Miniature sources of irradiation for intracavitary thermo radiotherapy

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Abstract. This report presents the development of a miniature ionizing and thermal radiation source for oncological diseases treatment namely the inward parts of the body. This source can be placed next to the tumor inside of the body. This report is only about methods and devices for the intracavitary therapy. Irradiation by external sources wasn't considered in our investigation.

Radiologic therapy can be represented as two directions: radiation therapy and hyperthermia (figure 1). In our opinion just these procedures can be the most helpful for oncological diseases treatment. Hyperthermia may be external with body heating or intracavitary with high-frequency sources for tumor overheating (microwave and infrared). Radiation therapy includes brachytherapy and radiotherapy (roentgen therapy). Brachytherapy uses radioactive isotopes either in front of implant or probe with isotopes which placed inside it.

Figure 1. Radiologic therapy.

One direction of Roentgen therapy is X-ray therapy with field emission cathode X-ray tubes. It would like to note that X-ray tubes with field emission cathode with nanotubes is really prospective. In this field our colleagues from the University of North Caroline, Nagoya institute of Technology (Japan), KAIST (Korea) and others have succeeded a lot.

Another direction of Roentgen therapy is use X-ray tubes with thermoemissive cathode. It is known that therapy can be administered with the use of either ionizing radiation or thermal effect (overheating). However, it is mentioned that the treatment is from 1.5 to 2 times more efficient with
the use of sequence ionizing and thermal irradiation, but when they are used simultaneously the
treatment is from 2 to 4 times more effective, that is the most efficient (figure 2).

Figure 2. Efficient of treatment by thermoradiation.

Meanwhile the authors of the named studies underline that devices for such treatment are absent. It
follows that the problem of making one source allowing irradiating with both X-ray and thermal fluxes
is very urgent. It is appropriate to mention one matter of principle here. Size of focal spot required for
diagnostics are not needed for therapy in general and for intracavitary therapy in particular. But
enhanced power is undoubtedly desirable for reduction of the treatment procedures duration.

Thereby, a source for intracavitary therapy shall fulfil the following requirements: possibility of
irradiating with both X-ray and thermal fluxes and enhanced power in spite of the small size on the
cathode and anode.

With all the advantages of cold cathodes sources they do not meet these requirements. That means
that thermoemissive cathode sources were to be considered. It is known that electron energy is
transformed into X-radiation and heat in X-ray tubes with thermoemissive cathodes (figure 3).

Figure 3. Distribution of electron energy.

At the same time less than 5 % of the energy of the electrons is transformed into X-ray, but more than
95 % is transformed into heat. That is why an X-ray tube should have been taken as the foundation.

But meanwhile it had to solve next questions. How to chill the tube? What materials of a small-
sized anode can withstand enhanced specific heat demand? What materials of a small-sized cathode
will provide enhanced emission characteristics? How to extract the radiation with the least loss for
absorption of gamma-radiation on the way from the anode to the tumor? What material should be used
for the envelope? How to provide heat insulation to the lateral surface of the envelope?

Authors of this report have developed such source that meets these requirements. It generates X-
radiation and the heat, emitted by electrons slowdown on the X-ray tube anode is used for heating the
tumor zone.
A controlled cooling system is developed for that purpose it is based on heat radiation, convection and the use of a heat pipe. There are several models of source design that differ from each other by the cooling systems construction and the positional relationship of the cathode, anode and the cooling system. One version suggests using a heat pipe for cooling. It is absolutely new decision for miniature X-ray tubes (figure 4).

![Figure 4. Different cooling systems.](image)

What was the main problem? The first – it needed to have sufficient electron flux density in the confined space. Secondly, anode should have taken increased unit load without damages in spite of its small size. These problems using new materials for cathode and anode that had not been used before for X-ray tubes production had solved. This way cathode and anode can be produced from monocrystal alloy or tungsten nanocomposite. The envelope can be produced of aluminium oxide. All these material are produced at institute of the authors.

Results of development and creation of nanocomposites of refractory metals with increased strength characteristics for anodes and emissive parameters cathodes are analyzed in this report too.

It is shown, that though monocrystals have shown the better characteristics in comparison with traditional polycrystals both as anodes and as cathodes (figures 5–8), more radical way of increase of operational characteristics of the miniature X-ray tubes is in application of the refractory nanostructural materials.

![Figure 5. Dependence of emission current:](image)

![Figure 6. Dose power dependence on the number of switches:](image)

Application of nanocrystal and monocrystal materials allows increase allowable unit loads of a miniature X-ray tube by reducing porosity, increasing strength and plasticity of anode and cathode materials. Some results of investigations in which the work function of nanocrystal tungsten is lower by 0.8 eV than that of polycrystals tungsten are given (figure 5, curve 3). This effect is explained by the fact that when forming nanomaterials current tubes with decreased work function arise close to grain boundaries in the region 10 nm wide. This effect is able to increase the intensity of X-radiation considerably (by a factor of more than 5) at the same cathode temperatures or decrease the temperature of a cathode by 400 °C at the same intensity of X-radiation.
Authors carried out some experiments to determine the creep of tungsten alloying by potassium on samples as foils 100 μm thick, used when manufacturing X-ray tube cathodes. The results of these experiments showed that high-temperature sample annealing resulted in an increase (by a factor of more than 3) in material creep resistance at a temperature of 2200 °C (figure 7).

The authors consider that this effect results from forming nanoscale little bubbles filled with potassium at the grain boundaries (figure 9). Scheme and photo of miniatures of sources for intracavitary thermo radiotherapy with thermal emission are represent (figures 10, 11).

A miniature source of irradiation for thermoradiotherapy produced from monocrystal and nanocrystal materials with a controlled cooling system has been developed. This source can be placed inside the organism nearby or directly at the tumor. This source allows to influence directly the tumor inside the organism by X-ray and heat radiation sequentially or simultaneously.
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