WORLD HEALTH ORGANIZATION ORGANISATION MONDIALE DE LA SANTE

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REPORT FROM THE CONSULTATION MEETING ON

THE WHO BASIC RADIOLOGICAL SYSTEMS

held at the WHO Collaborating Centre for
General and Continuing Radiological Education
University Hospital, Lund Sweden

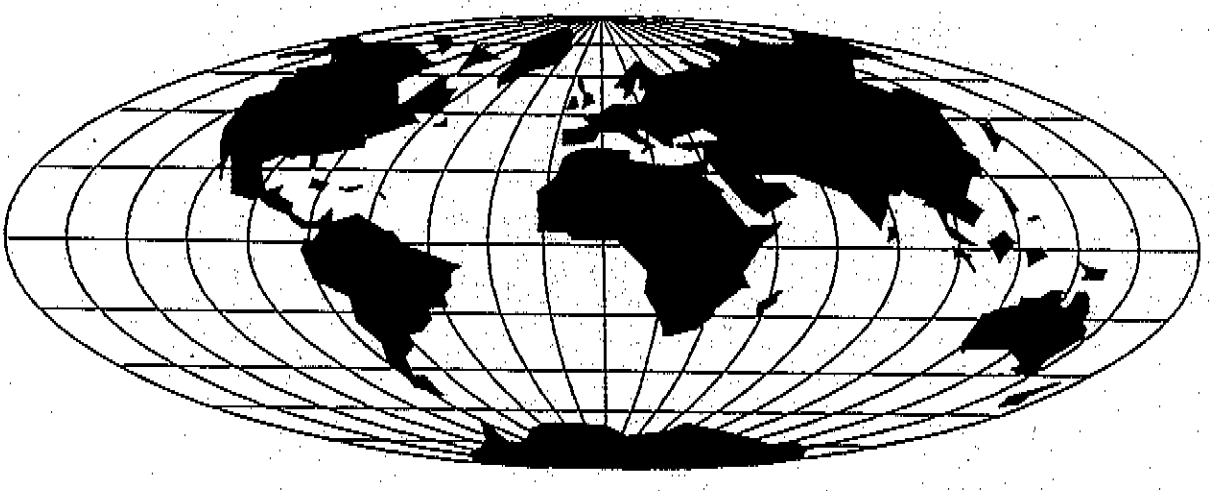
7-11 June 1993

including the

TECHNICAL SPECIFICATIONS FOR THE

WORLD HEALTH IMAGING SYSTEM FOR RADIOGRAPHY

the WHIS-RAD



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REPORT FROM THE CONSULTATION MEETING ON THE WHO BASIC RADIOLOGICAL SYSTEM

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University Hospital, Lund, Sweden, June 7-11, 1993

1. BACKGROUND AND INTRODUCTION

In March **1975** a meeting on *A Primary Care Radiological System* was held in Washington, DC, USA, on the initiative of the Pan American Health Organization (PAHO, the WHO Regional Office for the Americas) to review existing efforts to make diagnostic radiology available to all who need it. The estimate at this time was that about 70% of the world population had no access to diagnostic radiology. Participants of the meeting were radiologists, radiophysicists, administrators and technical representatives of manufacturers. The final report from this meeting contained the first *Proposed specifications for a primary care radiological unit.* These specifications were further developed at several advisory group meetings and in **1985** the *Technical specifications for the x-ray apparatus to be used in a basic radiological system* was published by the World Health Organization (WHO).

WHO has continued to develop this concept of diagnostic radiology, which since 1975 has been known by the name the **WHO Basic Radiological System (WHO-BRS).** The WHO-BRS was originally intended for use in regions deprived of radiodiagnostic service for economic or geographic reasons. This limitation no longer applies, since the new system, presented in this report, can be used with advantage anywhere.

The guiding priciples in the design of the WHO-specified radiographic unit have been:

1. The quality of the images must be excellent.
2. The equipment must be safe for patients and personnel.
3. The equipment must be easy to install and use.
4. The equipment must be reliable and usable when the electrical supply (and other services) are not up to those provided in big cities.
5. The equipment maintenance should be minimal.

1.1. RECENT DEVELOPMENTS

The hardware of the WHO-BRS has undergone further development and improvement since 1985 and by the end of **1992** a new **World Health Imaging System for Radiography (WHIS-RAD)** was ready for presentation.

WHO now has more than ten years of practical clinical experience with the early BRS concept, being used at numerous small hospitals and primary care centres all over the world.

The new WHIS-RAD Unit can perform more than 80% of all general radiographic procedures, required at large teaching hospitals. It is easier to operate than most conventional x-ray equipment and can be powered from batteries or any reliable 2.3 kW power source.

It is possible to manufacture the WHO-specified radiographic equipment at low cost and it functions extremely well in the front line of any health care system.

Nine different successful prototypes of WHO-BRS units were tested at the WHO Collaborating Centre for BRS in Lund, Sweden, between 1981 and 1992. The tests included more than a quarter million successful clinical x-ray examinations. The testing has continued after 1992 at the new **WHO Collaborating Centre for General and Continuing Radiological Education** at the same location.

1.2. CONSULTATION MEETING

A consultation meeting on the WHO Basic Radiological System was convened in Lund, Sweden, June 7-11, **1993,** at the **WHO Collaborating Centre for General and Continuing Radiological Education.** A list of participants is attached to this report.

Organizing committee:
Dr Holger Pettersson, Professor of Radiology and Deputy Medical Director at Lund University Hospital, Head, WHO Collaborating Centre for General and Continuing Radiological Education;
Dr Thure Holm, Consultant Radiologist and former Head of the WHO Collaborating Centre for Basic Radiological Systems at Lund University Hospital; and
Dr Gerald P. Hanson, Chief, Radiation Medicine, WHO, Geneva.

WHO Advisers: Six members of earlier consultation groups and four new Temporary Advisers having practical experience with the WHO-BRS were invited to this meeting, two of the latter being active superintendent radiographers with experience of radiography at first referral level x-ray departments in Africa.

Representatives of International Societies:
The International Society of Radiology, the International Society of Radiographers and Radiological Technologists, and the International Organization for Medical Physics were invited to participate and sent representatives.

Representatives of Industry: All manufacturers of x-ray equipment, known to the WHO at the time, were invited and eight participated, representing six equipment manufacturers and one x-ray film manufacturer.

The objectives of the meeting were:

- To review the technical specifications of the existing WHO-BRS, taking into consideration the concerns and advice from radiographers and equipment manufacturers.

- To consider the problems and obstacles which have inhibited a more widespread use of the WHO-BRS in the developing world.

- To agree on a forward-looking strategy to help implement the WHO goal of Health for All through equity in access to good quality medical radiography.

1.2.1. Reports from BRS activities

Dr **Gerald P. Hanson** summarized the WHO activities up to June 1993, partly presented above. He also mentioned that still, at least 70% of the world population has no access to diagnostic radiology.

Ms **Kerstin Åkerman** reported about 8 years of experience with two WHO-BRS units at mission hospitals in Africa without any major breakdown. The units are battery-operated and may remain operative for up to three weeks without recharging, making ten examinations per day, which is very useful during power breakdowns. She suggested that extra angulation possibilities of the x-ray tube be provided for examinations of severe trauma cases.

Mr **Emanuel Borg** noted that installation crews usually are competent to install the stand, x-ray tube and high-tension generator. But they very often don't know how to position the equipment in the examination room to protect the operator from radiation during the x-ray exposure and to permit the proper use of the patient trolley. He proposed that installation instructions should be included in the specifications.

Mr **Dick Rijkhoff** reported the results of a clinical test project led by SIMAVI, a charity organization in the Netherlands, which tested eight WHO-BRS units in Africa and one in Amsterdam. They found no problems with the BRS units, but correct installation instructions were not always followed and several units were delivered with the grids installed back-to-front at the factory. Important problems related mainly to the darkroom work.

Dr **Staffan Sandström** reported about a project in Moscow, where 50,000 high quality chest radiographs had been obtained with a single WHO-BRS unit in a nine month period without any breakdown. He mentioned some equipment positioning problems during the installation. These, however, were solved by Dr Holm or himself visiting from the WHO Collaborating Centre for BRS in Lund.

Two **manufacturers** (Bennett and Philips) presented new high-frequency x-ray generators, using 100 kHz and inverter technology. Prototypes of both have been tested in Lund and seem very promising.

Site visits were made by Meeting participants to BRS installations at two large primary care centres. They were able to study two Prime-X units, made by Siemens-Elema and used in routine clinical work for 6 and 3 years respectively at Roentgen St Lars (the WHO Collaborating Centre) and Roentgen Eslöv, and a new BRS prototype to be marketed by Philips under the name MRS (Multi Radiographic System), which had been installed during the meeting.

1.2.2. Technical discussions of the new specifications.

With the *Technical specifications for the x-ray apparatus to be used in a basic radiological system* (WHO RAD/85.1) serving as a background, Dr **Thure Holm's** outline of the new specifications for a WHIS-RAD unit were discussed line by line. Important items are reported below. The complete final specifications are included in this document.

- It was recommended that the new specifications will **define only one radiographic unit** and that this unit will be given a new name. The old BRS specifications will be referred to as the "WHO-BRS/85". The new specifications are modified to include a standard light-beam collimator and a cassette holder, accepting any standard format. Provisions will be included so that tube angulation and collimation outside the cassette holder's back-wall radiation protection may be used, if a qualified radiographer is operating the machine under special conditions.

- **Generator.** Only multipulse generators are considered. The WHO advisers recommend that the total energy available for a single exposure shall be 25 kWs, if only blue-sensitive x-ray film is available (used with blue-emitting intensifying screens).
If green-sensitive film is easily available and used in combination with green-emitting screens, it is possible to use a generator with an upper energy limit as low as 12.5 kWs.

- **The highest available x-ray tube tension** shall be 120 kV.

- **X-ray tube life.** The replacement of an x-ray tube is often a major economic and administrative problem. It is important that the x-ray tube has a long life, in this context meaning about 50,000 exposures of the mixture and composition, which is common in primary care and at the first referral level (item 3.2.1).

- **Tube filtration** should be specified as the total filtration expressed by means of HVL.

- **Collimator.** A standard, multilevel, light-beam collimator should be used. The collimator controls shall have reliable format indications for an FFD of 140 cm.

- **The examination stand.** The standard unit will require fixation to floor and wall.

A free-standing unit can be specified as an option.

- **X-ray tube angulation.** The examination stand shall be delivered to the installation site with the x-ray tube-head fixed, without other angulation possibilities than those, provided by the tube arm, connected to the cassette holder. Tube angulation away from the cassette holder may be used only by the senior radiographer, responsible for radiation safety, or by another radiographer or well trained operator after special instructions.

- **Cassette holder.** Any standard cassette format, used in the country where the equipment is installed, should be accepted. It must be possible to change and centre the cassettes with minimal difficulty, also when the x-ray beam is used in the vertical direction, with the cassette holder in close contact with the table top of the patient trolley.

- **Viewing boxes.** Film viewing should be done in the office of the x-ray department or in the generator control space. Viewing in the darkroom or the examination room interferes with other functions. Two light boxes, approximately 40 cm wide and 50 cm high side by side, or one lightbox about 80 cm wide and 50 cm high, are recommended. Best is to use fluorescent tubes behind milky-white glass. The luminance of the light surface should be in the range of 1800 - 2500 cd/m^2. There shall be an extra 230 V outlet socket on the side of each light box.

- **Screen-film combinations.** Different screen-film combinations are available. The image quality is judged by detail resolution and image contrast. Visible *quantum noise* will appear when the number of x-ray photons is so small

that image details are lost in random photon density variations. In general radiography this happens when the exposure at the image detector is somewhere in the range of 0.5 - 0.2 mR, corresponding to relative image detector speeds of 200 - 500.

The practical quantum noise limit for screen-film combinations, using *blue light*, having acceptable image quality, appears at a system speed of 200 - 250. For screen-film systems using *green light*, the critical speed range is 400 - 600.

Blue-sensitive film can be used *only* with blue- or ultraviolet-emitting screens. Most commonly used are calcium-tungstate screens.

Green-emitting screens (containing gadolinium-oxysulphide) shall be used only with green-sensitive film for acceptable results.

Never use both blue sensitive and green sensitive film in the same x-ray department.

The old WHO-BRS/85 specifications assumed the use of so called *Fast Tungstate* screens (nominal speed 200) for all examinations. This is no longer acceptable. Calcium-tungstate screens should be used in two speed categories: 50 or 100 for peripheral extremities, radiographed without a grid, and 200 for everything else. Gadolinium-oxysulphide screens may be used in three nominal speed groups: 100 for extremities, 200 for chest (lungs) and 400 for everything else.

1.2.3. Why is the WHO-BRS not more widely used?

Summary of the opinions of interested groups and the reasons for their resistance to the WHO-BRS concept:

The medical profession:
Lack of glamour. - Wrong name ?
Lack of understanding of the BRS concept.

Radiographers:
Threatening; perceived as de-skilling.
Lack of understanding of the BRS concept:
Fixed imaging geometry in pendulum configuration, limited choice of cassette formats, single x-ray focus, and 2-factor exposure technique (= few kV-values, many mAs steps, no operator influence on exposure time).

Industry:
Lack of profit. - No concerted strategy.
Internal competition with other x-ray projects in the same company. - Misuse of the BRS name by non-serious suppliers of poor equipment.

Government and hospital management:
High cost. - Lack of technical understanding.

WHO:
Lack of understanding and active promotion. Radiography has low priority in health care policy.

Individual comments on the summary:

Mr Lennart Nyström: Doctors should start recommending the WHO-BRS concept to potential health care purchasers.

Mr Enrico Barazzetti: The name BRS needs to be changed. Manufacturers who meet the new WHO specifications should be identified and listed. This would assist in identifying misleading representations.

When a bid process begins, the purchasing authority should first ask whether a machine has been tested in Lund.

The WHO should advise manufacturers with "approved" equipment about the names of those countries, which have plans for BRS projects.

Mr Bo Järlund: A bulk order is usually necesary in order to attract the manufacturers' interest. It would be helpful if the purchasing process could be speeded up. It usually takes several years between an expression of interest and the reception of a letter of credit.

Dr Gerald Hanson: It would be very helpful if WHO-BRS (WHIS-RAD) units were used in prestigious centers in western countries.

Dr Philip Palmer The cost of WHO-BRS units have deterred possible purchasers.

Example: an unsuitable machine (or a mobile unit) can be bought at half the cost of a WHO-BRS (or less). The price of the WHO-BRS needs to be reduced substantially. A price around US$ 20,000 would be acceptable.

Dr Said Mohammed: The local WHO representatives in countries with a special need for WHO-BRS units should start exercising their influence/support for the WHO-BRS with the local health care purchasers.

In the Middle East and Africa the negative influence of the high price of a WHO-BRS or a WHIS-RAD unit is secondary to a lack of information and awareness by would-be purchasers.

1.2.4. Promoting the concept of a WHO imaging system

The new specifications and the new name of the WHO Radiographic Unit will not by themselves guarantee that the concept of the WHIS-RAD will suddenly become widely accepted.

The original purpose behind the design of the WHO-BRS concept is clear: some 70 % of the world's population does not have access to good quality radiography when they need it, and the WHO-BRS was designed so as to significantly reduce this figure. Which, however, has not happened.

Possible reasons for this failure were identified:

Lack of glamour. The machine is designed for plain film radiography without the glamourous attractions of CT, MRI or interventional radiography, which all international radiology journals currently are dedicated to and which attract almost all the interest of radiologists in industrialized countries.

A higher profile would result, if WHIS-RAD units were used at teaching hospitals in the USA and Europe and this should be encouraged.

The name Basic Radiographic System may by some be associated with primitive technology and this has led to the opinion "not for me/us". The whole WHO Imaging System will be renamed (and include ultrasound), eliminating the word "basic". The WHIS-RAD unit is representing very modern technology and is definitely not primitive or "basic".

Antagonism from professionals. The existing antagonism is in part due to the name of the machine but also to the restrictions in kV-choice, format selection and tube angulation. The acceptance of *BRS operators* with limited training has been perceived as threatening by trained radiographers (RTs) and their professional organisations.

The new specifications contain most modifications proposed by members of the ISRRT: standard light beam collimators and any film format can be used, tube angulation *may* be used, and the supervision by a qualified radiographer is required for installation and regular use.

Manufacturers' internal competition. Other projects get higher priority because of the low profit expected. The market will open up only when the price comes down (e.g. when new manufacturers enter the field), and/or when bulk orders are placed.

Price. It is emphasised time and time again by health care purchasers that WHO-BRS units presently are too expensive. The WHO Radiation Medicine Unit must continue to seek manufacturers who will produce high quality machines which meet the WHO specifications at prices significantly lower than those, which have been in place during the last 10-15 years.

Radiography has a low priority in health care policy, compared with public health measures such as fighting communicable diseases. There is little that this group can do to produce a change except to increase the information about the WHIS-RAD. It needs to be recognized that many governments do not have a rational policy for planning health services in general, and diagnostic imaging in particular.

Lack of information. The information flow from the WHO Radiation Medicine Unit must increase and all members of this consultation group should participate.

The new specifications, included in this report, and the consensus of this meeting, should form the basis of a well designed launch. WHO should send out copies of this report, including the new specifications, to all regional offices and to all interested parties which request information from the WHO Radiation Medicine Unit. The new WHIS-RAD should be promoted at international fora, as well as in contacts with ministries of health, the World Bank, missionary organizations and aid donors.

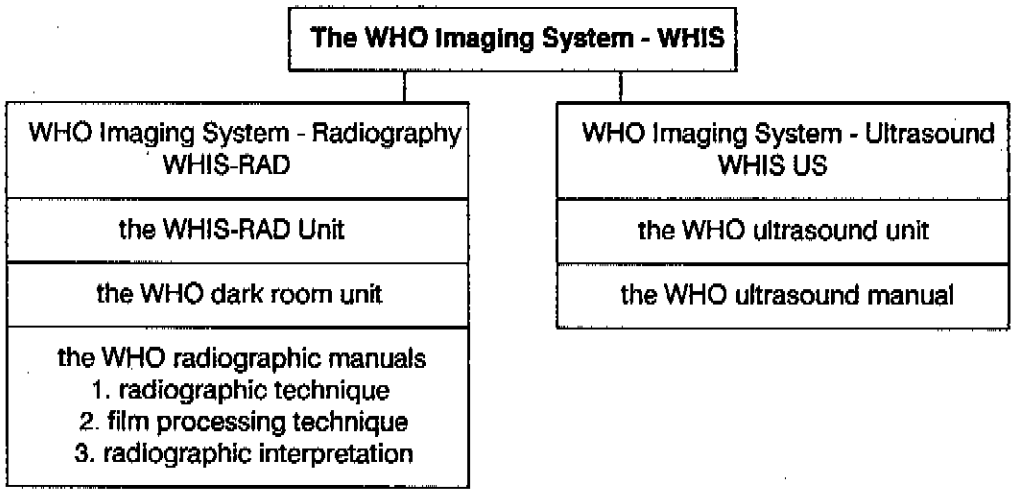
WHO promulgation of the WHIS-RAD concept. There has been a big commitment to the WHO-BRS project by WHO. But many countries, who really need it, do not buy it. The price, combined with a desire to start with more spectacular and glamourous equipment, have been major obstacles.

It is very important that the interest from WHO is renewed. This should be stimulated at headquarters, regional offices and local representatives in individual countries.

It is also important that regional offices and other sections within the WHO do not initiate their own simplified versions of the WHO-BRS or the WHIS-RAD, or authorize purchase of substandard equipment, creating confusion as to the correct specifications. Alterations in the specifications should be initiated by the WHO Radiation Medicine Unit only.

The meeting agreed that **a steering group** should be formed to accept the responsibility of taking "publications" forward.

Dr Gerald Hanson, Dr Holger Pettersson, and Mr Emanuel Borg were appointed to this group. The initiative stays with Dr Hanson at the WHO HQ.



1.2.5. Actions proposed by the meeting:

- **A new terminology** should be used for the WHO Imaging System, including diagnostic ultrasound, and eliminating the word *Basic* from the terminology.

- **Technical specifications** for the hardware of the new World Health Imaging System for RADiography - the WHIS-RAD Unit - should be developed and published, making use of the practical experience with existing WHO-BRS units and the advice of this consultation meeting.

NOTE: Since the meeting in Lund in June 1993, consistency controls made by the WHO Collaborating Centre in Lund and further technical consultations with manufacturers and others have resulted in a few minor modifications of the originally proposed recommendations. These are mainly related to an adaptation to the average body size and constitution of people in different parts of the world. It seems to be wasteful to require the same maximum power output of x-ray generators and tubes and the same large film formats for all WHIS-RAD units, if they are practically never used or needed in the region for which the unit in question is intended.

- **More and better information** should be prepared and distributed:

a. Excellent testing reports from independent bodies have shown that the WHO-BRS is easy to handle, the image quality is outstanding and the radiation doses are lower than with most other equipment.

b. Very few radiologists know, how little energy really is needed for a single radiograph. A 12 - 15 kW multipulse x-ray generator with a 23 kW x-ray tube and a total energy-capability of 23 - 30 kWs can handle all projections used in general radiography with a focus-film distance of 140 cm, without exceeding an exposure time of 2.5 seconds for very dense objects.

c. A non-glamourous name, including the word *basic*, in combination with the suspiciously low price in comparison with conventional equipment for the same use, has made many radiologists believe that battery-powered, single-tube x-ray units cannot be used in large hospitals.

d. The price is low, when compared with conventional equipment for general radiography, but the price is high, when compared with the cost of the many existing, very substandard, low-powered, single-phase x-ray units, some using the name BRS, some being mobile units, which require much more professional skill for acceptable clinical results. Consequently, purchasing

agencies without sufficient technical knowledge have preferred to buy cheap, "well-tried" x-ray units instead of new and much superior equipment.

e. More information about technical specifications and quality aspects must be spread by WHO Headquarter Units and Regional Offices.

f. Government and inter-governmental purchasing agencies must be better informed.

g. Improper or poor quality installations of BRS equipment have often prevented its correct use. Consequently, a new and revised version of *Guidelines for the installation of WHO Basic Radiological Systems* should be published (in 1996). It should contain general advice on planning of the premises, positioning of the x-ray equipment, and suitable service routines.

h. A new *Manual of Film Processing* is planned to replace the old *Manual of Darkroom Technique* and a supplement with new information should be added to the *WHO Manual of Radiographic Technique*.

i. Members of WHO's advisory groups on radiography should be encouraged to publish more about successful use of the old WHO-BRS and the new WHIS-RAD.

k. Manufacturers should show their WHIS-RAD units at exhibitions, emphasizing the high-level technology and outstanding clinical results.

2.0. DESCRIPTION OF THE WHIS-RAD

2.1. PLACE OF USE.

The **WHIS-RAD Unit** is intended for use in primary care and at first level referral x-ray departments anywhere. WHIS-RAD equipment is especially suited for use in small rural hospitals, large health care centres and polyclinics but serves well also in x-ray departments of large hospitals, where it can be a first choice unit for radiography with horizontal beam but also usable for any type of general radiography. Its ease of use, independence of special high-power mains and low price in comparison with conventional modern x-ray equipment also will bring top radiodiagnostic image quality within reach of privately financed practices.

2.2. EXAMINATIONS TO BE MADE

All general radiographic examinations, which do not require fluoroscopy, tomography or rapid film changing, can be made with a WHIS-RAD Unit. All skeletal examinations can be made, including skull examinations. The unit is a first choice chest unit, much superior to common chest wall stands and wall buckies. Abdominal examinations, including urography (IVP), cholecystography and (if ultrasound is unavailable) obstetric examinatons, can be made. Soft tissue examinations except mammography can be made.

2.3. TECHNICAL CHARACTERISTICS OF THE WHIS-RAD APPARATUS

The WHIS-RAD Unit is designed to be used by any fully qualified radiographer (RT) or by less trained operators, *radiographer's assistants*, working under the supervision of qualified radiographers.

To assure optimum imaging geometry, eliminating the negative influences of a variable focus-film distance and angulation of the antiscatter grid, the unit operates with a **single x-ray tube** in **fixed geometry** in relation to the cassette holder, using the pendulum principle to vary the direction of the x-ray beam.

The x-ray tube normally cannot be angulated away from the cassette holder, with its radiation protection in the back wall. This restriction interferes with very few general radiographic procedures. The few exceptions include the conventional lateral view of the fractured femoral neck (using horizontal x-ray beam), a few projections for fracture patients in traction, and multi-trauma patients, who cannot be moved from the stretcher or bed on which they arrive. These cases represent a very small number of examinations in support of primary care.

A possibility may be provided to angulate the tube away from the cassette holder to provide these rare projections, but the reduction of the built-in radiation protection must be considered, when this possibility is used.

The x-ray generator must use some kind of **energy storage** and should function according to its specifications when connected to any grounded 2.3 kW AC source (e.g. 230 V, 10 A).

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3. TECHNICAL SPECIFICATIONS FOR THE RADIATION SOURCE OF THE WHIS-RAD:

HT GENERATOR AND X-RAY TUBE

Sections 3 and 4 are dedicated to technical specifications of (3) the radiation source (high-tension generator with x-ray tube) and (4) the radiographic examination stand.

The specifications were developed after 18 years of practical testing and numerous consultation meetings. They are based on recommendations by the consultation meeting, held in 1993 at the WHO Collaborating Centre for General and Continuing Radiological Education in Lund with radiologists, radiographers, physicists, and technical representatives of the manufacturers participating. The specifications should be a guide for manufacturers, purchasing agents and users. They are not an international standard.

3.1. HIGH-TENSION GENERATOR

3.1.1. Mains connection

A wall outlet or a separate 50/60 Hz AC generator, which can deliver 2.3 kW within 10%, is required. This corresponds to nominal values of 10 A at 230 V or 20 A at 115 V.

NOTE: Solutions without mains connection, using a battery with other type of charging, e.g. solar cells or a small AC generator, are also acceptable.

3.1.2. Energy storage

The power rating of the x-ray generator will be much higher than the instantaneous power (2.3 kW) available from the AC source described above. The high tension generator therefore must have an integrated energy storage unit. An individual exposure of a very dense object may in rare occations require close to 30 kWs (kilowatt-seconds) at 90 kV. Generators without energy storage, intended to operate directly from the mains, are not recommended. Peak power loads in the range of 12-30 kW for 0.1 s and 12-15 kW for 2 s may be expected.

NOTE: The energy storage unit shall be maintenance-free and carry a 5 year pro rata temporis *warranty. It is preferable to use a* **battery** *for energy storage but other methods may also be acceptable, such as a large* **capacitor** *on the primary side of the high-tension transformer or a* **fly-wheel.**

3.1.3. High-tension transformer frequency

Only high-tension generators using **multipulse inverter technology** are acceptable. Frequencies from a few kHz to 100 kHz are used with satisfactory results. The high-tension voltage ripple shall be no larger than 4%, measured at 100 kV (kVp) and 100 mA.

3.1.4. Generator control panel

Only the following switches or controls shall be available: ON/OFF, kV-selector, mAs-selector, anode rotation, and exposure. The exposure switch should be mounted on the control panel, so that the operator must stand behind a protective screen or wall during exposures. The selected values for kV and mAs shall be shown before and after the exposure. A light signal shall indicate if the generator is READY for the selected tube loading. The actual tube loading (exposure) shall be indicated with a sound and/or a light signal.

3.1.5. Nominal x-ray tube voltage

The nominal x-ray tube voltage (highest available kV) shall be at least 120 kV.

NOTE: The high-tension generator must have circuits which automatically protect the x-ray tube from overload (tension and temperature) and the high-tension circuit from damage by flash-over.

3.1.6. Available x-ray tube current

The tube current shall be or exceed 100 mA.

3.1.7. Electric power rating

The *nominal electric power* rating (kW) shall be stated as the highest constant electric power in kilowatts, which the high-tension generator can deliver for a loading time of 0.1 s in the voltage range of 90 - 100 kV. The minimum acceptable power rating for a WHIS-RAD generator is 12 kW at 100 kV.

3.1.8. Electric energy rating

The *nominal electric energy* (total available energy for one single exposure), measured at 90 kV and a tube loading time not exceeding 2.5 s, shall be in the range of 23 - 30 kWs (kilowatt-seconds). (See below and NOTE under item 3.1.9.d.)

The measurement at 90 kV (instead of 100 kV, which is customary) depends on the fixed selection of kV-values used in the WHIS-RAD philosophy. Typical peak load situations, using current and exposure time values available in the Renard-10 series (see item 3.1.9.d), are 90 kV + 160 mA + 2 s, resulting in 28.8 kWs or 90 kV + 100 mA + 2.5 s, resulting in 22.5 kWs.

NOTE: This type of electric energy rating (not yet applied by the International Electrotechnical Commission - IEC) is necessary if the generator uses power storage or falling tube current during the tube loading (exposure).

EXCEPTION: The electric energy rating specified above, presumes that the image recording medium (screen-film combination) used has a nominal speed of at least 200 in the 70 - 120 kV range, corresponding to an exposure requirement of 0.5 mR (air kerma of close to 5 μGy) at the input side of the film cassette. When a recording medium is used, which has a nominal speed of 500, requiring 0.2 mR/exposure (air kerma close to 2 μGy) at 90 kV (retaining acceptable image quality), the nominal electric energy, measured as above, may be as small as 12 kWs.

For the time being this requires the use of green-emitting intensifying screens and green-sensitive x-ray film (see item 6.1). The use of such film requires special attention to the darkroom lighting and the film development. Free access to green-sensitive (orthochromatic) x-ray film is also required, which may be a problem in some remote areas.

3.1.9. Selection of loading factors

The selection of loading (exposure) factors is optimized in the WHIS-RAD Unit and limited to kV- and mAs-values. Exposure times and mA-values shall not be set separately, but only selected as current-time products (mAs-values). The shortest possible exposure time and the highest possible mA-value shall be automatically selected for each mAs-value used.

Adequate information shall be available to the operator before, during and after the loading of the x-ray tube about which loading factors (kV and mAs) that are used.

a) **Values of x-ray tube voltage** shall be measured as kVp but indicated as kilovolts (kV) because the voltage ripple is no more than 4%. The concept of kVp shall not be used in the manual or on the control panel.

   For didactic reasons the choice of **kV-values** is limited to a small number of fixed steps, which do not limit the practical use of different radiation qualities in radiography.

Recommended values of x-ray tube tension:
46 - 53 - (60) - 70 - 80 - 90 - (100) - 120 kV

   NOTE: 60 kV and 100 kV are required for testing purposes, but not needed for clinical use. A larger number of kV-steps or continuously variable tube tension are not acceptable.

   The selected kV-value must not fall more than 5% from the initial value during the exposure (corresponding to about 10% in air kerma loss).

b) **Values of x-ray tube current** shall be selected automatically and not displayed. If the tube current is constant during the exposure, its minimum value shall be 100 mA. If the tube current is falling during the exposure, the initial value should be in the range of 200 - 320 mA.

   NOTE: If exposure times and mA-values are selected from ranges of fixed values, these must be taken from the Renard-10 series, thus resulting in mAs-values according to item 3.1.9.d below.

c) **Values of loading time** (exposure time) need not be displayed.
   Shortest reproducible exposure time (measured as the time during which the kV is 75% of the selected value) shall be 5 ms or shorter. Exposure times longer than 2.5 seconds are not permitted.

d) **Values for current-time product** shall be indicated in milliampere-seconds (mAs) and shall be chosen as decimal multiples and submultiples from the rounded values of the Renard-10 series (R'10) shown on page 11 (ISO Standard 497/1973).

R'10 = the Renard-10 Series

1	1.25	1.6	2	2.5	3.2	4	5	6.3	8
1.0000	1.2589	1.5849	1.9953	2.5119	3.1623	3.9811	5.0119	6.3096	7.9433

The minimum range of fixed mAs-values to be used in the WHIS-RAD is:

							0.5	0.63	0.8
1	1.25	1.6	2	2.5	3.2	4	5	6.3	8
10	12.5	16	20	25	32	40	50	63	80
100	125	160	200	250	(320)				

NOTE: It is not required that the entire range of mAs-values is available at all tube tensions. Thus it is acceptable that only 20 kWs is reached at 80 kV (with 250 mAs) and that only 12 kWs is reached at 120 kV (with 100 mAs).

The combination of 250 mAs and 90 kV (= 22.5 kWs) is usually enough as the peak output. The combination of 320 mAs and 90 kV (= 28.8 kWs) is needed extremely seldom in a population with an average weight of individuals around 80 kg and never in a population with an average weight of 70 kg.

e) **Precalculated current-time products** shall be shown by the control panel. The lowest mAs-value should be stated, which is within the specified ranges of compliance for linearity and constancy (see below).

NOTE: This information is very important. The energy loss in the high-tension circuit may be in the order of magnitude of 0.06 kWs at each exposure, which corresponds to 0.5 mAs at 120 kV (= the lowest possible combination of loading factors used in chest radiography).

3.1.10. Reproducibility, linearity and constancy of radiation output

Multipulse x-ray generators with energy storage inherently have much better reproducibility and linearity than required in the IEC Standard 601-2-7/1987 *(Medical electrical equipment, part 2: Particular requirements for the safety of high voltage generators of diagnostic x-ray generators)*. This standard does not apply to battery-operated generators.

a] **Reproducibility of air kerma:** The coefficient of variation of measured values of air kerma shall not be greater than 0.1 (10%) for any combination of loading factors within the available range.

b] **Linearity of air kerma:** Within the available x-ray tube voltage range (46 - 120 kV) the quotient of the measured values of air kerma divided by the indicated *precalculated* value of current-time product (μGy/mAs) shall not differ from the quotient of the measured value of air kerma and indicated current-time product at 10 mAs by more than 0.1 (10%) of that latter quotient.

Comments: **Measurements of air kerma** shall be made with a minimum added filtration on the x-ray tube of 20 mm Al or equivalent.

Measurements of mAs inside the x-ray tube are not made and measurements in the grounded centerpoint of the high-tension transformer are of no value. The linearity requirement is only related to the magnitude of the steps in the precalculated mAs-scale, representing 26% increments of air kerma.

The linearity requirement is more strict than the corresponding IEC requirement for mains-connected x-ray generators. Practical experience at the WHO Collaborating Centre for General and Continuing Radiological Education in Lund, Sweden, has shown, however, that multipulse x-ray generators using energy storage can easily be modified to give a μGy/mAs quotient, which does not differ more than 2-5% from the reference value (at 10 mAs) over the entire mAs-range.

c] **Agreement between indicated and measured values of loading factors.**

At a given measurement date, using the same measuring instrument, the permissible *average error* of the indicated value of x-ray **tube voltages** shall not be greater than 0.025 (2.5%), approximately corresponding to the requirements for air kerma given above.

Under the same conditions the permissible *average error* of **current-time products** shall not exceed the value 0.05 (5%) or 0.1 mAs, whichever is larger.

3.2. THE X-RAY TUBE

Due to the long time usually required to change an x-ray tube at a remote location and the very high tube replacement costs, longevity of the x-ray tube is a very important characteristic. An x-ray tube for a WHIS-RAD Unit benefits from design features which promote a long tube life such as a large anode diameter and renium/tungsten alloy in the anode surface.

3.2.1. Expected lifetime

An x-ray tube for a WHIS-RAD installation should have an expected lifetime of 10 years or more with the types and mixture of examinations to be found in an x-ray department at primary-care or first referral level (see box). This may correspond to a total of about 50,000 exposures in normal use.

Distribution of examinations to be expected in primary care or at first referral level:	
35-40% chest **8-10% abdomen**	**38-42% extremities** **10-15% spine and pelvis** **3-4% head and neck**

The anode of an x-ray tube develops small cracks in the target surface due to heat variations. These cracks lead to reduction in the output of the x-ray tube. When the output reduction reaches 20%, corresponding to one exposure step in the Renard-10 series, the demand on the x-ray generator power output has increased with 25%, which may prove critical for some examinations.

The average tube load at this type of work is around 3 kWs/exposure, corresponding to 10% of the permitted maximum load. However, the actual tube load varies within a very wide range: from 0.25 kWs for a normal PA chest to 30 kWs for a lateral view of the lumbo-sacral junction of a heavy person.

3.2.2. Focal spot

A rotating anode must be used. The **focal spot** of the x-ray tube shall have a nominal size no larger than 1 mm, measured according to IEC 336.

NOTE: A new IEC standard for focal spot measurements is anticipated in 1995/96. In this the nominal figure for focal spot size is dimensionless and specified in terms of detail resolution in lines/mm at a specified geometric magnification. This practice, however, is not yet in general use by manufacturers, users or purchasing agents and its introduction is beyond the scope of this publication. For practical purposes the nominal values may still be interpreted as representing millimeters.

3.2.3. Anode angle

The **anode angle** should be in the range of 12-15^{O}. No special recommendations are given about anode diameter or rotation speed.

NOTE: An anode angle in the range of 12-15^{O} is compatible with a nominal focal spot size of 0.8 - 1.0 (mm) and a tube rating of 23 - 30 kW (at 0.1 s).

An anode angle of 12^{O} easily permits an x-ray field of 45 x 45 cm without visible heel effect at the expected working conditions.

Comments: The **aging of the anode** is very dependent on how it can withstand heat. Anodes made of pure tungsten may not live up to the requirements stated in this paragraph. Reliable figures for the drop in anode output with normal clinical use are not available. The output from a tungsten target containing 10% renium and 90% tungsten drops at a rate which is about 25% of the rate for a pure tungsten target. The overall lifetime of a 90/10% tungsten/renium target is about 4 times longer than that of a pure tungsten target.

3.2.4. Tube rating

- The **high-tension rating** of the x-ray tube shall be 125 kV (from a low-ripple HT generator).

- The **nominal power rating** shall be in the

range of 23-30 kW at an exposure time of 0.1 s.

- The **long time power rating** shall be in the range of 12 - 15 kW at an exposure time of 2 s, corresponding to a total energy load of 24 - 30 kWs.

3.2.4. Tube filtration

The **total filtration** (inherent + added) shall be within the range of 3 - 4 mm Al. The filtration shall be determined by Half Value Layer (HVL) measurements of the emerging radiation, which may be performed with a penetrameter.

3.2.5. X-ray beam collimator

It is recommended to use a standard, multilevel light-beam collimator. Special attention should be paid to the following features:

- The controls should have reliable format indicators (e.g. for 12, 18, 24, 35 and 43 cm) for a focus-film distance of 140 cm, so that the collimator can be used also in case of mains power failure or a light-bulb blow-out.

- It is advantageous if the collimator controls are no more than 110 cm away from the front wall of the cassette holder, enabling a person not taller than 155 cm to reach them, when the x-ray tube is in normal position for examination of a recumbent patient on a 70 cm high patient trolley.

- The collimator should be designed in such a way that the light bulb can be replaced with retained exact position without the use of special tools. The position of the centre of the light field shall not vary more than 14 mm (1% of the FFD) from the point, where the central x-ray beam reaches the cassette holder. The limits of the light field may not vary more than 1% of the FFD from the limits of the x-ray field.

- Spare collimator bulbs, sufficient for an estimated 10 year's consumption, should be provided.

4.0. SPECIFICATION FOR THE WHIS-RAD EXAMINATION UNIT

4.1. GENERAL DESCRIPTION OF THE EXAMINATION UNIT

The examination unit consists of a support for the x-ray tube and the cassette holder, usually called *the stand,* and a *patient trolley,* which can be used as a floating-top table.

The examination unit combines the functions of a chest unit, a vertical bucky, and a floating-top table with an x-ray tube stand. It must permit the use of horizontal, vertical and angulated x-ray beam on lying, sitting and standing patients, also in emergency situations.

4.2. THE SUPPORT FOR X-RAY TUBE AND CASSETTE HOLDER

It is necessary to use a design of the stand which will ensure that the x-ray tube can always be connected to the cassette holder in a rigid and stable way, providing precise and simple centering of the x-ray beam.

The focus-film distance (FFD) shall be fixed at 140 cm. The x-ray tube and the cassette holder shall be mounted in such a way that also a recumbent patient can be examined with a horizontal x-ray beam. The arm assembly shall be perfectly balanced (with a 24 x 30 cm cassette in place) in two basic positions: horizontal and vertical.

It must be possible to angulate the arm +/- 30^{o} from both these positions, retaining the balance, and to use a horizontal central x-ray beam in the minimum range of 50 - 170 cm above the floor. No individual tube angulation is acceptable in a standard installation.

Comment: If a WHIS-RAD unit is extensively used in traumatology, e.g. in an emergency room, it should be possible to create a horizontal x-ray beam, which is *not* directed towards the cassette holder. It should also be possible to tilt the x-ray beam 90^{o} downwards, when the tube arm is horizontal, for radiography of patients which cannot be moved from the bed or strecher, on which they have arrived. This use implies taking away the radiation protection included in the cassette holder and should be applied only under the supervision of a qualified radiographer.

4.3. CASSETTE HOLDER

The cassette holder shall be fixed at right angles to the central x-ray beam and shall accept any standard cassette format in longitudinal and transversal position. Critical dimensions are given in Table 4.6.

NOTE: The largest format may be different in different parts of the world, depending on the size and constitution of the individuals to be radiographed. In many parts of the world the 35.6 x 35.6 cm format ("35x35") is satisfactory for PA chest, abdomen and pelvis due to the advantageous imaging geometry of the WHIS-RAD (the FFD is 140 cm and the skin-film distance is 2.5 cm in chest radiography). However, the 35x43 cm format is required in large parts of Africa and in most parts of Australia, Europe, and North America.

It must be possible to change cassettes with minimal difficulty also when the x-ray beam is used in the vertical direction, with the trolley in place above the cassette holder.

The cassette holder may be used as a small horizontal examination table without using the trolley. It must permit a load of at least 15 kg without unwanted downward movement or disalignment of the focussed grid.

The **centre** of the x-ray beam and **vertical film format dimensions** for the four most used film formats shall be indicated on the *front wall* of the cassette holder. If the 35x43 cm format is anticipated to be used also in the transverse position, this must be indicated on the cassette holder.

The *front wall* of the cassette holder shall contain a fixed **anti-scatter grid** (see below).
The *back wall* of the cassette holder shall contain a protective screen with a density equivalent to 0.8 mm of lead and outer dimensions not smaller than 49 x 49 cm.

4.4. ANTI-SCATTER GRID

The anti-scatter grid must be focused at a distance of 135 - 140 cm. The grid ratio shall be 10:1 with a line density of 40 - 60 lines/cm. The grid shall be large enough to cover a vertical film format of 35 x 43 cm. If the 35 x 43 cm format will be used in transversal position, the grid must be 43 x 43 cm.

NOTE: Practical experience has shown that a grid with 40 lines/cm is satisfactory and practically invisible, when correctly focused and when the resulting film is viewed at a distance longer than 30 cm. Lead with interspacing aluminium is advantageous in the 90 - 120 kV-range and acceptable in the 70 - 80 kV-range.
Grids using carbon fiber as interspacing material usually come with at least 60 lines/cm. They are advantageous in the 53 - 70 kV range but not equally effective (resulting in lower contrast) in the 90 - 120 kV range.

4.5. EXAMINATION TABLE

The **examination table** shall be a trolley, which can be used as a floating-top table. The table top shall be rigid and be able to support a patient weighing 110 kg, sitting on the middle of the table, without appreciable distorsion. The equivalent density of the table top should not be more than 1 mm Al.

The design of the trolley must permit the use of the cassette holder in horizontal position under the trolley in such a way that the distance between the table top and the film plane does not exceed 8 cm. In this position it must be possible to use the trolley as a floating-top table, so that the longitudinal midline of the trolley can be offset no less than +/- 12 cm from the midline of the cassette holder.

The trolley shall have large wheels, with locks on at least two of them. A central lock for the wheels is preferred. The table surface should be flat. Dimensions are given on the following page in section *4.6: Summary of critical dimensions of the examination unit.*

5.0. PROTECTIVE DEVICES

It is recommended that the control panel is installed behind a protective screen or wall, separating an area from the x-ray room, large enough for two people (e.g. operator and interpreter or parent). The lead equivalence of the wall should be no less than 0.5 mm Pb.
The screen or wall must have a lead glass window, adjusted to the average height of a standing radiographer, thus providing a good view of the patient being examined. The lead glass window may be as small as 30 x 30 cm in a thin screen but should be at least 40 x 50 cm in a brick wall.

The back wall of the cassette holder contains

4.6. Table: SUMMARY OF CRITICAL DIMENSIONS OF THE EXAMINATION UNIT:

Focus-film distance (fixed, not variable) Distance between arm pivot and x-ray film		140 cm 80 - 100 cm
Space available for trolley with patient a. minimum trolley clearance at a level 8 cm below the central horizontal x-ray beam: b. minimum possible lateral movement of the patient trolley with vertical x-ray beam: c. space under cassette holder arm for patient lying in lateral decubitus position:		trolley width + 5 cm (min 70 cm) +/- 12 cm from central x-ray beam minimum 25 cm from arm to central x-ray beam
Tube/cassette-holder arm angulation from vertical and horizontal position: - Brake for arm rotation - Brake for height adjustment (additonal option) - Distance from pivot to central x-ray beam		+/- 30° mechanical mechanical (electro-magnetic brake) 0 (or *very* short)
Height above floor for horizontal beam:		variable: min 50-170 cm
Optional tube angulation of horizontal arm for use in traumatology by qualified operator:		30° down and 90° down
Cassette holder - Cassette holder height (= length): - Distance between front wall and film: - Largest distance between front wall and floor at vertical x-ray beam: - Film cassette formats:		maximum 50 cm 2 - 3 cm 90 - 100 cm
small format intermediate format long format large format	recommended 18x24cm 24x30cm 18x43cm 35x43cm	alternate - - 15/20x40 35x35
Patient trolley: table width table length table height table top density equivalence dimension of wheels		65 - 70 cm 200 - 210 cm 70 cm +/- 1 cm 1 mm Al or less diameter 10 - 15 cm
distance from table top to film with no angulation of the x-ray beam:		maximum 8 cm

0.8 mm lead (or equivalent), which usually will make regular solid 12 cm thick brick or concrete walls satisfactory as general radiation protection around the x-ray room, if the room is at least 18 square meters in size and no more than 2000 examinations are made per year.

At least two full length (shoulder to knee, adjusted to the size of a normal person) radiation protection aprons and two pairs of radiation protection gloves with 0.25 mm Pb equivalence should be offered with the x-ray equipment.

6.0. CASSETTES AND FLUORESCENT SCREENS

6.1. RECOMMENDED SCREEN TYPES

Calcium tungstate intensifying screens emit **blue light** and are available in three speeds:	
Detail/50 Universal/Parspeed/100 Fast/HiPlus/200	for hands and feet for head & extremities for everything else
The speed (light/μGy) is almost kV-independent.	

Gadolinium-oxysulphide intensifying screens emit **green light** and come in four speed groups:	
Fine/100 Medium/200 Regular/400 Fast/600-800	for hands and feet for chest for everything else for *very* dense objects
The speed (light/μGy) varies with kV used.	

The speed (= sensitivity) of gadolinium-oxysulphide screens is highest in the upper end of the clinically used kV-range (90 - 120 kV), reducing exposure times for very dense objects (90 kV) and chest (120 kV). The speed approximately doubles, when the tube tension is changed from 50 to 100 kV. This is advantageous, because the sensitivity to scattered radiation is then lower than to primary radiation.

The nominal speed is usually given for 70 - 80 kV. All speed information refers to the use of standard x-ray film.

It is recommended to choose the **basic screen system** described below in *Section 6.2*, if the choice of intensifying screens and x-ray film is limited in the area, where the WHIS-RAD is going to be used. If the choice of screens and film types is unrestricted, or if the energy rating of the x-ray generator is below 23 kWs, the **advanced screen system** is preferred. The detail resolution of the advanced system is considerably better than that of the basic system in all screen types except in the Detail/Fine category.

Speed groups of blue-emitting calcium-tungstate and green-emitting gadolinium-oxysulphide intensifying screens

Calcium-tungstate screens with blue-sensitive film at 46 - 120 kV
Detail/50 Univ./Parspeed/100 Fast/200

Gadolinium-oxy-sulphide screens used at kV:	Rel. speed with green-sensitive film					
	no grid		with Pb/Al grid, ratio 10:1			
	46	53	60	70	80	90 - 120
Fine/100	50	63	80	**100**	-	-
Medium/200	100	125	160	**200**	225	250
Regular/400	-	-	320	**400**	450	500
Fast/600-800	-	-	-	**630**	700	800

6.2.

CHOICE OF X-RAY CASSETTES	format (cm)	designation	speed grp	use
Basic screen system: A minimum supply of cassettes should include those listed to the right, intended for **blue-emitting calcium-tungstate screens:** * Alternative choice for extremities	18x24 18x24 24x30 18x43(15x40) 35x43(35x35) 18x24*	Detail Fast Fast Fast Fast Universal*	50 200 200 200 200 100*	no grid grid grid grid grid +/- grid
Advanced screen system: If green-sensitive, orthochromatic film is available, it is better to choose **green-emitting intensifying screens** as shown to the right: **(speed varies with kV)** * Alternative choice for extremities	18x24 18x24 24x30 18x43(15x40) 35x43(35x35) 35x43(35x35) 18x24*	Fine Regular Regular Regular Regular Medium Medium*	50-80 320-500 320-500 320-500 320-500 200-250 100-160*	no grid grid grid grid grid chest+gr +/- grid

Cassettes must be marked on the back side with name and **speed** category of the screens, **type of film** to be used (blue- or green-sensitive), and **date** of initial usage.

All intensifying screens in a group of cassettes, used in the same room, must belong to the same type and generation. It is therefore recommended to provide at least 3 cassettes of each type, even if 2 of each would be satisfactory for the anticipated workload.

6.3. OPTIONAL LOOSE ANTISCATTER GRIDS

Some projections make use of a loose cassette on top of the cassette holder or the trolley. Separate antiscatter grids, mounted on these cassettes may then be required.

WHO recommends the use of grids, which can be fixed to cassettes of two formats: 24 x 30 cm and 35 x 43 cm. The ratio of these grids should be 6:1.

7. FINAL COMMENTS

7.1. OPERATIONAL ACCESSORIES (to be offered with the WHIS-RAD Unit)

a) Two 15 x 32 cm lead rubber sheets (0.5 mm Pb equivalent) to cover cassettes, when used on the table top. This will allow two exposures on the same film: For example two times 12 x 18 cm for the wrist on an 18 x 24 cm format or two times 12 x 30 cm for the forearm on a 24 x 30 cm format.

b) A parallel-sliding measuring caliper, graduated in cm, to determine body part thickness at exposure factor calculations.

c) A standard set of foam-plastic wedges and sandbags, used for radiographic positioning of patients.

7.2. MANUALS

One set of WHO manuals on radiographic technique, film processing and film interpretation should be delivered with the equipment.

Equipment manufacturers are required to supply adequate manuals for installation, use, maintenance and repair of their own equipment.

7.3. FILM PROCESSING

It is anticipated that film processing will be manual, using strict time/temperature control *(without visual control of the development).* In certain conditions, however, there may be a case for the use of a small automatic processor, but this requires a totally reliable mains connection and access to maintenance service.

Upon request, the WHO Radiation Medicine Unit will provide advice. A separate publication will deal with questions related to film processing.

8. TESTING AND FIELD TRIALS

Upon request, WHO is prepared to arrange for evaluation of prototype WHIS-RAD equipment and organization of field trials of such equipment in cooperation with the WHO Collaborating Centre for General and Continuing Radiological Education, Department of Radiology, Lund University Hospital, S-22185 Lund, Sweden.

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