allowing a longer stroke and a higher speed, gastrointestinal work might be improved.

This article was read before the meeting but never published on account of a visit soon after by Dr. Eugene Caldwell who stopped on his way to Kansas. During the

day's visit the conversation focused on the grid diaphragm problem and Dr. Caldwell was freely shown the results of experiments including the final development of the curved parallel grid in the hope that he would volunteer some information as to his experiments of which rumors were afloat. Since he remained silent and I cherished a secret ambition to "beat" him to the correct solution, a letter was sent immediately to Dr. Caldwell asking him point blank what results, if any, he had so far obtained. He answered by the following rather informative letter:

Dr. Hollis E. Potter March 8, 1917.
1410 Peoples Gas Bldg.,
Chicago, Illinois.
Dear Doctor:

In answer to your letter of February 27th., which reached me only a day or two ago, I have to say that immediately after the publication of the Bucky apparatus, I conceived the idea of moving the screen to get rid of the shadows of the grid, and did a little experimenting in this direction. At the same time, I looked up the patent question and found that Bucky himself had described about every possible means of moving the screen for this purpose. I found also that there was a German patent which covered particular forms of the moving grid which are similar to those you have used. I am unable to get a copy of this German patent but I send you herewith a copy of Bucky's United States patent, application for which was filed February 3, 1914, and of my patent, application for which was filed October 12, 1915. You will see that my patent refers to a time switch in connection with an automatic device for moving of Bucky screen through a very small space. So far as my patent is concerned, it has no relation whatever to your work. The Bucky patent probably covers everything that you have done.

I think that these patents need not deter you in the least from any experimentation you wish to do if you care to repeat work that has already been done. It is so easy to find out from the patent office what has been done in such a case that I think we should really investigate this before publishing work as our own.

I am just a little sensitive over the criticism that has been made in regard to patents granted to me. Most of this criticism I think is due to ignorance, but some of it seems to be malicious. About all the patents have ever done for me is to establish a date and to give proof of priority. I have felt that anything upon which the patent office would allow me a patent, was very likely original with me. In a great many instances the patent office has informed me that devices which I supposed were new and original with me, were really very old.

There is no money to be made out of patents on such x-ray devices. One does not even recover the cost of doing the development work and experimentation. Theoretically, at least, one benefits his colleagues by patenting anything useful that he may develop, because he is then able to insist that any maker who undertakes the construction of these devices shall make them well and also because it should be easier to induce a maker to manufacture a patented article, the sale of which he cannot control. The insinuation that has sometimes been made, to the effect that one patents such a device for the sake of preventing his colleagues from using it or in order to accumulate wealth by taxing his colleagues for royalties, is of course absurd. One's colleagues seldom appreciate the amount of labor and expense necessary to develop even a simple device to a point where it can be manufactured.

Yours very truly,
(signed) E. W. Caldwell.

I was amazed and somewhat taken aback by the letter and the two patents included therewith. Caldwell's silence during his visit had resulted, of course, from his natural reticence and a desire to injure no one's feelings. The letters patent were read at length and were particularly interesting in that they showed the fact that at least three experimenters had traversed about the same routes up to a certain point. Up to this time I had never heard that Bucky had conceived the idea of making the grid invisible by movement and had only heard rumors that Caldwell was working on the Bucky diaphragm principle.

This disillusionment meant of course that it would be unfair to speak or write further on the grid diaphragm until the close of the war. Experiments could go on and apparatus be perfected but Bucky should be given every chance to show any

experimental results or any practical working apparatus. Caldwell should be given opportunity to enlarge upon his work.

Bucky's claims were rather broad but specifically favored a cross-grid construction as most advantageous. He showed in detail a mechanism for moving this grid "so that each point in said grid will describe a circular path" and distinctly specified that the diameter of the circle of motion should be just equal to the length of the side of the smallest squares of the grid. He makes his claims broad by mentioning other forms of grid construction and in a sweeping manner assumes that their proper movement will result in an absence of grid shadows on the plate. No attempt is made to prove that the circular movement of a flat crossed grid will result in its invisibility, but he makes this dashing statement, "The velocity of the drive must be such that the walls of the grid will not cast a visible shadow upon the photographic plate or upon the fluorescent screen." The required velocity is not mentioned.

It has proved unfortunate for Bucky that he did not accompany his patented ideas with such experiments as would lead to a true solution of "invisibility" in the use of his admirable grid principle. It would seem to me that his patent was couched in terms broad enough to cover almost anything, but the Austrian Patent Court has ruled that his claims cover only the honeycomb type of construction described at length in his patent.

Caldwell also favored a crossed grid but desired that it be moved in a linear direction corresponding to the diagonals of the squares, and makes claim for originality for a device which will stop the grid at points beyond the start equal to one or more diagonals. This, he says, will produce an equality of grid shadows over the entire plate. The "start-and-stop" device was combined with an arrangement for closing the x-ray circuit at "start" and opening it again at "stop."

Thus on March 8, 1917, I was somewhat rebuked by Caldwell for a lack of information regarding the proceedings of the Patent Office. The usual channels of medical and roentgen literature could not be depended upon for the latest in experimental advance but only the legal department. Never having seen a patent or talked with a patent lawyer and not caring to become educated regarding them, I turned to other lines of experimentation, occasionally reverting to the problem of perfecting the

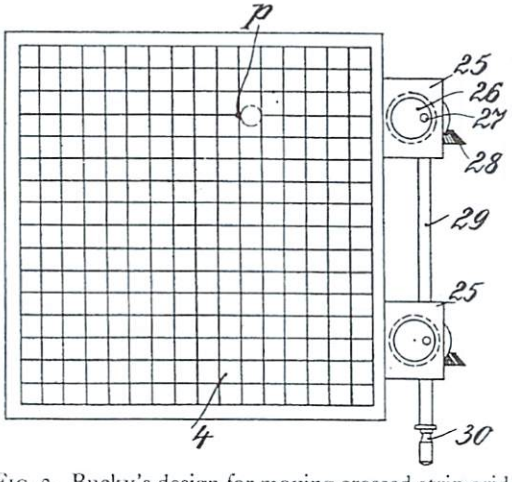

Fig. 2. Bucky's design for moving crossed strip grid. The bandle, 30, through shaft and gears actuates excentric, 26, causing the grid to move in a circular path of diameter shown at *p*.

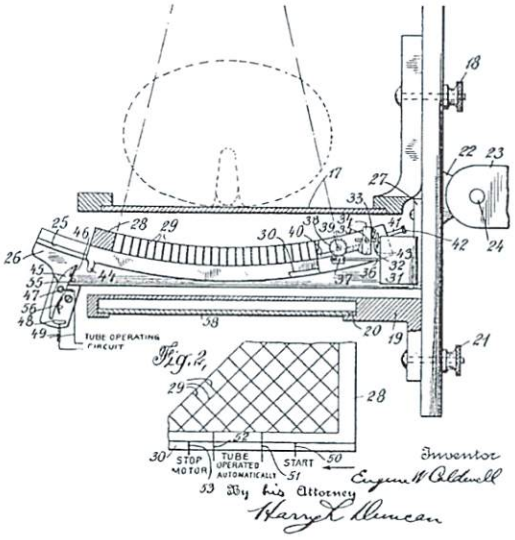

Fig. 3. Caldwell's start-and-stop mechanism for moving cross type grid along line of diagonals.

smooth action of the parallel slotted grid apparatus. It was Carl Lundberg, an assistant supplying vacancies during the war, who superintended much of the building of the first 14 by 17 model equipped with an oil dash-pot for smoothly regulating the motion.

This somewhat cumbersome model was used occasionally and started rumors. Directly after the mid-winter meeting of the Central Section in Chicago, February 22, 1919, Mr. Henry Engeln was consulted about building a special table to accommodate this unit. After seeing a series of plates made with it he rounded up a number of members whose trains East were not yet due and they stayed over for a private demonstration the following morning.

By this time, I had been able to find out that nothing in the way of practical progress had been made or reported by Bucky or others during the war. Immediately after the armistice Dr. Coolidge and Mr. Carl Darnell made a rather thorough survey of the roentgen-ray situation on the Continent. They reported that they could find no one using the grid principle except Albers-Schönberg who had a fixed cross-grid Bucky grating mounted for fluoroscopic work. Other visiting American workers soon reported the same.

I was placed in a position where it was beginning to look as if something were being held back from the profession. Numerous letters of inquiry were received urging that manufacturers make the apparatus available for general use. The silence maintained since the Caldwell letters no longer seemed justified. No one else working in this field of experiment had produced anything of practical value. Accordingly the Cincinnati article of February, 1917, was smoothed up and sent to this Journal where it was published in June, 1920, under the heading, "The Bucky Diaphragm Principle applied to Roentgenography."[6] Full cooperation was given any manufacturers who desired to furnish the device for public use. At the next annual meeting of the American Roentgen Ray Society, Minneapolis, September, 1920, several dozen films were displayed to accompany the paper, "The Bucky Diaphragm Principle applied to Radiography of the Spine," later published in this Journal.[7] At this meeting a slightly improved copy of the apparatus was shown by George W. Brady.

It was not until the perfection of duplitized film to the point where it could reasonably displace glass plates that grid diaphragms could be used with facility or even with safety. The excessive ray quantities overtaxed the gas tubes and the smaller capacity Coolidge tubes. Moreover a short series of adequate exposures through the same skin areas involved the use of an erythema dose when corpulent individuals were being handled. With the duplitized film and double screen technique made available in the first half of 1920 the grid diaphragm could and did become widely used.

Shortly after the public demonstration of the parallel type of moving grid diaphragm apparatus which manufacturers courteously called the "Potter-Bucky Diaphragm," the research department of the Eastman Kodak Company agreeably volunteered to make quantitative measurements of scattered rays as met with in ordinary working conditions and this was carried on by Dr. R. B. Wilsey in a most admirable and thorough manner. His results were published in these columns as follows:

"The Intensity of Scattered X-Rays in Radiography," June, 1921.[8]
"The Effects of Scattered X-Rays in Radiography," October, 1921.[9]
"The Efficiency of the Bucky-Diaphragm Principle," January, 1922.[10]

These articles give an exhaustive analysis of the quantities and values concerned in the suppression of scattered rays. They are in a form which appeals to the scientist and contain basic facts which must underlie any accurate conception of grid function. They stand as a handbook for anyone wishing to experiment with the form or efficiency of grid apparatus.

SUMMARY

The essential points in the history of diaphragming roentgen rays by the grid diaphragm are therefore:

1. The original announcement by Gustav Bucky in German and English roentgen-ray journals in 1913 of the valuable function of the metallic cellular grating.

2. The conception by Bucky, Caldwell, Potter and others, that some form of grid construction combined with some type of grid movement might neutralize or efface the shadows of the grid itself.

3. The writer's experimental demonstration that the constructions and movements favored by Bucky and Caldwell could not be made to result in invisibility but that parallel strip construction would do so when combined with a movement of the most critical uniformity.

4. The writer's experimental proof that parallel lead strips give approximately the same total scattered ray absorption as any form of tubular or cellular grating and could be constructed with greater ease and accuracy.

5. The writer's demonstration that for maximum flexibility of operation and with least probability of visible grid shadow formation the parallel strip complex should be curved to the form of a cylindrical shell, with center of curvature equal to the intended operating distance of the tube.

6. Wilsey's experimental measurement of scattered rays emerging from the deeper body tissues and the experimental proof of grid diaphragm efficiency in their absorption.

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