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(54) X-ray generating system.

(57) An X-ray generating system including an X-ray tube for generating X-rays and a tube voltage setting unit for setting a tube voltage applied to the X-ray tube. The system further includes an irradiation time setting unit for setting an irradiation time of the X-rays by the X-ray tube, a high voltage generating unit for supplying the tube voltage to the X-ray tube to cause the X-ray tube to generate the X-rays based on the tube voltage, and an irradiation control unit connected to the tube voltage setting unit and the irradiation time setting unit. The irradiation control unit compares the irradiation time with a maximum irradiation time determined by the tube voltage, divides the irradiation time into a plurality of divided irradiation times each being equal to or smaller than the maximum irradiation time when the irradiation time is larger than the maximum irradiation time, calculates a plurality of cooling times for the X-ray tube between the divided irradiation times and after a final one of the divided irradiation times when the irradiation time is larger than the maximum irradiation time, and controls the high voltage generating unit to cause the X-ray tube to generate the X-rays for one of divided irradiation times, respectively, and to cause the X-ray tube to suspend irradiation of the X-rays for one of cooling times, respectively.

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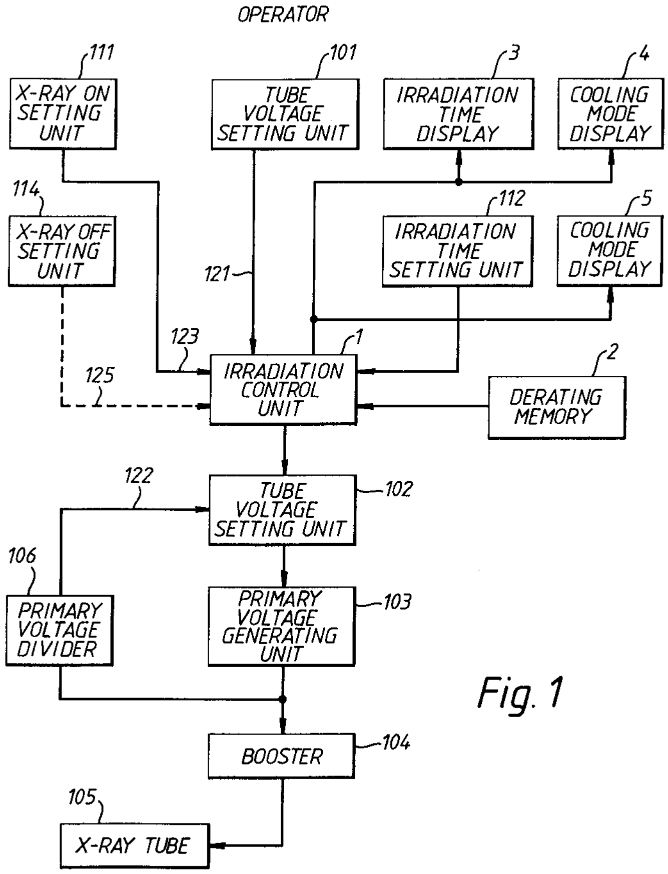

OPERATOR
111
X-RAY ON SETTING UNIT
101
TUBE VOLTAGE SETTING UNIT
3
IRRADIATION TIME DISPLAY
4
COOLING MODE DISPLAY
114
X-RAY OFF SETTING UNIT
112
IRRADIATION TIME SETTING UNIT
5
COOLING MODE DISPLAY
121
123
125
1
IRRADIATION CONTROL UNIT
2
DERATING MEMORY
122
TUBE VOLTAGE SETTING UNIT
102
106
PRIMARY VOLTAGE DIVIDER
PRIMARY VOLTAGE GENERATING UNIT
103
BOOSTER
104
105
X-RAY TUBE

Fig. 1

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to an X-ray generating system, and more particularly to a portable type X-ray generating system which causes intermittent generation of X-rays for cooling the X-ray tube.

Description of the Related Art

As a prior art X-ray generating system, there is, for example, the system shown in Figure 10. In this X-ray generating system, when an X-ray irradiation demand 123 is outputted from an X-ray ON setting unit 111, a desired tube voltage (the voltage between the anode and the cathode of an X-ray tube 105) set value 121 set by a tube voltage setting unit 101 as tube voltage setting means is outputted to a tube voltage control unit 102. Tube voltage control unit 102 controls the value of a primary voltage, which is generated by a primary voltage generating unit 103, from the difference between tube voltage set value 121 and a tube voltage feed-back value 122. The primary voltage generated by primary voltage generating unit 103 is converted to the tube voltage required by X-ray tube 105 by a booster 104. Thus it is designed so that the desired tube voltage is applied to X-ray tube 105. At the same time, the primary voltage is converted to tube voltage feed-back value 122 through a primary voltage divider 106, and then it is outputted to tube voltage control unit 102. Apart from this operation, when X-ray irradiation demand 123 is outputted from X-ray ON setting unit 111, an irradiation time monitor 113 starts a down-count from the irradiation time set by an irradiation time setting unit 112 as irradiation time setting means. X-ray irradiation continues until an X-ray irradiation stop demand 125 is outputted by an X-ray OFF instruction unit 114 or until X-ray irradiation is stopped by a "Time Up" signal 124 from irradiation time monitor 113.

In the operation of this type of X-ray generating system, heat is generated at the anode of X-ray rube 105 during X-ray generation. In the case of normal X-ray generating systems such as stationary or floor type, the design is that, by executing forced cooling through circulation of water or oil, no damage to the X-ray tube due to heat occurs, even if X-rays are continuously generated from the X-ray tube. Accordingly, the prior art normal X-ray generating system is designed, so that when X-ray irradiation demand 123 is outputted by X-ray ON setting unit 111, after irradiating for one maximum irradiation available time, it is immediately possible to irradiate X-rays.

However, in portable type X-ray generating systems, importance is placed on making the system lighter by omitting or simplifying the cooling system. In this type of X-ray generating system, it becomes necessary to make the system operate intermittently by performing cooling after X-ray irradiation, and re-irradiating X-rays when the X-ray tube has been cooled.

The prior art portable type X-ray generating system described above had the following problems. The operator was required to perform control of the duty cycle (percentage of X-ray irradiation time and cooling time). Consequently: (a) the operator used to memorize the time of starting X-ray irradiation, and when that X-ray irradiation was completed the operator did not carry out the next X-ray irradiation until a time which matched the previous irradiation time had elapsed. (b) Even if tube voltages differed, the operator carried out cooling with a constant duty cycle. For that reason, in the case of a low tube voltage, even though there was little heat generation in the X-ray tube, much time was wasted, since cooling was carried out for a time matching the maximum tube voltage. (c) When carrying out warming-up (a method of increasing the withstand-voltage of the X-ray tube by gradually raising the tube voltage) for a long time in the case of irradiation not having been carried out for a long period, or when carrying out X-ray irradiation which exceeded one maximum permitted irradiation time, the operator had to be in constant attendance. In this way, operators themselves had to control X-ray irradiation and cooling time. Therefore the operators has great responsibility. Also, there were occasions when this control was incorrect or there was erroneous operation, and there was a risk of damaging the X-ray tube on such occasions. Moreover, much time was wasted in the operation of the prior art system.

SUMMARY OF THE INVENTION

Accordingly, one object of this invention is to provide an X-ray generating system which does not cause heat damage to the X-ray tube.

Another object of this invention is to provide an X-ray generating system which is capable of efficient system management.

Still another object of this invention is to provide an X-ray generating system which is capable of reducing the operator's responsibility.

These and other objects of this invention can be achieved by providing an X-ray generating system including an X-ray tube for generating X-rays and a tube voltage setting unit for setting a tube voltage applied to the X-ray tube. The system further includes an irradiation time setting unit for setting an irradiation time of the X-rays by the X-ray tube, a high voltage generating unit for supplying the tube voltage to the X-ray tube to cause the X-ray tube to generate the X-rays based on the tube voltage, and an irradiation control unit connected to the tube voltage setting unit and the irradiation time setting unit. The irradiation control unit compares the irradiation time with a maximum irradiation time determined by the tube voltage, divides the irradiation time into a plurality of divided irradiation times each being equal to or smaller than the maximum irradiation time when the irradiation time is larger than the maximum irradiation time, calculates a plurality of cooling times for the X-ray tube between the divided irradiation times and after a final one of the divided irradiation times when the irradiation time is larger than the maximum irradiation time, and controls the high voltage generating unit to cause the X-ray tube to generate the X-rays for one of the plurality of divided irradiation times, respectively, and to cause the X-ray tube to suspend irradiation of the X-rays for one of the plurality of cooling times, respectively.

According to another aspect of this invention, there is provided an X-ray generating system including an X-ray tube for generating X-rays, a high voltage generating unit for supplying a tube voltage to the X-ray tube to cause the X-ray tube to generate the X-rays based on the tube voltage, and an irradiation control unit. The irradiation control unit prepares, based on an elapsed time from a completion time of a previous X-ray irradiation, a plurality of divided irradiation times each being given a respective tube voltage and a plurality of cooling times between the divided irradiation times and after a final one of the divided irradiation times, each of the cooling times being determined based on one of the divided irradiation times along with the respective tube voltage, respectively. The irradiation control unit also controls the high voltage generating unit to cause the X-ray tube to generate the X-rays at the respective tube voltage for one of the plurality of divided irradiation times, respectively, and to cause the X-ray tube to suspend irradiation of the X-rays for one of the plurality of cooling times, respectively.

According to still another aspect of this invention, there is provided an X-ray generating system including an X-ray tube for generating X-rays, a tube voltage setting unit for setting a tube voltage applied to the X-ray tube. The system further includes an irradiation time setting unit for setting an irradiation time of the X-rays by the X-ray tube, a high voltage generating unit for supplying the tube voltage to the X-ray tube to cause the X-ray tube to generate the X-rays based on the tube voltage, a temperature detection unit for detecting a temperature of the X-ray tube, and an irradiation control unit connected to the tube voltage setting unit and the irradiation time setting unit. The irradiation control unit controls the high voltage generating unit to cause the X-ray tube to generate the X-rays for a plurality of divided irradiation times separately, a total of which being the irradiation time, based on the temperature and to cause the X-ray tube to suspend irradiation of the X-rays between the divided irradiation times and after a final one of the divided irradiation times based on the temperature to prepare a plurality of cooling times for the X-ray tube.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

Figure 1 is a block diagram showing an X-ray generating system according to an embodiment of this invention;

Figure 1A is a diagram showing one example of derating data stored in derating memory 2;

Figure 2 is a timing chart of illustrate the general algorithm in the embodiment;

Figure 3 is a timing chart to illustrate the algorithm in the case when the irradiation time is longer than one maximum irradiation available time in the embodiment;

Figure 3A is a flow chart illustrating the operations of irradiation control unit 1 in the cases of Figures 2 and 3;

Figure 4 is a timing chart to illustrate the algorithm in the case when an X-ray irradiation demand is received during the cooling time in the embodiment;

Figure 4A is a flow chart illustrating the operation of irradiation control unit 1 in the case of Figure 4;

Figure 5 is a timing chart to illustrate the algorithm in the case when the power source is switched OFF during the cooling time in the embodiment;

Figure 6 is a timing chart to illustrate the algorithm in the case of warming-up in the embodiment;

Figure 7 is a block diagram showing an X-ray generating system according to another embodiment of this invention;

Figure 8 is a timing chart to illustrate the general algorithm in the another embodiment;

Figure 8A is a flow chart illustrating the operation of irradiation control unit 1 in the case of Figure 8;

Figure 9 is a timing chart to illustrate the algorithm in the case when an X-ray irradiation demand is received during the cooling time when no X-ray irradiation is scheduled after cooling in the another embodiment;

Figure 9A is a flow chart illustrating the operation of irradiation control unit 1 in the case of Figure 9; and

Figure 10 is a block diagram showing a prior art X-ray generating system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, wherein like reference numerals designate identical or corresponding parts throughout the several views, the embodiments of this invention will be described below.

Figure 1 is a block diagram showing an X-ray generating system according to an embodiment of this invention. In this embodiment, the following are provided in addition to the composition in Figure 10:

an irradiation control unit 1 as irradiation control means;

a derating memory 2 which stores derating data (percentages of irradiation time and cooling time) for tube voltage, one example of derating data being shown in Figure 1A;

an irradiation time display 3 as irradiation time display means,

a cooling mode display 4 as first cooling mode display means which displays the normal cooling mode "Cooling 1"; and

a cooling mode display 5 as second cooling mode display means which displays the cooling mode "Cooling 2" when the next X-ray irradiation is scheduled.

The functions of irradiation control unit 1 are achieved by a microprocessor. Irradiation time monitor 113 which is provided in the prior art X-ray generating system is incorporated in irradiation control unit 1.

First, the basic operations performed by the operator and the functions centered on irradiation control unit 1 in an X-ray generating system with this type of composition are described. The operator sets the desired tube voltage on tube voltage setting unit 101, and sets the desired irradiation time on irradiation time setting unit 112. Also, the X-ray ON instruction is performed on X-ray ON setting unit 111. By this instruction, the X-ray generating system executes X-ray irradiation for the X-ray irradiation time as a whole which has been set. Whether the X-ray irradiation is executed by the divided irradiation or by the continuous radiation is judged by the X-ray generating system itself. If the X-ray OFF instruction is executed by X-ray OFF setting unit 114 during X-ray irradiation, the X-ray ON instruction is suspended.

Irradiation control unit 1 processes an irradiation and cooling schedule to the following rules, and executes it. (1) One irradiation time must not exceed the maximum irradiation time determined by the tube voltage. The maximum irradiation time is stored in derating memory 2. (2) When the set irradiation time exceeds the maximum irradiation time, divide the set irradiation time into each maximum irradiation time, and insert the cooling between each of these. (3) If irradiating for an irradiation time Te, execute cooling for a cooling time Tc-($=Te \bullet (y/x)$), Where, (y/x)(=cooling time/irradiation time) is derating data, and differs depending on the tube voltage, and it is stored in derating memory 2, as shown in Figure 1A. (4) Execute a display during cooling. Change the display as follows: the case of stoppage of X-ray irradiation after completion of this cooling is referred to as "Cooling A", and the case of executing X-ray irradiation after completion of this cooling is referred to as "Cooling B". (5) When there is an X-ray ON instruction during "Cooling A", execute X-ray irradiation only for an irradiation time Te_2 ($=(x/y).Tc_{11}$) based on the cooling time Tc_{11} already completed, where, (x/y) is stored in derating memory 2. After completion of X-ray irradiation, execute cooling in which cooling matched to this irradiation time Te_2 and the remainder of the previous cooling are combined. (6) Ignore X-ray ON instructions during X-ray irradiation or during "Cooling B". (7) When there is an X-ray OFF instruction during X-ray irradiation, suspend X-ray irradiation and execute cooling matched to the irradiation time already completed. (8) When there is an X-ray OFF instruction during "Cooling B", suspend the following schedule and execute only cooling.

The following are descriptions of examples of operations with reference to the drawings.

First, the case of the set irradiation time being less than one maximum irradiation time is described with reference to Figure 2. The irradiation time is taken as Te, the cooling time as Tc, and the derating data for the set tube voltage value stored in derating memory 2 as "irradiation time : cooling time"(=x:y). Irradiation control unit 1 finds cooling time Tc by the following equation from irradiation time Te and the derating data for the tube voltage value.

$$\text{Cooling time } Tc = (y/x) \times \text{Irradiation time } Te$$

When the X-ray ON instruction is outputted, irradiation control unit 1 controls to commence X-ray irradiation and, at the same time, commences a down-count of irradiation time Te. This result of the down-count is displayed on irradiation time display 3. When "Time Up" is reached, irradiation control unit 1 commences a down-count of cooling time Tc, and the cooling remainder time (the result of down-count) is displayed on irradiation time display 3. At the same time, a "Cooling" display is executed on cooling mode display 4. But no display is executed on cooling mode display 5 because the X-ray irradiation is completed.

The following is a description of the case when the set irradiation time exceeds one maximum irradiation time with reference to Figure 3. The total irradiation time is taken as Te, the i-th irradiation time as $Te_i(i = 1...n)$, and the i-th cooling time as $Tc_i(i = 1...n)$. Thus the total irradiation time Te is divided into n-irradiation times $Te_i(i = 1...n)$. The derating data for the set tube voltage value is taken as "irradiation time : cooling time"(= x:y). Irradiation control unit 1 finds cooling time Tc_i by the following equations from the set total irradiation time Te and the derating data for the tube voltage value stored in derating memory 2.

1st time:

Irradiation time Te_1 = One maximum irradiation time max-Te Cooling time $Tc_1 = (y/x) \times$ Irradiation time Te_1

nth time:

Irradiation time Te_n = Total irradiation time Te -(One maximum irradiation time max-Te x (n - 1))

Cooling time $Tc_n = (y/x) \times$ Irradiation time Te_n

Here, $Te = Te_1 + Te_2 + ... + Te_{(n-1)} + Te_n$

$Te_1 = Te_2 = ... = Te_{(n-1)} =$ max-Te

When X-ray irradiation demand 123 is outputted, irradiation control unit 1 controls to commence X-ray irradiation and, at the same time, commences the down-count of total irradiation time Te and displays the result of the down-count on irradiation time display 3. When the first irradiation time Te_1, which has been previously computed, is complete, irradiation control unit 1 automatically switches OFF X-ray irradiation. Then, it displays the cooling remainder time on irradiation time display 3. At the same time, it displays "Cooling" on cooling mode display 4 and executes a warning display on cooling mode display 5 in order to warn that it will automatically commence X-ray irradiation after completion of the cooling time. When the cooling is completed for cooling time Tc_1, irradiation control unit 1 again executes X-ray irradiation ON. In the same way, it repeats the same operations n-1 times. In n-th time, X-ray irradiation is executed for irradiation time Te_n, and then cooling is executed for cooling time Tc_n. However, for the final cooling time Tc_n, because there will be no following automatic X-ray irradiation, the X-ray irradiation warning display is not executed on cooling mode display 5. In the cases of the operations shown in Figures 2 and 3, a flow chart is shown in Figure 3A, which illustrates in detail the operation of irradiation control unit 1.

The operation in the case when an X-ray ON demand has been outputted during the final cooling time "Cooling A" is described with reference to Figure 4. In this case, Figure 4A shows a flow chart illustrating the operation of irradiation control unit 1 in detail. When X-ray irradiation demand 123 is outputted during the final cooling time, the cooling time of the final cooling time which has been completed at that time is taken as Tc_{11} and the cooling time of the final cooling time which has not been completed is taken as Tc_{12}. Also, when the derating for the newly set tube voltage value at that time is taken as "irradiation time : cooling time" (=x:y), the time Te_2 for which irradiation is immediately available is found by the following equation.

Irradiation available time $Te_2 = (x/y) \times$ Completed cooling time Tc_{11}

The reason for this is so that irradiation available time Te_2 will not exceed one maximum irradiation available time. When the irradiation for irradiation time Te_2 ends, cooling is executed for cooling time Tc_{21}, which matches this irradiation for irradiation time Te_2 and cooling time Tc_{12} which is the remainder for the previous cooling time Te_1. In other words irradiation control unit 1 finds cooling time Tc_2 by the following equation.

Cooling time Tc_2 = Previous cooling remainder time $Tc_{12} + ((y/x) \times$ Irradiation time $Te_2)$

After this, irradiation control unit 1 controls the scheduled irradiation and cooling by the operations for the previously described case when the irradiation remainder time is less than one maximum irradiation time (Figure 2) or the case when the irradiation remainder time exceeds one maximum irradiation time (Figure 3). Here, Figure 4 shows the case when the second irradiation time, which is the irradiation remainder time, does not exceed one maximum irradiation available time, so the X-ray irradiation warning display is not executed on cooling mode display 5.

The case when the power source is switched OFF during cooling time is described with reference to Figure 5. This case occurs, for example, when the portable type X-ray generating system is moved to another place for testing a test piece positioned there, the power source is switched OFF. After moving the system at the another place, the power source is switched ON again. The time when the power source is switched OFF is taken as T_{off}, and the cooling remainder time at that time is taken as Tc_1. The time when the power source is switched ON is taken as T_{on}, and the required cooling remainder time at that time is taken as Tc_2. Times T_{off} and T_{on} are found by a battery-operated clock incorporated in the system. When the power source is switched OFF during cooling, irradiation control unit 1 stores time T_{off} when the power source was switched OFF and the cooling remainder time Tc_1 at that time in a memory which is not shown in Figure 1. Then, when the power source is switched ON again, irradiation control unit 1 reads T_{on} from that clock and finds whether or not cooling is required and the required cooling time Tc_2 by the following equation.

Time T during when the power source was in the OFF state
= Power source ON time T_{on} - Power source OFF time T_{off} Required cooling time Tc_2
= Cooling remainder time Tc_1 when power source OFF - Time T x α

Where, α is a derating parameter and is the value equal to or smaller than 1. Figure 5 shows the case where α is equal to 1.

When required cooling time Tc_2 thus calculated in larger than zero, further cooling is required. At this time, cooling is executed again, and irradiation control unit 1 displays the cooling remainder time Tc_2 on irradiation time display 3 and, at the same time, displays "Cooling" on cooling mode dispay 4. In this case, the power source is switched OFF during cooling after the previous X-ray irradiation is completed, so the X-ray irradiation warning is not executed on cooling mode display 5.

In the operation shown in Figure 3, when the cooling is completed for cooling time Tc_1, irradiation control unit 1 automatically executes X-ray irradiation ON. This invention is not limited to this embodiment. Control of the system may be executed manually. For example, when the cooling is completed, at time T_M, irradiation control unit 1 displays "X-ray ON input waiting" on a display (not shown). When finding this display, the operator inputs "X-ray ON demand" to the system. Based on this input, irradiation control unit 1 starts to execute X-ray irradiation for time Te_2, and cooling for time Tc_2. In the same way, the system and the operator repeat the same operation.

In the above-described embodiment, irradiation control unit 1 controls the system using the derating data stored in derating memory 2. This invention is not limited to this embodiment. In another embodiment, derating memory 2 may be omitted, and irradiation control unit 1 calculates every cooling time based on the tube voltage and the present irradiation time and executes next cooling for the calculated cooling time.

Next, the operation when warming-up is described with reference to Figure 6. When the X-ray generating system is made to re-irradiate X-rays after a long period of suspension, it is necessary to start irradiation at a low tube voltage and then gradually raise the voltage over a period of time. If this is not done, there is a risk of damaging X-ray tube 105 due to the generation of a discharge. This operation is called "warming-up". The longer the suspension time, the more necessary it is to take time over gradual warming-up. When the suspension time is long, warming-up cannot be performed in one X-ray irradiation. In this system, warming-up sequences for every suspension time are stored in irradiation control unit 1. The design is to judge the suspension time with a built-in clock and automatically to select the sequence for the detected suspension time. Warming-up is stored as repeated sequences of irradiation, starting from a low tube voltage and rising to a high tube voltage by the rules described above, and cooling, which are all automatically executed.

The warming-up operation of the X-ray generating system will be described in more detail with reference to Figure 6. In Figure 6, when warming-up is started, a first X-ray irradiation is executed at a first tube voltage of 150 KV for a first irradiation time and then a first cooling is executed for a first cooling time determined by the first tube voltage and the first irradiation time. Next, a second X-ray irradiation is executed at a second tube voltage of 200 KV higher than the first tube voltage for a second irradiation time shorter than the first irradiation time, and then a second cooling is executed for a second cooling time longer than the first cooling time which is determined by the second tube voltage and the second irradiation time. After that, X-ray irradiations and coolings are executed alternately, with raising the tube voltages from 250 KV to 300 KV. Finally, a final X-ray irradiation is executed at a final tube voltage of 300 KV for a final irradiation time again, and then cooling is executed for a final cooling time determined by the final tube voltage and the final irradiation time. When the final cooling is finished, the warming-up is completed.

When using this embodiment as described above, the following effects can be obtained. (a) When the tube voltage and the irradiation time have been set, alternate X-ray irradiation and cooling are automatically repeated without any judgements by the operator. Therefore, there is no heat damage to the X-ray tube. (b) X-ray irradiation is continued without any waste at minimum times. Therefore, efficient operation of the system is possible. (c) Even if the power source is cut off in error, there will be no damage to the X-ray tube, since the system calculates whether the suspension time is complete or not, and exercises control. (d) Since the irradiation control unit uses a microprocessor, small-scale circuitry is sufficient. Also, it is flexible since it can respond using software.

This embodiment is provided with two cooling mode displays. However, these may be made one, and the case of stopping irradiation after completion of cooling and the case of continuous X-ray irradiation can be distinguished, for example, by changing the display mode.

Next, another embodiment of this invention is shown in Figures 7 to 9. As shown in Figure 7, in the X-ray generating system of this embodiment, in addition to the composition in Figure 1, a temperature detection unit 6 is provided as the temperature detection means which can detect the temperature of X-ray tube 105. In this embodiment, however, derating memory 2 shown in Figure 1 is not necessary, so that it is omitted in Figure 7.

The operation of this X-ray generating system is described using Figures 8 and 9. First, in the case of Figure 8, when the operator outputs X-ray ON demand 123 from X-ray ON setting unit 111, irradiation control unit 1 judges whether the temperature detected by temperature detection unit 6 is within the irradiation available range or not. If it is in the available range, that is, the detected temperature is below a temperature t_2, irradiation control unit 1 starts X-ray irradiation and, at the same time, starts the irradiation time down-count by its built-in timer. Also, it executes a display for the irradiation remainder time on irradiation time display 3. Irradiation control unit 1 always monitors the temperature of X-ray tube 105 by temperature detection unit 6. If the temperature is outside the irradiation available range, that is, the detected temperature is over a temperature t_1, it automatically switches OFF X-ray irradiation. It then starts to execute cooling and displays "Cooling" on cooling mode display 4. Also, when executing further X-ray irradiation after the completion of cooling, it executes an irradiation warning display on cooling mode display 5. At the same time, irradiation control unit 1 monitors the temperature from temperature detection unit 6 and continues to execute cooling until the temperature once more reaches the irradiation available temperature (until the irradiation available re-set temperature t_2 is reached). Then, when the irradiation available temperature t_2 is reached, in the case of some irradiation time still remaining, irradiation control unit 1 automatically starts X-ray irradiation. It then repeats the same operations. This is continued until "Time Up" is reached, or until X-ray OFF demand 125 is received. Here, when no further X-ray irradiation is scheduled, irradiation control unit 1 only displays "Cooling" on cooling mode display 4.

Also, hysteresis is provided at the irradiation available temperature. This is because, when the temperature rises to X-ray irradiation available upper limit value t_1, the system enters the cooling mode. Then, the temperature begins to fall from that upper limit value t_1. However, if X-ray irradiation is commenced immediately on the basis that the temperature is below that upper limit value t_1, the temperature will rapidly reach that upper limit value t_1 again and the system will enter the cooling mode again. If this happens, the X-ray irradiation time will become very short and damage to X-ray tube 105 will occur. It is for this reason that hysteresis is provided in the irradiation available temperature.

The case in Figure 9 is an example of a case when a repeat X-ray ON command is received during cooling "A" when no X-ray irradiation was scheduled after cooling. When X-ray ON command 123 is received during cooling "A", although the temperature has not yet been below irradiation available reset temperature t_2, X-ray irradiation will become immediately available. Then, after this, X-ray irradiation and cooling will be repeated by the same operation as in the case of Figure 8. In this case, simple switching to an algorithm can also be performed that X-ray irradiation is not available if irradiation available re-set temperature t_2 has not been reached.

In the cases of the operations shown in Figures 8 and 9, flow charts are shown in Figures 8A and 9A, which illustrate the operations of irradiation control unit 1 in detail, respectively. When using this embodiment as described above, the following effects can be obtained. That is, there is no heat damage to the X-ray tube, and the efficient operation of the system is possible. Furthermore, the small-circuitry is sufficient for the system, and it is flexible since it can respond using software.

In the operation shown in Figure 8, when the temperature reaches the temperature t_1 at time T_M,irradiation control unit 1 automatically executes X-ray irradiation ON. This invention is not limited to this embodiment. Control of the system of this case may also executed manually as described before, the same as in the operation shown in Figure 3.

As described above, according to the X-ray generating system of this invention, the following effects can be obtained.

In the above composition, firstly, when the set irradiation time exceeds the maximum irradiation time determined by the set tube voltage, that set irradiation time is divided into multiple irradiation times which are within the maximum irradiation time. Cooling is performed for the respective required times between each of these divided irradiation times and after the final irradiation time. In this way, it is possible to operate the system efficiently and without causing heat damage to the X-ray tube by repeating X-ray irradiation for within the maximum irradiation time and cooling for the required time alternately. Moreover, it is possible to reduce the responsibility of the operator.

Secondly, after a single continuous X-ray irradiation, cooling is carried out for a cooling time calculated based on that X-ray irradiation time and the set tube voltage value. By this means, it is possible to ensure prevention of heat damage to the X-ray tube and, at the same time, efficient operation of the system can be performed.

Thirdly, when an X-ray irradiation instruction is inputted during cooling after X-ray irradiation, X-ray irradiation is performed by calculating the irradiation permitted time so that it does not exceed one maximum irradiation available time based on the cooling elapsed time at the time of reception of that instruction and the set tube voltage value. After completion of this X-ray irradiation, cooling is performed by calculating the cooling time from the remaining cooling time at the time of reception of the instruction, that permitted X-ray irradiation time and the set tube voltage value. By this means, heat damage to the X-ray tube is prevented, and efficient operation of the system can be performed.

Fourthly, when X-ray irradiation is re-performed after a long period has elapsed since the time of completion of the previous X-ray irradiation, warming-up is required. More than one series of plans for the tube voltage values and the irradiation times corresponding to this kind of warming-up are stored in the irradiation control unit. X-ray irradiation is controlled by selecting one of these plans based on the time elapsed from the time of completion of the previous X-ray irradiation. By this means, even in X-ray irradiation after a long period of time has elapsed since the time of completion of the previous X-ray irradiation, efficient system operation can be performed without resulting in heat damage to the X-ray tube.

Fifthly, X-ray irradiation and cooling can also be controlled by monitoring the temperature of the X-ray tube. In this way also, efficient system operation is possible without resulting in heat damage to the X-ray tube by monitoring the temperature of the X-ray tube.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

Claims

1. An X-ray generating system, comprising:

an X-ray tube for generating X-rays;

tube voltage setting means for setting a tube voltage applied to said X-ray tube;

irradiation time setting means for setting an irradiation time of said X-rays generated from said X-ray tube;

high voltage generating means for supplying said tube voltage to said X-ray tube to cause said X-ray tube to generate said X-rays based on said tube voltage; and

irradiation control means connected to said tube voltage setting means and said irradiation time setting means for comparing said irradiation time with a maximum irradiation time determined by said tube voltage, for dividing said irradiation time into a plurality of divided irradiation times each being equal to or smaller than said maximum irradiation time when said irradiation time is larger than said maximum irradiation time, for calculating a plurality of cooling times for said X-ray tube between said divided irradiation times and after a final one of said divided irradiation times when said irradiation time is larger than said maximum irradiation time, and for controlling said high voltage generating means to cause said X-ray tube to generate said X-rays for one of said plurality of divided irradiation times, respectively, and to cause said X-ray tube to suspend irradiation of said X-rays for one of said plurality of cooling times, respectively.

2. The X-ray generating system according to claim 1, wherein said irradiation control means calculates each of said of cooling times based on one of said divided irradiation times and said tube voltage, respectively.

3. The X-ray generating system according to claim 2,

wherein said irradiation control means calculates remainder times for each of said divided irradiation times for generating irradiation remainder times and calculates remainder times for each of said plurality of cooling times for generating cooling remainder times;

further comprising irradiation time display means connected to said irradiation control means for displaying one of said irradiation remainder times during irradiation operation of said X-ray generating system and one of said cooling remainder times during cooling operation of said X-ray generating system.

4. The X-ray generating system according to claim 2,

wherein said irradiation control means generates a cooling information related to a cooling which is a suspension of X-ray irradiation of said X-ray tube;

further comprising cooling mode display

means connected to said irradiation control means for displaying said cooling information during cooling operation of said X-ray generating system.

5. The X-ray generating system according to claim 4,
wherein said irradiation control means generates said cooling information including a first cooling information showing that said X-ray generating system is in said cooling operation and a second cooling information showing that said X-ray generating system is in said cooling operation and automatically commence said X-ray irradiation after completion of a present cooling time; and
wherein said cooling mode display means includes a first cooling mode display for displaying said first cooling information and a second cooling mode display for displaying said second cooling information.

6. The X-ray generating system according to claim 1,
wherein said irradiation control means further includes means for receiving a next X-ray irradiation instruction during a final cooling time after said final one of said divided irradiation times, for calculating an irradiation permitted time based on an elapsed time of said final cooling time and a next set tube voltage at the time of receiving said next X-ray irradiation instruction, for calculating a first cooling time of said next X-ray irradiation instruction for said X-ray tube based on a remaining time of said final cooling time at said time of receiving said next X-ray irradiation instruction, said irradiation permitted time and said next set tube voltage, and for controlling said high voltage generating means to cause said X-ray tube to generate said X-rays for said irradiation permitted time at said next set tube voltage and to cause said X-ray tube to suspend irradiation of said X-rays for said first cooling time.

7. The X-ray generating system according to claim 6,
wherein said irradiation control means calculates said first cooling times based on said irradiation permitted time and said next set tube voltage.

8. The X-ray generating system according to claim 1,
wherein said irradiation control means further includes means for detecting that a power source for said system is switched OFF at a first time and switched ON again at a second time, for finding a cooling elapsed time at said first time, for calculating a cooling remainder time at said second time based on said cooling elapsed time at said first time and a time difference between said first time and said second time, for finding whether or not further cooling is required, and for controlling said high voltage generating means to cause said X-ray tube to suspend irradiation of said X-rays for said cooling remainder time when said further cooling is required.

9. An X-ray generating system, comprising:
an X-ray tube for generating X-rays;
high voltage generating means for supplying a tube voltage to said X-ray tube to cause said X-ray tube to generate said X-rays based on said tube voltage; and
irradiation control means for preparing, based on an elapsed time from a completion time of a previous X-ray irradiation, a plurality of divided irradiation times each being given a respective tube voltage and a plurality of cooling times between said divided irradiation times and after a final one of said divided irradiation times, each of said cooling times being determined based on one of said divided irradiation times along with said respective tube voltage, respectively, and for controlling said high voltage generating means to cause said X-ray tube to generate said X-rays at said respective tube voltage for one of said plurality of divided irradiation times, respectively, and to cause said X-ray tube to suspend irradiation of said X-rays for one of said plurality of cooling times, respectively.

10. An X-ray generating system, comprising:
an X-ray tube for generating X-rays;
tube voltage setting means for setting a tube voltage applied to said X-ray tube;
irradiation time setting means for setting an irradiation time of said X-rays generated from said X-ray tube;
high voltage generating means for supplying said tube voltage to said X-ray tube to cause said X-ray tube to generate said X-rays based on said tube voltage;
temperature detection means for detecting a temperature of said X-ray tube; and
irradiation control means connected to said tube voltage setting means and said irradiation time setting means for controlling said high voltage generating means to cause said X-ray tube to generate said X-rays for a plurality of divided irradiation times separately, a total of which being said irradiation time, based on said temperature and to cause said X-ray tube

to suspend irradiation of said X-rays between said divided irradiation times and after a final one of said divided irradiation times based on said temperature to prepare a plurality of cooling times for said X-ray tube.

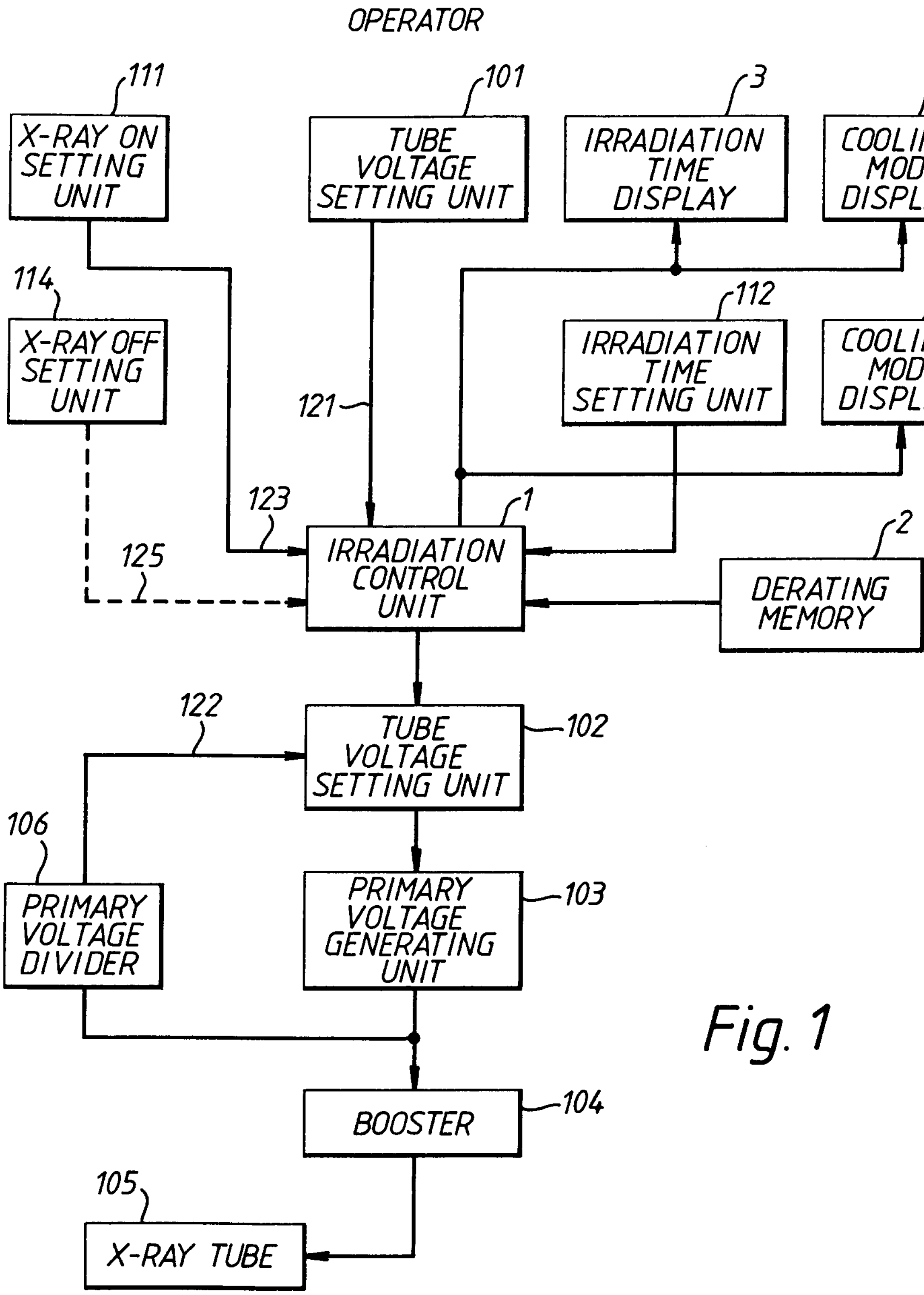

OPERATOR
111
X-RAY ON SETTING UNIT
101
TUBE VOLTAGE SETTING UNIT
3
IRRADIATION TIME DISPLAY
4
COOLING MODE DISPLAY
114
X-RAY OFF SETTING UNIT
112
IRRADIATION TIME SETTING UNIT
5
COOLING MODE DISPLAY
121
123
1
125
IRRADIATION CONTROL UNIT
2
DERATING MEMORY
122
TUBE VOLTAGE SETTING UNIT
102
106
PRIMARY VOLTAGE DIVIDER
PRIMARY VOLTAGE GENERATING UNIT
103
BOOSTER
104
105
X-RAY TUBE

Fig. 1

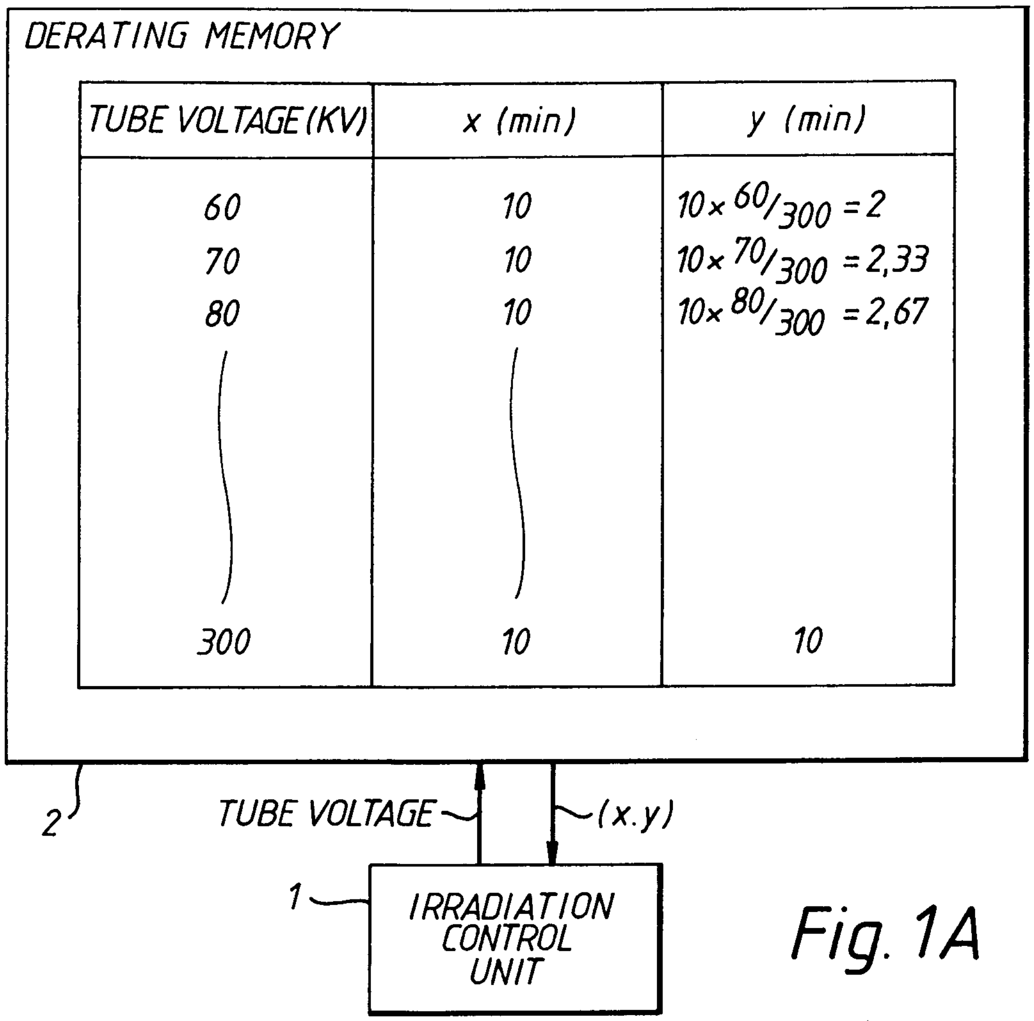

DERATING MEMORY
TUBE VOLTAGE (KV)
x (min)
y (min)
60
70
80
300
10
10
10
10
10×60/300 =2
10×70/300 =2,33
10×80/300 =2,67
10
2
TUBE VOLTAGE
(x.y)
1
IRRADIATION CONTROL UNIT

Fig. 1A

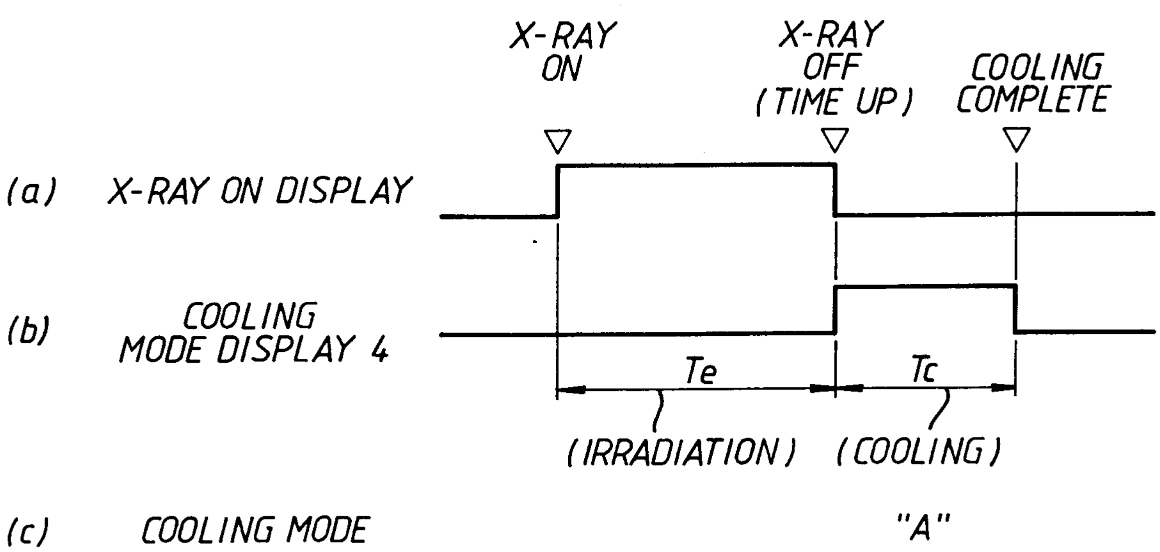

X-RAY ON
X-RAY OFF (TIME UP)
COOLING COMPLETE
(a) X-RAY ON DISPLAY
(b) COOLING MODE DISPLAY 4
Te
Tc
(IRRADIATION)
(COOLING)
(c) COOLING MODE
"A"

Fig. 2

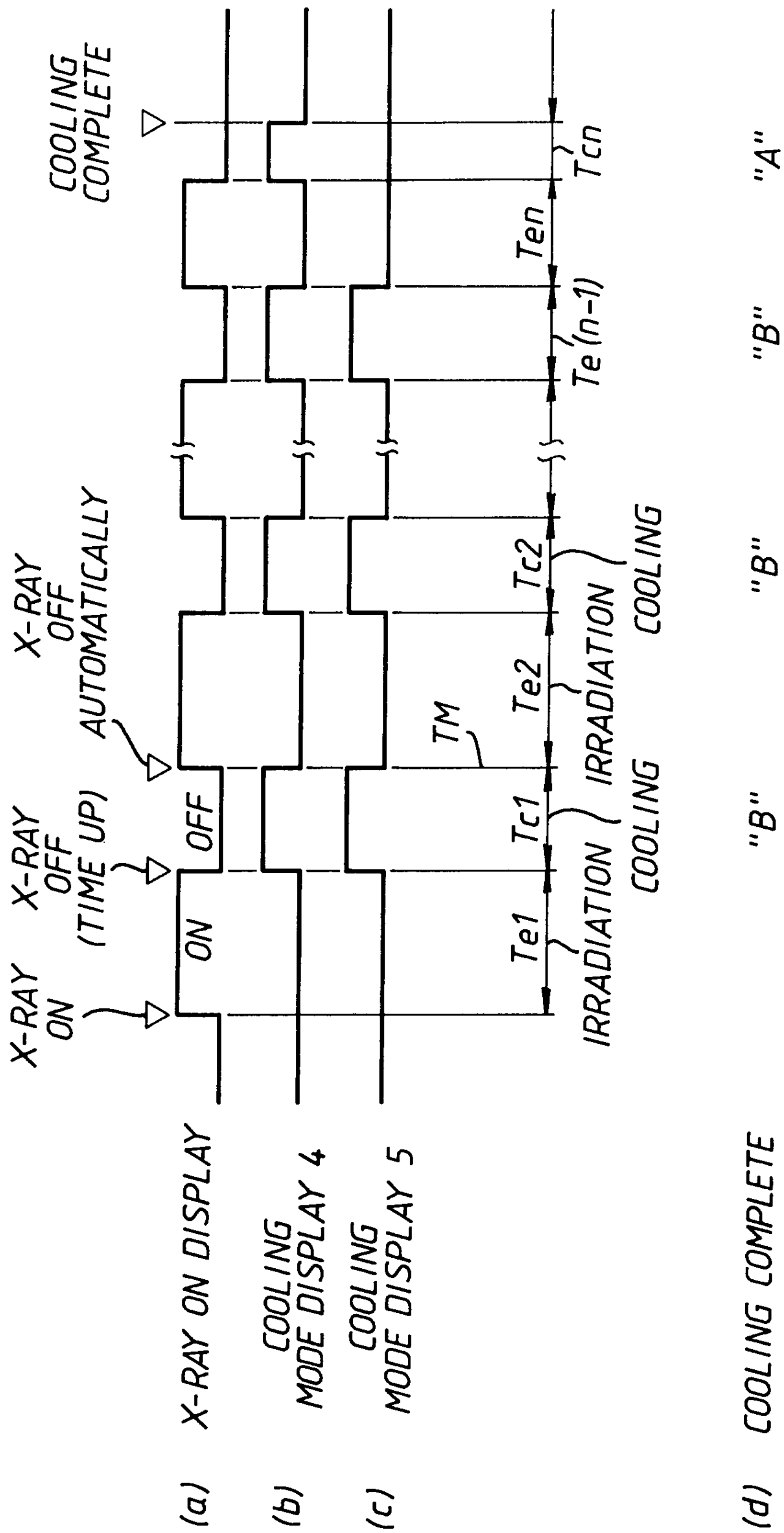

(a) X-RAY ON DISPLAY
(b) COOLING MODE DISPLAY 4
(c) COOLING MODE DISPLAY 5
(d) COOLING COMPLETE
X-RAY ON
X-RAY OFF (TIME UP)
X-RAY OFF AUTOMATICALLY
COOLING COMPLETE
ON
OFF
TM
Te1
Tc1
Te2
Tc2
Te(n-1)
Ten
Tcn
IRRADIATION
COOLING
IRRADIATION
COOLING
"B"
"B"
"B"
"A"

Fig.3

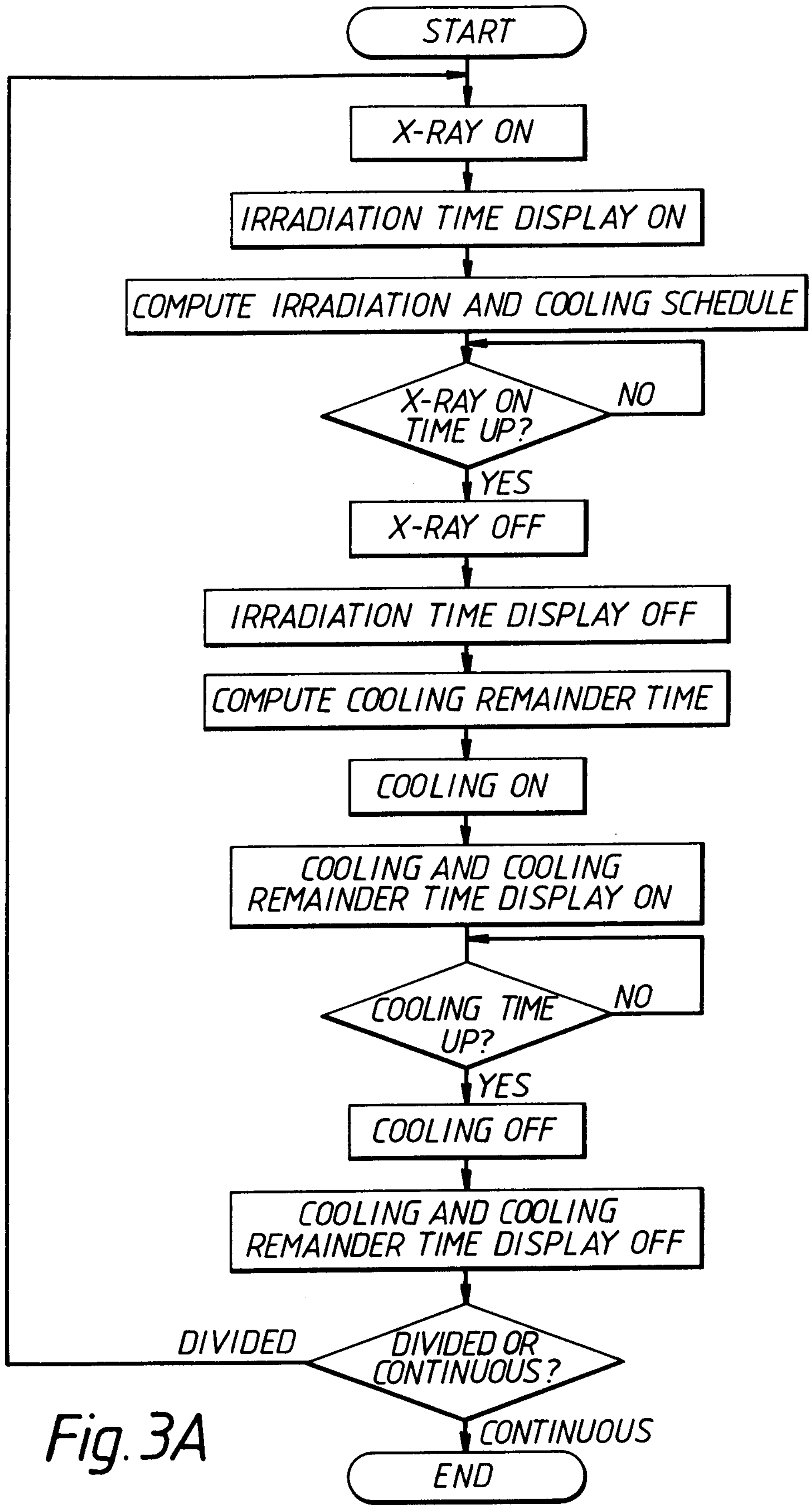

START
X-RAY ON
IRRADIATION TIME DISPLAY ON
COMPUTE IRRADIATION AND COOLING SCHEDULE
X-RAY ON TIME UP?
NO
YES
X-RAY OFF
IRRADIATION TIME DISPLAY OFF
COMPUTE COOLING REMAINDER TIME
COOLING ON
COOLING AND COOLING REMAINDER TIME DISPLAY ON
COOLING TIME UP?
NO
YES
COOLING OFF
COOLING AND COOLING REMAINDER TIME DISPLAY OFF
DIVIDED
DIVIDED OR CONTINUOUS?
CONTINUOUS
END

Fig. 3A

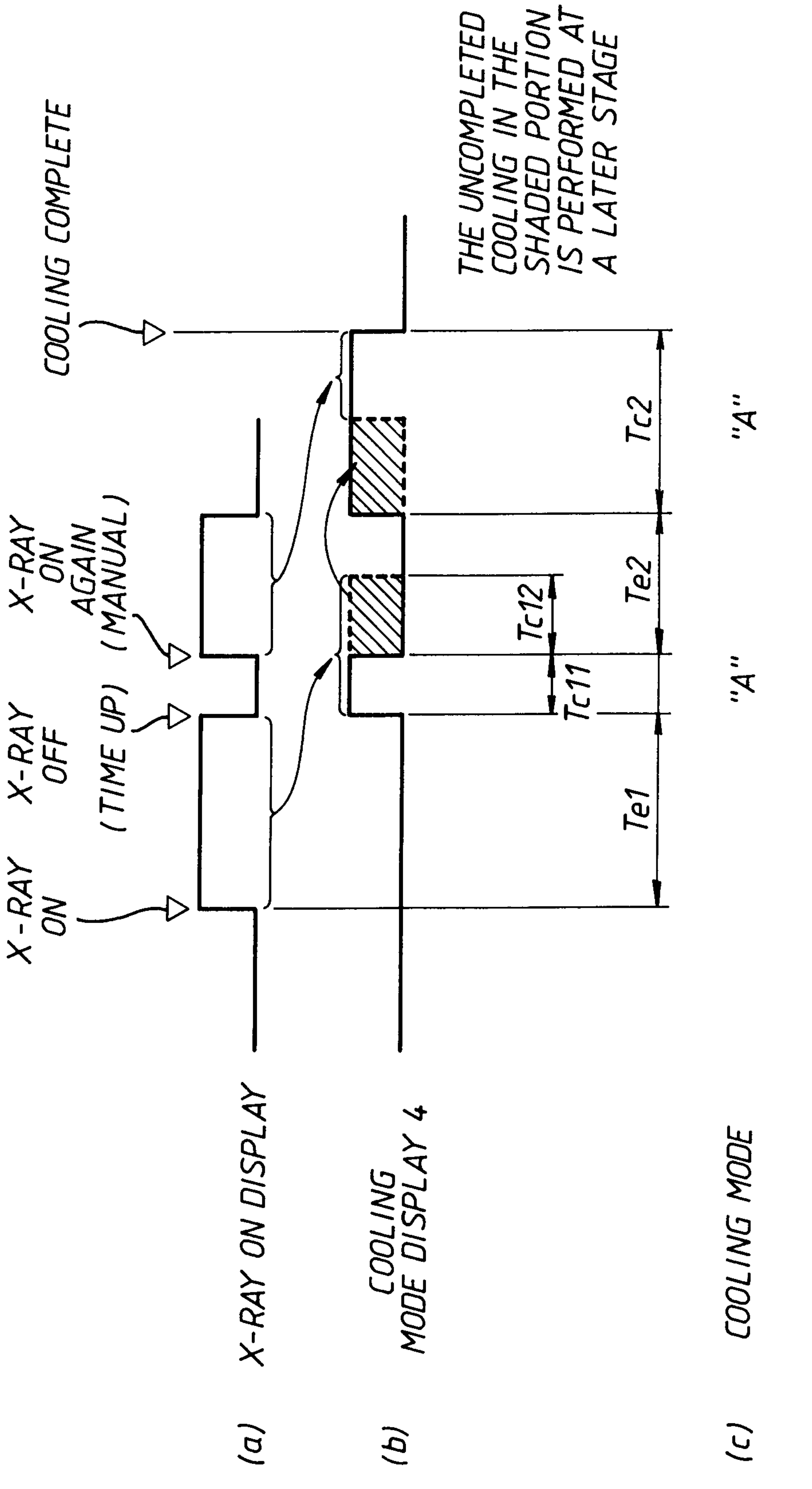

(a) X-RAY ON DISPLAY
(b) COOLING MODE DISPLAY 4
(c) COOLING MODE
X-RAY ON
X-RAY OFF (TIME UP)
X-RAY ON AGAIN (MANUAL)
COOLING COMPLETE
THE UNCOMPLETED COOLING IN THE SHADED PORTION IS PERFORMED AT A LATER STAGE
Te1
Tc11
Tc12
Te2
Tc2
"A"
"A"

Fig. 4

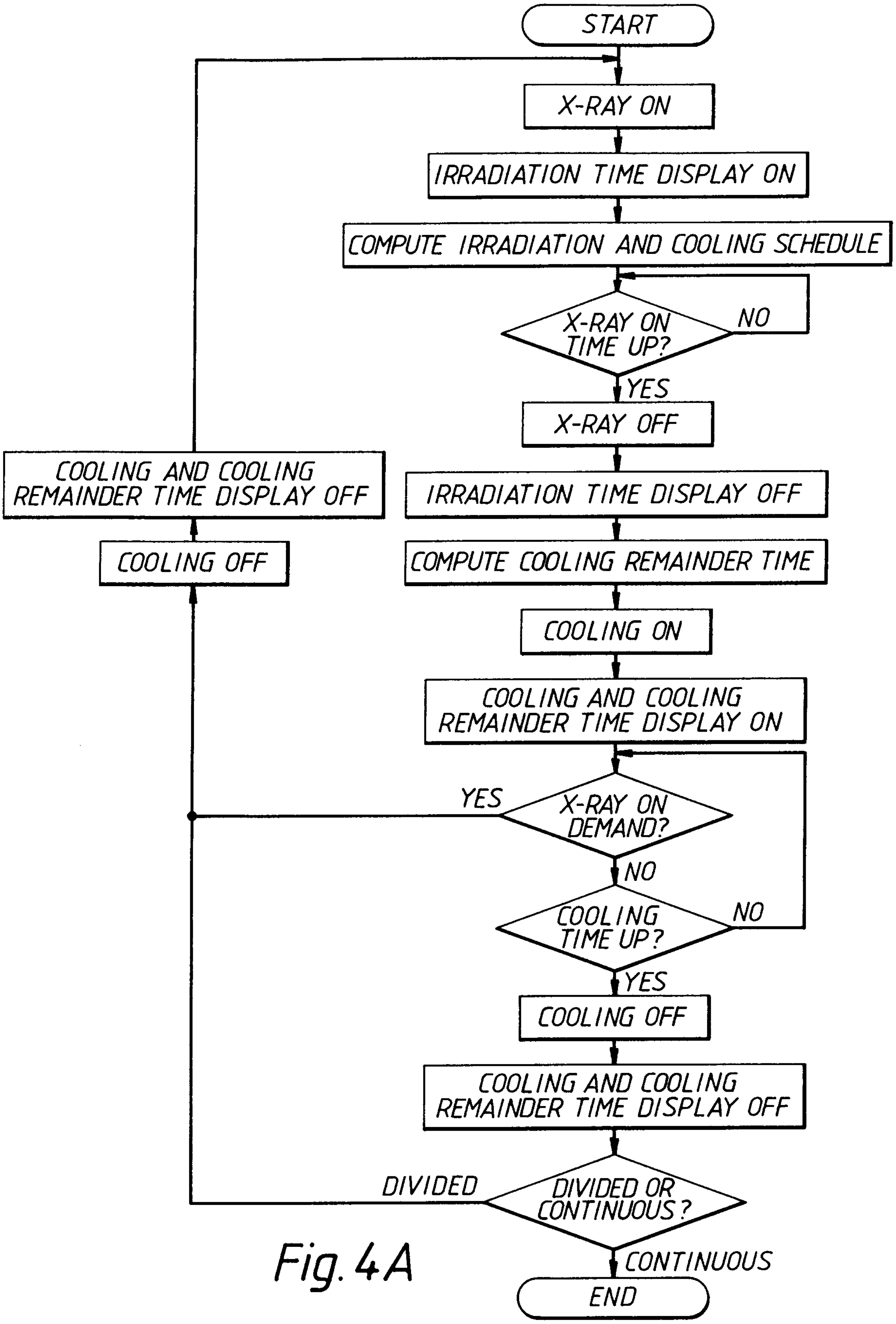

START
X-RAY ON
IRRADIATION TIME DISPLAY ON
COMPUTE IRRADIATION AND COOLING SCHEDULE
X-RAY ON TIME UP?
NO
YES
X-RAY OFF
IRRADIATION TIME DISPLAY OFF
COMPUTE COOLING REMAINDER TIME
COOLING ON
COOLING AND COOLING REMAINDER TIME DISPLAY ON
X-RAY ON DEMAND?
YES
NO
COOLING TIME UP?
NO
YES
COOLING OFF
COOLING AND COOLING REMAINDER TIME DISPLAY OFF
DIVIDED OR CONTINUOUS?
DIVIDED
CONTINUOUS
END
COOLING OFF
COOLING AND COOLING REMAINDER TIME DISPLAY OFF

Fig. 4A

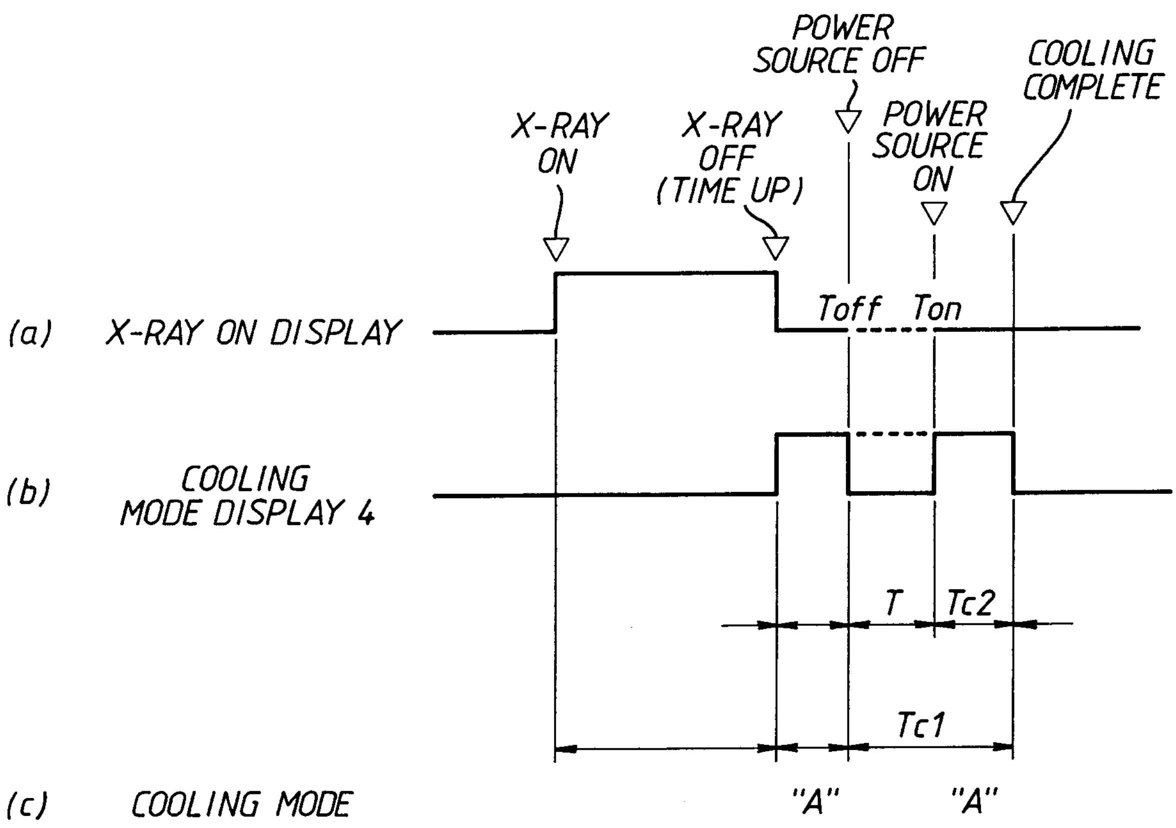
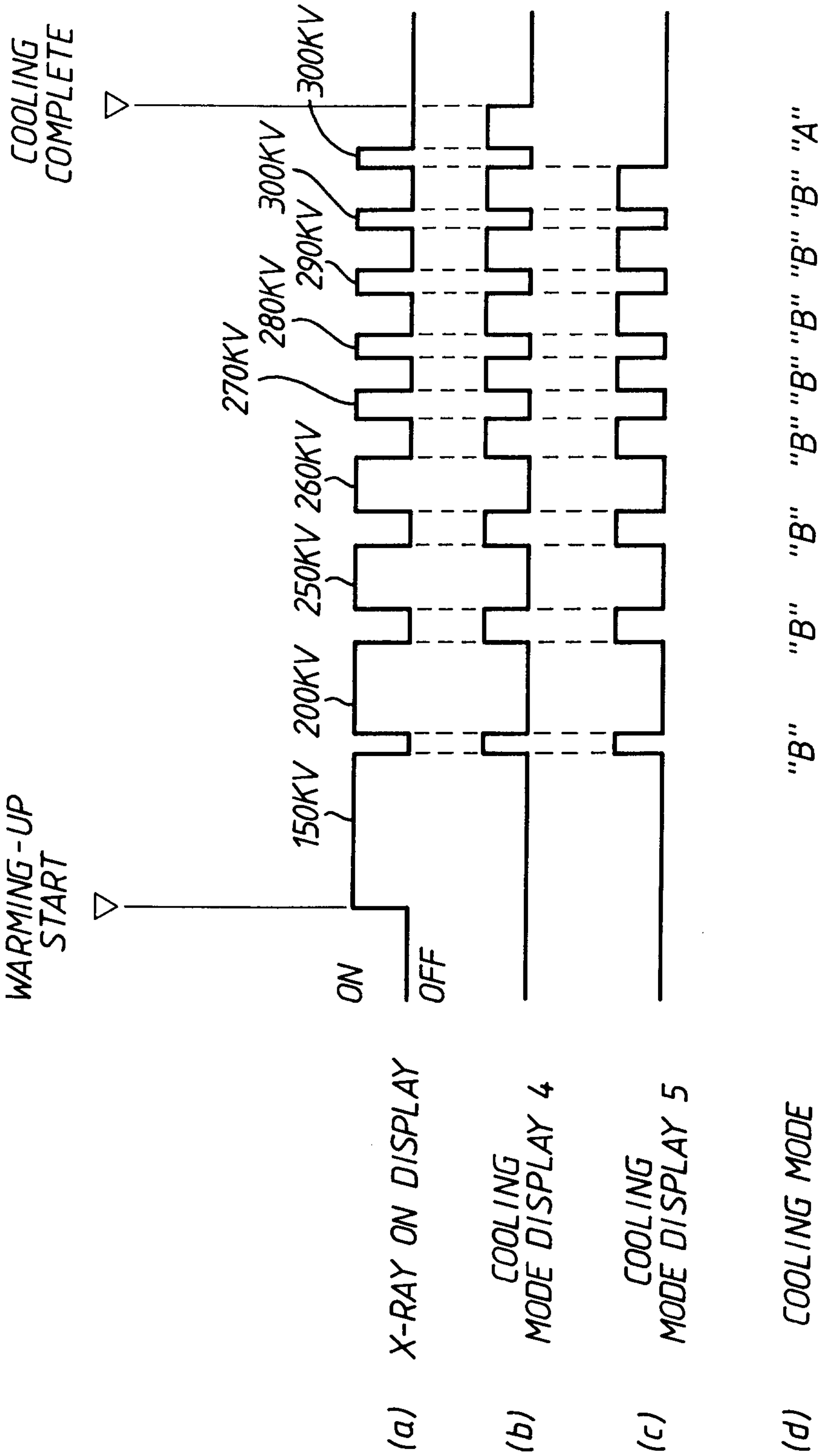

POWER
SOURCE OFF
COOLING
COMPLETE
X-RAY
ON
X-RAY
OFF
(TIME UP)
POWER
SOURCE
ON
Toff
Ton
(a)
X-RAY ON DISPLAY
(b)
COOLING
MODE DISPLAY 4
T
Tc2
Tc1
(c)
COOLING MODE
"A"
"A"

Fig. 5



WARMING-UP START
COOLING COMPLETE
ON
OFF
150KV
200KV
250KV
260KV
270KV
280KV
290KV
300KV
300KV
(a) X-RAY ON DISPLAY
(b) COOLING MODE DISPLAY 4
(c) COOLING MODE DISPLAY 5
(d) COOLING MODE
"B" "B" "B" "B" "B" "B" "B" "B" "B" "A"

Fig. 6

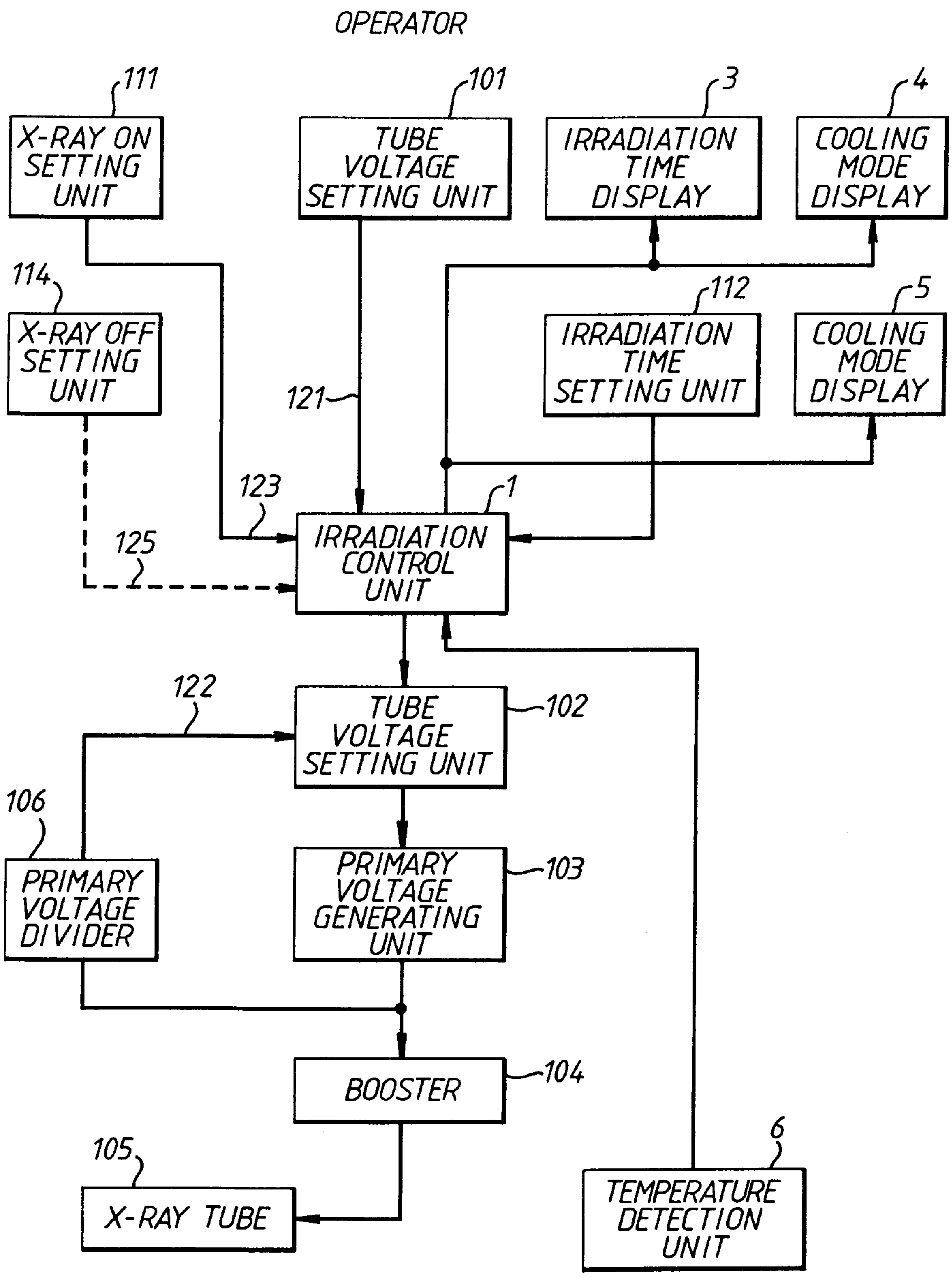

OPERATOR
111
X-RAY ON SETTING UNIT
101
TUBE VOLTAGE SETTING UNIT
3
IRRADIATION TIME DISPLAY
4
COOLING MODE DISPLAY
114
X-RAY OFF SETTING UNIT
112
IRRADIATION TIME SETTING UNIT
5
COOLING MODE DISPLAY
121
123
125
1
IRRADIATION CONTROL UNIT
122
TUBE VOLTAGE SETTING UNIT
102
106
PRIMARY VOLTAGE DIVIDER
PRIMARY VOLTAGE GENERATING UNIT
103
BOOSTER
104
105
X-RAY TUBE
6
TEMPERATURE DETECTION UNIT

Fig. 7

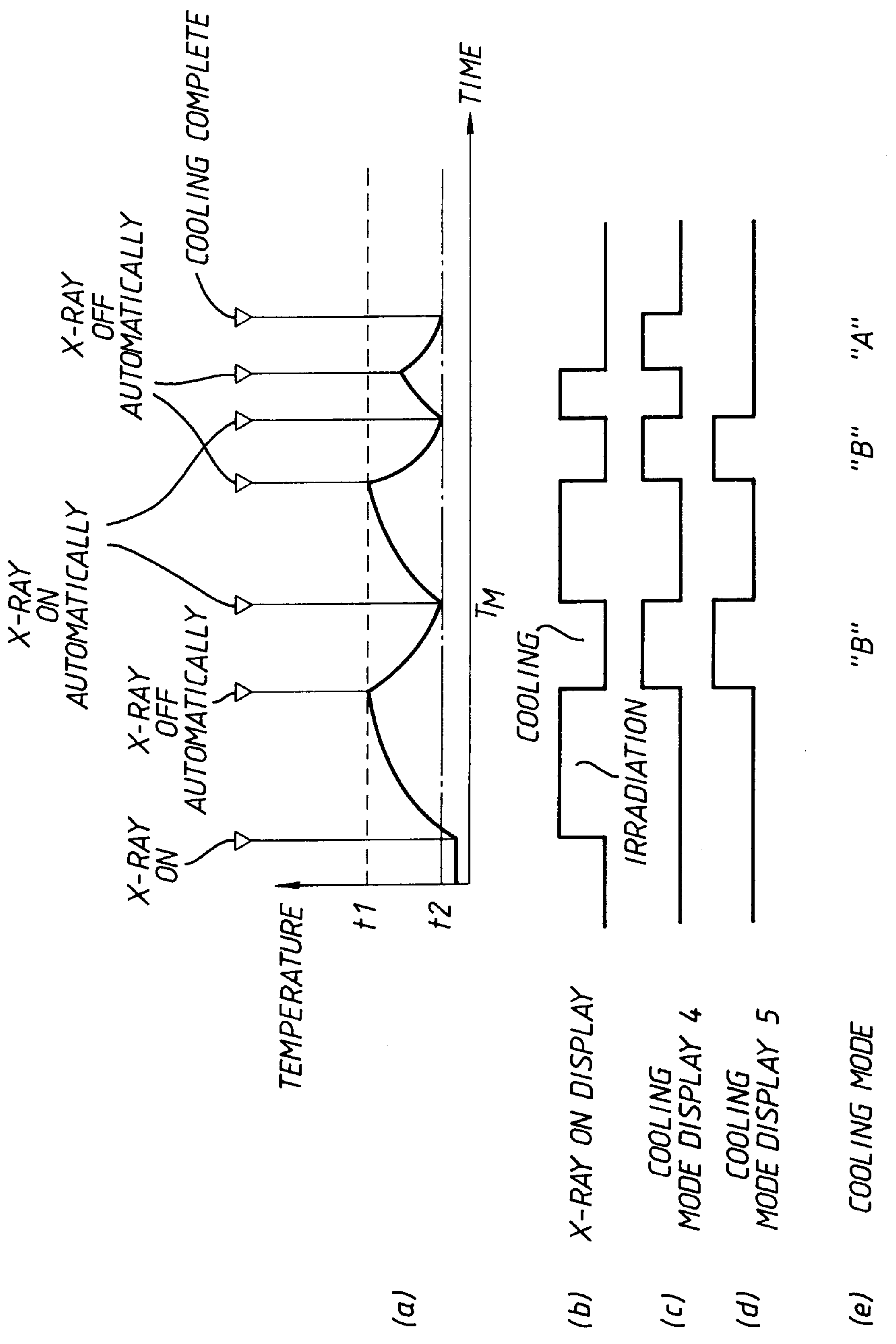

(a)
TEMPERATURE
t1
t2
TIME
TM
X-RAY ON
X-RAY OFF AUTOMATICALLY
X-RAY ON AUTOMATICALLY
X-RAY OFF AUTOMATICALLY
COOLING COMPLETE
(b)
X-RAY ON DISPLAY
IRRADIATION
COOLING
(c)
COOLING MODE DISPLAY 4
(d)
COOLING MODE DISPLAY 5
(e)
COOLING MODE
"B"
"B"
"A"

Fig.8

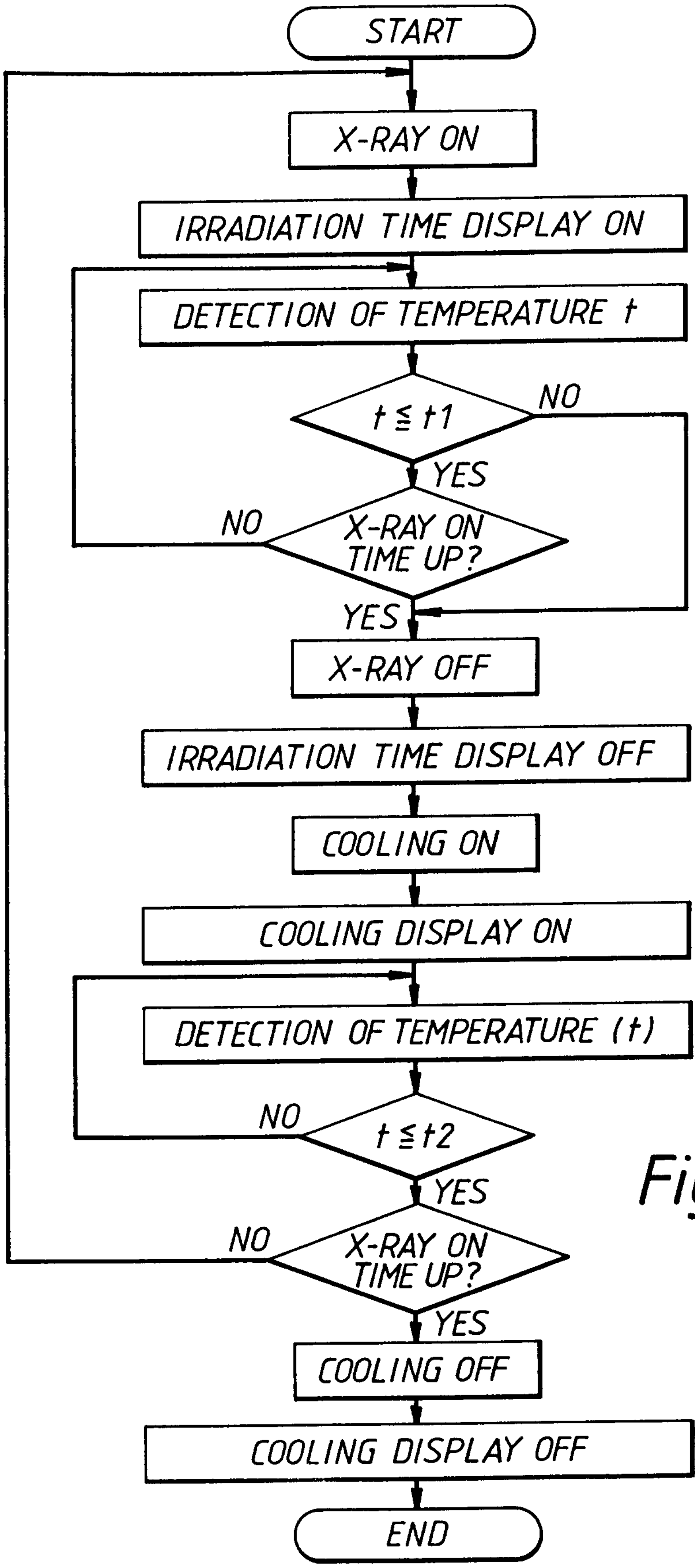

START
X-RAY ON
IRRADIATION TIME DISPLAY ON
DETECTION OF TEMPERATURE t
t ≦ t1
NO
YES
NO
X-RAY ON TIME UP?
YES
X-RAY OFF
IRRADIATION TIME DISPLAY OFF
COOLING ON
COOLING DISPLAY ON
DETECTION OF TEMPERATURE (t)
NO
t ≦ t2
YES
NO
X-RAY ON TIME UP?
YES
COOLING OFF
COOLING DISPLAY OFF
END

Fig. 8A

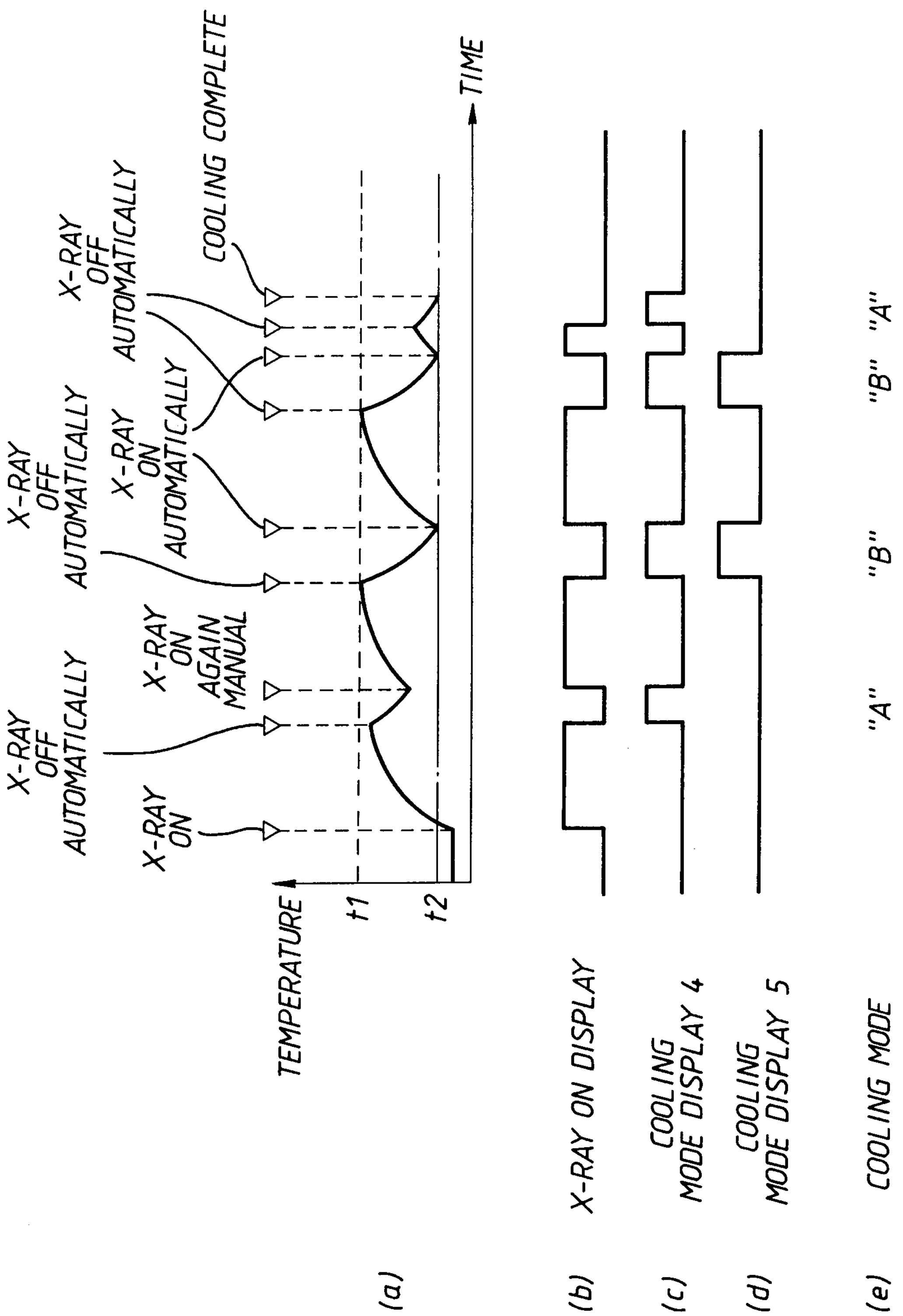

(a)
TEMPERATURE
t1
t2
TIME
X-RAY ON
X-RAY OFF AUTOMATICALLY
X-RAY ON AGAIN MANUAL
X-RAY OFF AUTOMATICALLY
X-RAY ON AUTOMATICALLY
X-RAY OFF AUTOMATICALLY
COOLING COMPLETE
(b) X-RAY ON DISPLAY
(c) COOLING MODE DISPLAY 4
(d) COOLING MODE DISPLAY 5
(e) COOLING MODE
"A"
"B"
"B"
"A"

Fig. 9

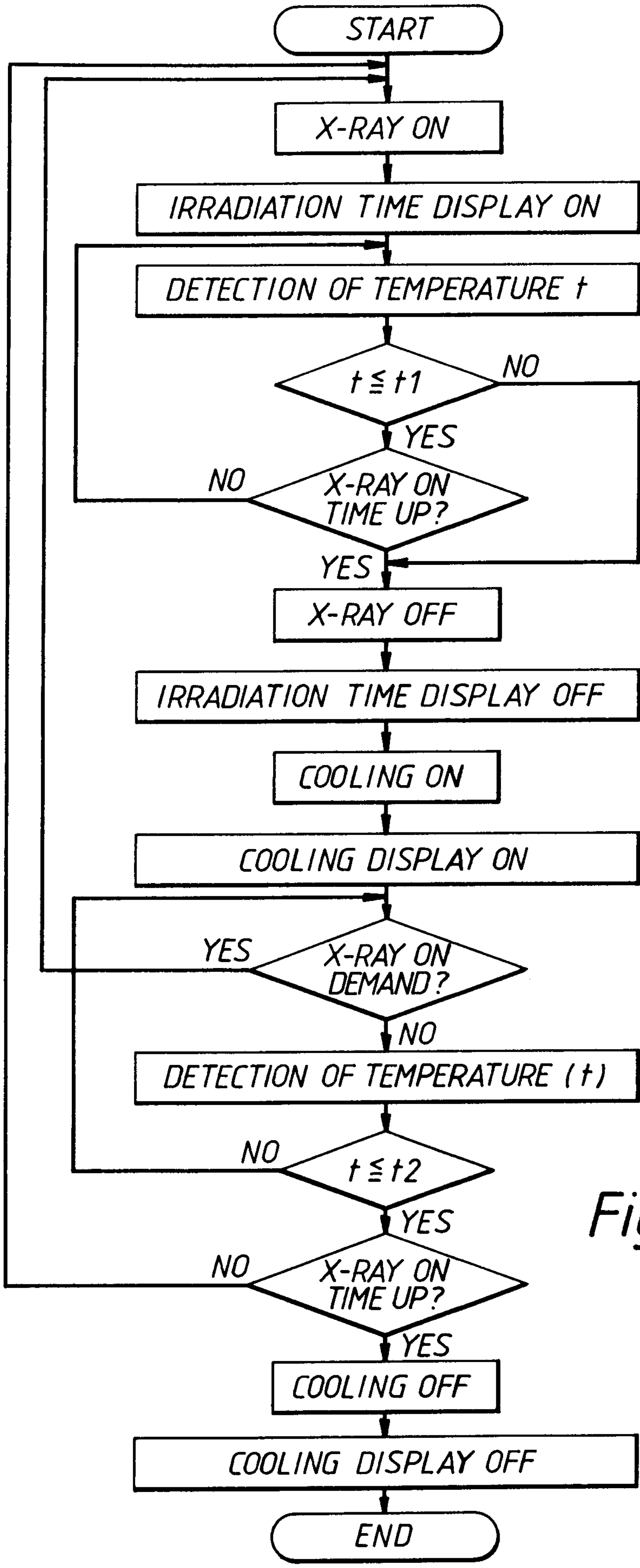

START
X-RAY ON
IRRADIATION TIME DISPLAY ON
DETECTION OF TEMPERATURE t
t ≦ t1
NO
YES
X-RAY ON TIME UP?
NO
YES
X-RAY OFF
IRRADIATION TIME DISPLAY OFF
COOLING ON
COOLING DISPLAY ON
X-RAY ON DEMAND?
YES
NO
DETECTION OF TEMPERATURE (t)
t ≦ t2
NO
YES
X-RAY ON TIME UP?
NO
YES
COOLING OFF
COOLING DISPLAY OFF
END

Fig. 9A

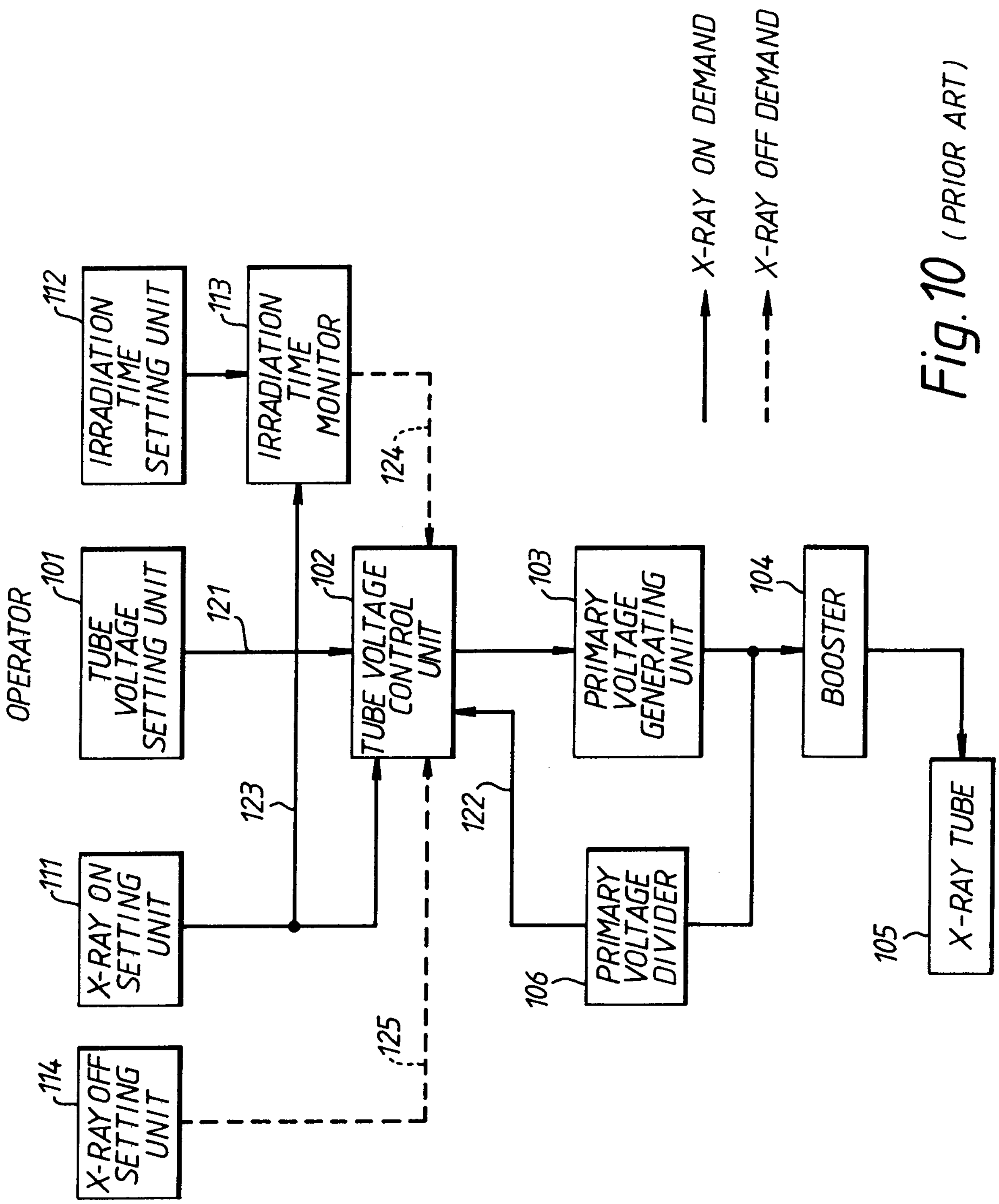


Fig. 10 (PRIOR ART)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 30 3246

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
A	GB-A-1 498 824 (PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED) * page 1, line 15 - page 2, line 105 * * page 3, line 27 - page 4, line 96; figures 1,2 *	1,9,10	H05G1/26 H05G1/36 H05G1/54
A	US-A-4 386 320 (R.R. LAFRANCE) * abstract * * column 4, line 3 - column 7, line 68; figures 1-3 *	1,9,10	
A	US-A-4 819 259 (S. TANAKA) * abstract * * column 2, line 35 - column 3, line 28 *	1,9,10	
A	EP-A-0 022 295 (N.V. PHILIPS' GLOEILAMPENFABRIEKEN) * abstract * * page 6, line 29 - page 15, line 20; figures 1-3 *	1,9,10	**TECHNICAL FIELDS SEARCHED (Int.Cl.5)**
A	PATENT ABSTRACTS OF JAPAN vol. 5, no. 82 (E-59) (754) 29 May 1981 & JP-A-56 030 297 (TOKYO SHIBAURA DENKI K.K.) 26 March 1981 * abstract *	1,9,10	H05G
A	US-A-3 961 173 (J.T. PERRY ET AL.) * abstract *	1,9,10	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	5 August 1994	Horak, G

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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