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CONSUMER GUIDE FOR THE PURCHASE OF X-RAY EQUIPMENT

by

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1. Choice of equipment for diagnostic imaging at large primary health care centres and small hospitals

According to *The Hospital in Rural and Urban Districts* (WHO Technical Report Series # 819), the **first referral level** of a district health system is the level to which patients can be referred, directly or from *primary health care centres* for *diagnosis, treatment and care 24 hours per day.* Surgical facilities, laboratory and diagnostic imaging services are available. Cases, which cannot be diagnosed or treated at this level, are sent to a *second referral level hospital.*

IMAGING EQUIPMENT FOR SMALL HOSPITALS:
Choice and recommended order of acquisition.

1. Universal unit for general radiography

The most important and most easily understood imaging service in the frontline of medical care is *plain radiography.* The X-ray unit used must be able to perform all essential **general radiographic examinations** of bone, chest and abdomen including simple contrast studies, relevant to local diseases (e.g. examinations of the urinary tract).

Mammography, fluoroscopy tomography, or rapid serial radiography (e.g. angiography) shall not be performed at the first referral level.

Special requirements must be fulfilled to provide reliable X-ray services in remote clinics and hospitals where climate may be extremely hot or cold, clean water may be scarce, electrical power may be unreliable, and fully trained radiologists and radiographers are not available. (See chapter 2, in which the infrastructure is discussed.)

The **X-ray generator** must be equipped with *energy storage* (lead/acid battery or large capacitor), and use *multipeak inverter technology.* The **power rating** for the generator and X-ray tube shall be large enough to permit chest radiography at exposure times below 50 ms (aiming for < 20 ms), and the **energy rating** must permit single tube loads of 23 – 30 kWs at 90 kV in less than 2.5 seconds. The indoor climate must be controlled if temperatures above 35° C or humidity over 90% can be expected.

The **examination stand** must permit examinations of standing, sitting or lying patients using a special trolley with a radiolucent top and wheels. It must be possible to use horizontal, angulated, or vertical X-ray beam.

The stand must use **fixed geometry** between the X-ray source and the image detector in a cassette holder, provided with a *focused antiscatter grid.*

Fixed geometry is the single characteristic of greatest importance for the image quality. It can be sacrificed for greater flexibility, only if the operator is a highly qualified radiographer.

The **X-ray equipment of choice** at the first referral level is the WHIS-RAD unit, developed from the WHO-BRS/85, and first presented in 1995 in the technical specifications WHO/RAD/TS/95.1. General radiography with this unit allows better accuracy and reproducibility, and less radiation dose to patients and personnel than with *any* other X-ray unit.

Background for the WHIS-RAD Unit

The idea of a Basic Radiological System was first presented by Richard Chamberlain, MD, (professor of Radiology at the University of Pennsylvania, Philadelphia, USA) at a large consultation meeting organised by the Pan American Health Organization in 1975. The goal was to design and build an X-ray unit suitable for the 70% of the world's population which had no access whatsoever to diagnostic radiology. A preliminary specification was written. A few prototype X-ray units were developed by industry, tested clinically and evaluated at several WHO Advisory Group meetings.

In 1985 "The technical specifications for the X-ray apparatus to be used in a basic radiological system" (the WHO-BRS/85) was published by WHO. The WHO-BRS was intended for use in developing countries. However, the image quality was better than with most standard X-ray units.

In 1991 WHO and the International Society of Radiology (ISR) assembled 20 sets of 10 different standard radiographic films with high image quality from 20 teaching hospitals all over the world, including one set from a WHO-BRS test site in Lund, Sweden. Films were selected by a group of ISR members and displayed for viewing, evaluation, and voting by the attendants of RSNA 1991.

Quote from the report of the International Commission for Radiology Education, ISR (Chairman W. Peter Cockshott, MD):

"It is noteworthy that the institution that provided the highest number of films, of first preference by the voters, used only a Basic Radiology System apparatus, developed by industry in response to the WHO specifications. This low-cost, simplified unit, designed initially for the Third World, unexpectedly proved itself in this global competition and proved the merit of its design concept."

The WHIS-RAD unit would improve image quality in any X-ray department. It can make more than 80% of all general X-ray examinations made at teaching hospitals, and 95% of all X-ray examinations made in the world (1993). It is easier to operate than most conventional X-ray units, and can be powered from batteries.

The WHIS-RAD unit is the only X-ray unit needed at a **primary health care centre**, or in a **small hospital** at the **first referral level**.
Any other X-ray unit, which does not meet the WHIS-RAD specifications, would be a questionable investment.

For this reason, X-ray installations using a single X-ray tube in combination with a bucky table and a wall bucky, *without automatic control of the geometry*, are not recommended for general radiography.

Practical experience in industrialised countries has proven that WHIS-RAD units are very useful in any hospital, and especially in emergency departments.

The clinical capacity of a single WHIS-RAD unit is about 6,000 general radiographic examinations/year, assuming 300 workdays/year.

2. Ultrasound

A **general purpose ultrasound system** (GPUS) is recommended as a second imaging unit at any clinical level provided that a *competent operator* is available (usually a doctor). Ultrasound equipment is not acceptable as a first choice for imaging because of its very limited usefulness in examinations of chest (lungs), and skeleton.

Ultrasound is especially suited for examinations of soft tissue (liver, spleen, kidneys, pelvis, and scrotal contents). It is often the first choice for studies of abdominal organs and in obstetrics.

Ultrasound equipment ideally should be purchased at the same time as the first unit for general radiography. Specifications for the GPUS are presented in the *WHO Manual of Diagnostic Ultrasound* (WHO, Geneva 1995), available on sale from WHO.

3. Mobile X-ray unit

A mobile X-ray unit should be the third imaging unit to be purchased. Almost every patient in a small hospital can be brought to a stationary X-ray unit, which will always provide much better radiographs than a mobile unit.

A mobile unit should *not* be used for general radiography in wards or casualty departments, *nor* as a stationary unit in the X-ray department. It should be used mainly in the operating room, and for patients who cannot be brought to the X-ray room, e.g. patients in orthopaedic traction, or intensive care.

A mobile unit connected to a standard grounded wall outlet of 230 V and 10 A (16 A for 3 s with a slow 10 A fuse) cannot deliver more than 3.7 kW. This is not enough for bedside examinations of chest or abdomen. The minimum *power* requirements is 10 – 12 kW. The *energy* required for a hip joint examination is 8 – 10 kWs within an exposure time of 2.5 s.

To achieve this, a **multipeak generator** with **energy storage** must be used. A lead/acid battery, or large capacitor on the input side of the high-tension transformer are good solutions. The X-ray tube for this mobile unit should have a rotating anode with a nominal power rating around 12 kW.

Successful use of mobile units requires much more knowledge and competence than the use of a unit with fixed geometry.

A combination of all three units mentioned above is recommended for a **large first level referral hospital** with at least two doctors and an active operating room, and for **small second level referral hospitals.**

The X-ray department of a **second level referral hospital** in a developing country, a **large policlinic,** or a **primary health care centre** in an industrialised country, *staffed by qualified radiographers*, may also need a floating-top bucky table with an overhead X-ray tube to increase the productivity.

4. Floating-top table with movable over-head X-ray tube

When fully trained radiographers are available, this addition should be considered. It offers more flexibility in positioning for examinations of fractures in traction, broken hip joints, and multi-trauma cases, and is useful for very heavy patients (> 100 kg).

The overhead X-ray tube should NOT be combined with a wall bucky (unless it is automatically centred towards the bucky). An X-ray unit with fixed geometry (such as the WHIS-RAD) is totally superior for use with a horizontal X-ray beam.

A *WHIS-RAD examination stand* an a *floating-top table* can be installed in the same room (minimum 4.5 x 6 m = 27 m^2), and be served by the same multipulse X-ray generator. This combination will allow 8,000 clinical examinations per year (160 examinations per week). If the two units are installed in separate rooms with separate X-ray generators, 25% more examinations will be possible with the same staff. With additional staff, or longer working hours this equipment can handle even more examinations.

5. Tilting fluoroscope plus over-head X-ray tube

A tilting fluoroscope should be operated only by *qualified specialists*. The tilting should be from vertical to –15° (head down). A simple spotfilming programme (with up to 4 images on a 24 x 30 cm film), and a 23 – 25 cm image intensifier with TV is satisfactory.

A vertical column on rails, or a ceiling crane (if the building construction permits) for an *overhead X-ray tube* should be included in this installation.

This double unit should be connected to a 32 – 40 kW multipeak inverter generator for two X-ray tubes. *The cheapest and most reliable solution is a battery powered inverter generator, which can be served by a single-phase mains supply (10 A at 230 V).*

NOTE: Only if the X-ray room already has a reliable 3-phase mains supply of 80 A at 400 V (32 kW) with an impedance (apparent mains resistance) of 0.27 Ω or less (IEC 60601-2-7/1998), would it be advisable to refrain from energy storage in batteries, and use direct mains connection. No single-phase mains supply can handle a 32 kW load.

A combination of the four X-ray units mentioned above (plus the ultrasound unit) should be required for **second level referral hospitals** in the developing world, or for **large primary health care centres** in the industrialized world.

6. Surgical C-arm with image intensifier

A C-arm with image intensifier is very useful for surgeons, provided they have been trained in radiation safety. It is advisable to choose an input screen with a diameter of 17 – 23 cm; it is difficult to work with smaller screens.

7. Film processing equipment

Professional support is very important. It is often advantageous if the manufacturer of the X-ray equipment, or the dealer also accepts responsibility for the film processing equipment.

Manual processing is recommended when less than 50 films are developed per day (< 6,000 examinations per year). Standard sets of processing tanks are available for a wide range of capacity (films processed per day). A separate **film-dryer** will be needed after manual processing.

Manual processing requires much more precision and attention from the darkroom attendant, especially if the temperature is high, the development time short, and the ventilation poor.

Air-conditioning may be required to control ventilation and temperature in the darkroom. If the room temperature is over 27° C, the time in the developing tank will become too short (< 2 min) to work with precision.

Automatic processing may be used when more than 50 films are processed each day (> 6,000 examinations per year). It is difficult to maintain the stability of an automatic processing cycle with a smaller number of films.

Equipment for automatic processing requires access to a stable mains supply (3 – 4 kW), plenty of clean, running water, daily maintenance, and good professional service. The upper temperature limit for automatic processing is about 33° C.

Experience with automatic processing is discouraging in most developing countries. The expected useful lifetime of an automatic film processor is less than a year, unless local competent service is available.

8. Water purification

If running water is not available, it is recommended to use a small **water treatment system** to recirculate the rinse water after elimination of fixer chemicals, metal ions, bacteria, and algae.

Water purification is strongly recommended for manual processing, but it is absolutely necessary for automatic processing.

9. Film Viewing

A minimum of two identical light boxes for 35 x 43 cm films should be used. Each light box requires three 15 W (437 mm) fluorescent tubes with a colour temperature in the range of 3,800 – 4,000 K°.

2. The World Health Imaging System for Radiography (WHIS-RAD): Infrastructure, staffing and components

PREMISES

The small X-ray department described below is intended for *2,000 – 6,000 X-ray examinations per year* with an average of 2 ½ films per examination, and the following average distribution of examinations, representative for large primary health care centres and small first referral level hospitals:

> 38 – 42% extremities; 35 – 40% chest (lungs); 10 – 15% spine & pelvis; 8 – 10% abdomen; and 3 – 4% head and neck.

Sizes of the various rooms are related to workload and staffing. The total net floor space of the department should be 40 – 50 m^2.

Even a small X-ray department will need **at least three separate rooms:**

- *X-ray room* (including generator control area)
- *darkroom*
- *office / viewing room*

Some functions may be shared with other departments: *toilets* (large enough to permit patient assistance), *waiting room, dressing cubicles*, and extra *storage space*.

Examination room

The ideal size of the **X-ray room** is 18 – 24 m^2, including the control area. If patients arrive in bed, a *parking space* of 3 m^2 must be added.

The **ceiling height** should be at least 2.5 m to permit full angulation of the swivel arm of a WHIS-RAD examination stand.

The **walls** should be constructed of materials easily obtained locally. **Concrete blocks** or solid **baked bricks** are preferred for adequate radiation shielding. Channelled or hollow bricks, often used for insulation purposes against heat or cold, are usually inadequate for radiation protection, but may become adequate if covered by a layer of thinner, but solid bricks.

Wooden walls are usually not acceptable, because they would have to be covered by lead sheets mounted on boards intended for wall application. Such boards are usually unavailable, or very expensive in developing countries.

Windows are acceptable only if positioned so that nobody outside can be exposed to radiation (or look into the room).

The width of the main **entrance door** should be 110 cm, or 90 + 30 cm (two doors, hung on opposite sides) with no step or threshold. The door(s) must contain iron or lead for radiation protection, therefore the doorframe must be of iron or steel to carry the weight.

The **floor** should be level and strong enough to support the X-ray tube stand, which may weigh as much as 300 kg concentrated on a small support area (about 20 x 30 cm). The best material is levelled concrete, covered by wood or PVC (polyvinyl-chloride).

The examination room must be well ventilated, especially in hot climates: **forced ventilation** is recommended. If the indoor temperature may exceed 35° C, and the humidity may be over 90%, **air-conditioning** may be required to protect some solid state circuits (the manufacturer of the X-ray generator should be consulted).

Use **fluorescent light** sources with a colour temperature of 3,400 – 3,800 K° in the ceiling (at least 2 x 60 W), mounted close to the shorter walls, and independent from the fuse of the electric wall-outlets in the room.

A regular **kitchen sink** with a flat bottom and hot and cold water plus some **shelves** for accessories are also required in the examination room. See page 9 for electric wall outlets.

Control area, or control room

The X-ray *generator control* area (net 4 – 5 m^2) may be located inside the X-ray room behind a lead screen with a **lead-glass window** (min 30 x 30 cm), or in a separate control room with a larger window (min 40 x 50 cm) in a brick, or concrete wall.

Darkroom

A darkroom for manual processing in a temperate climate may be as small as 5 – 6 m^2 with a minimum volume of 15 m^3 (cubic meters), unless it is permanently manned. *A permanently manned darkroom must be larger* (8 – 10 m^2). **Very effective ventilation** must be used in hot climates. A ceiling height of 3 m is recommended, and the total **room volume** should be at least 25 m^3.

The darkroom must be **entirely light proof**. This must be visually controlled by someone who has spent at least 10 min in the darkroom in total darkness.

The colour of the walls and the ceiling must reflect as much as possible of the light transmitted by the safelight filters. Best is a pure chrome-yellow paint (without white pigment added). This will not reflect any light that may affect blue-sensitive film. It is acceptable to use primrose-yellow, ivory, or cream, which all have a high reflectance of the light transmitted by the filters of the darkroom lanterns. Black walls may hide a light leak. The surface of the walls should be semi-glossy and easy to clean with water. The ceiling may be painted white.

The entrance to the darkroom must be completely light-tight. It must be possible to lock the door from the inside, and it should have a big sign "KNOCK AND WAIT!" (or the equivalent in the local language) on the outside. If a single door cannot be made completely light-tight, a 1 m^2 *light trap* with double doors is a preferable solution.

The floor should be tiled, or made of non-porous concrete, covered with movable wooden slats. The floor must have a small slope towards a draining gutter close to the rinse tank, so that it can be flushed clean with water.

The darkroom has a dry and a wet side, which must be separated from each other:

Dry-bench: This is a workbench for *loading* and *unloading* of film cassettes, and *marking* of films with a **photographic film marker** before the film processing. A width of 120 cm is recommended. The depth should be 60 cm, and the work height 80 – 90 cm, depending upon the height of the darkroom attendant.

If the darkroom is permanently manned, it must have a light-tight **passbox** for X-ray cassettes in the wall between the examination room / control area and the dry bench. This is also the best place to store cassettes. If the passbox door(s) open directly above the dry bench, a 5 cm free space must be left for cassettes lying on the table top. The passbox must be **shielded against radiation** if it sits in a wall of the X-ray room.

Films, directly available for cassette loading, are stored under the dry-bench in a special, lockable, hinged, and light-proof storage compartment, available from any X-ray equipment dealer.

Processing equipment: The **wet side** of the darkroom has large processing tanks, for developing, fixing, and rinsing of the films. Complete sets of tanks with appropriate measures are available from X-ray equipment dealers, and should not be built on location. Acid proof stainless steel tanks are best, but also the most expensive. PVC (polyvinyl-chloride) tanks are cheaper, but have a shorter life expectancy.

The *developing tank* should hold 20 – 26 litres, and the *fixing tank* should be about 50% larger. The size of the *rinsing tank* depends on the anticipated film flow. With running water available it should be at least three times larger than the developing tank. Special tank configurations are sometimes useful. A *stop bath* (10 litres) with 2% acetic acid, between developer and fixer, will increase the life of the fixer. A small *water treatment system* for recycling of rinsing water may be required if the water supply is scarce.

There must be a small rectangular, **acid proof sink** with flat bottom on the wet side.

Darkroom lights. These are of two types: *safe-light* to be used during film processing, and *white light* to be used when the room is cleaned, chemicals are mixed, etc. The *switches for these two lights must be separated* to avoid accidental mistakes. Both should be located close to the entrance door: for the darkroom light 110 - 130 cm, for the white light 170 – 180 cm above the floor.

Safelight lanterns shall be mounted 120 – 130 cm from the surface of the dry-bench and the processing tanks, respectively, and have a coloured filter. The colour depends on the film type used, and is specified by the film manufacturer. It is usually *amber* (orange-brown) for blue-sensitive film, and *ruby* for green-sensitive (orthochromatic) film. A safelight lantern must use a 15 W incandescent bulb. The coloured filter will rapidly be destroyed by heat from a stronger bulb, resulting in light leaks and fogged films.

The **white light** shall use an incandescent bulb (60 W), mounted in, or hanging from the ceiling. Fluorescent light should not be used because of its afterglow. **No film viewing box is permitted in the darkroom!**

Storage shelves for a small amount of unexposed film are also needed in the darkroom. *The shelf should not be mounted on the X-ray room wall.*

Film drying equipment. It is possible to use an *open frame console* for film hangers inside the darkroom, but this requires very good active ventilation during a one hour break in the middle of a day, and after the last examination of the day. A **drying cabinet** for wet film is better, but should be located outside the darkroom. The best place is in the office, close to the darkroom door.

Office

The office should be 10 – 16 m^2, depending on the workload. If the office contains a film file, the room must be larger. The office is used by all visitors who are not patients, and must have a separate entrance. *Entrance through the X-ray room is not acceptable.* The X-ray room is off limits for others than X-ray staff and patients.

Records are kept, and film viewing (consultations) takes place in the office. Supplies may be stored here. Unexposed X-ray film may be stored here, or in a separate storage room. Film boxes must be stored upright as books on a shelf, away from heat, humidity, and radiation, and never close to a wall of the X-ray room.

The office must contain a *desk* for office work, *bookshelf, storage shelves* (for film, envelops, file, patient register, etc.), and **light boxes** for film viewing. One viewing box (with a drip tray), used for *wet film* immediately after the processing, should be located close to the darkroom door. Another viewing box for *dry film* should be available for consultations. (Light boxes should also be available in the surgery, and the operating room).

Both viewing boxes should have a light area of about 44 x 72 cm (H x W), and use 4 – 5 fluorescent tubes mounted vertically (15 W, 437 mm long, colour temperature 3,600 – 4,000 K°, *not* "day-light" tubes). The luminance of the light surface should be in the range of 2,400 – 3,000 cd/m^2 when the fluorescent tubes are new. Expected life time is 8,000 hours.

Ultrasound room

A separate **ultrasound room** (12 – 15 m^2) should be added to the X-ray department. It does not require any radiation shielding, but should be located inside, or very close to the X-ray department.

Other rooms

Toilet(s), large enough for patient assistance (3 – 4 m^2), **changing cubicle(s)** (1.5 – 3 m^2 each), separate **storage space** away from the X-ray room, separate **viewing and file room** (if many examinations are performed).

STAFFING AND ORGANISATIONAL ASPECTS

Staffing

The work in the X-ray department is of three categories: *patient examinations,* or supervision, *darkroom work,* and *communication* with other parts of the clinic/hospital.

The *minimum* staff is two persons working together, even if both only work part time. A patient should never be left alone (e.g. during the darkroom work), and it must be possible to send someone for help in emergencies. At least one of the regular staff must be a registered nurse, or a fully trained radiographer, but both must be trained as WHIS-RAD operators, and in radiation protection measurements.

Location within the clinic or hospital

The X-ray department should be on the ground floor, close to the out-patient department, because a majority of the patients will normally be out-patients referred from that department. It must also be easy to bring in-patients from the wards, or from the operating room to the X-ray department. Some patients will arrive in wheelchairs, or on trolleys or stretchers.

Separate entrances are needed for patients to the X-ray room, and for visitors (staff, patient attendants, or companions) to the office.

Flow patterns inside the X-ray department

The X-ray room shall have only two doors: one is the patient entrance from the waiting area, the other is the door to the control room or office. Both must provide necessary radiation protection. There should be no direct door between the X-ray room and the darkroom, especially if the darkroom is permanently manned. Unexposed film in the darkroom may be damaged if the door is accidentally opened during an X-ray examination.

The control room shall have direct access to the X-ray room, the darkroom, and the office. The control room may be integrated with the X-ray room, or the office.

The darkroom shall have an entrance from the control room/area through a light-tight door, or a light trap with double doors. In the darkroom wall, close to the dry-bench, there may be a light-tight passbox for cassettes from the control area. The passbox may sit in the wall of the X-ray room if it is shielded with lead. If the passbox opens directly above the dry-bench, its door(s) must leave about 5 cm free above the table top (for two cassettes).

The office shall have one door to the control room, and one to the main hospital corridor, or the waiting area.

Other rooms. The patient toilet(s) must be close to the X-ray room, and the waiting area. The storage space must be close to the office.

MAINS SUPPLY

Units

Anybody who selects X-ray equipment for purchase must be familiar with the **electrical units** used in radiography. The most commonly used units are shown in table 1.

Radiation quality is determined by the **tube voltage**, measured in **kV** (kilovolt). The unit refers to the peak voltage value applied to the X-ray tube. For single-phase generators it may be replaced by **kVp** (kV-peak) to emphasise their considerable voltage ripple (amplitude variations). Ripple below 4% may justify the name *constant potential **(kVcp)***. ***Tube current*** is always measured in mA (milliampere.)

Table 1. Electrical units

tube voltage	**tube current**	**exposure time**
V = volt **kV** = kilovolt	A = ampere mA = milliampere	s = second **ms** = millisecond
	mAs = milliampere-second	
power: (kVA=) **kW** = kilowatt		
energy: kWs = kilowatt-second		

Tube loading time (**exposure time**) is measured in seconds **(s)**, or milliseconds **(ms)**. The amount of radiation is selected with the current-time product (the **mAs value**). Tube voltage (kV) multiplied by tube current (mA) gives **power**, applied to the X-ray tube. It is measured in watt **(W)**. (note that "kilo" and "milli" neutralize each other at the multiplication).

Power describes the rate of energy transfer (W = J / s), but gives no information about the total amount of energy used.

Energy is power multiplied by time, and is measured in joule (**J**), which is the same as watt-seconds (**Ws**). The unit kWs (kilowatt-second, meaning 1,000 Ws) is used in radiography to emphasize the relation between power (W) and time (s).

> *COMMENT: The energy unit used by electric power companies, the kilowatt-hour (kWh), is inconveniently large for use in radiography, except for batteries, used as power source. They may store 2 – 4 kWh. The average single tube-load in general radiography is only 3 kWs (range 0.1 – 30 kWs), which is 0.00083 kWh.*

Recommended power supply

All X-ray generators recommended by WHO use some kind of energy storage, and have small demands on the mains supply. A plain grounded "household" wall outlet, or a fuel-powered AC generator for 2.3 kW (10 A at 230 V) is enough for a WHIS-RAD unit. If the energy is stored in a battery, it may even be charged from solar panels, but this is rather expensive.

Some generators may require that the impedance (see below) of the supply mains is no larger than 0.3 Ω, and that a slow 10 A fuse is used, which permits 16 A for at least 3 s.

Ordinary lighting, darkroom light, light boxes for film viewing, film marking equipment, and a small film-dryer cabinet will require an additional 2 – 3 kW. (An automatic film processor would need a *separate*, very stable mains supply for 3 – 4 kW, and would add a lot of heat to the room).

Mains impedance is the apparent electrical resistance of the power line. Impedance values below 0.3 Ω are seldom available in 230 V mains networks. With *energy storage* in the X-ray generator, the impedance value is non-critical. Table 2 shows the maximum impedance values permitted for directly mains-connected X-ray generators.

Table 2. Maximum mains impedance values permitted for directly mains-connected X-ray generators
(excerpt from 60601-2-7/IEC 1998, table 101)

Waveform of high voltage	Nominal power (kW) at 0.1 s exposure time	Mains impedance (Ω) at mains voltage	
		400 V	230 V
six peak, twelve peak, and up to constant potential	16	0.55	0.18
	20	0.44	0.15
	30	**0.29**	(0.10)
	32	0.27	-
	40	0.22	-

There is no **single-phase** X-ray generator on the market, which could handle these power demands. The impedance would have to be < 0.1 Ω at 230 V, or < 0.3 Ω at 400 V.

A **3-phase** X-ray generator would require a separate power line with an impedance below 0.3 Ω to deliver 75 A at 400 V (30 kW for *chest* in 10 ms), but a total energy output of 29 kWs would be no problem.

However, the power line would probably be more expensive than the X-ray generator.

The most demanding tube loading in general radiography are those for chest (high power), and lateral view of the lumbosacral junction – "lateral L5" (high energy). The longest possible exposure time is 2 seconds. Table 3 gives an overview of power and energy needed in general radiography.

Table 3. Power and energy needed in general radiography

object	kV	mA	power kW	time s	energy kWs
chest	120	250	**30**	0.01	0.3
lateral L5	90	160	14.4	2.0	**28.8**

A multipeak generator with **energy storage** in batteries can use a 230 V 10 A "household" wall outlet and still easily handle 30 kW for chest and 30 kWs for lateral L5. The 30 kW power output is also no problem for a generator with energy storage in a capacitor, but for the moment there is no such generator on the market, which can deliver more energy than 18 kWs at a single tube loading.

All standard **electrical wall outlets** in the X-ray department shall be for 230 V, 10 A, and must be *double* and *grounded.*

Three double outlets are needed in the *X-ray room* for life preserving equipment, extra light sources, etc.: one behind the examination stand, and two on the opposite long wall. The *darkroom* needs at least two, and the office will need two, or three double wall outlets.

WATER SUPPLY

All water used for film processing should go through a filter, which eliminates impurities such as unwanted particles, larger bacteria, and iron salts.

Manual film processing normally requires a final rinse in running water. It is possible, however, to use water, which is recirculated through a small water treatment system, which eliminates salts and metal ions. *Automatic processing* requires large volumes of clean water.

3. Summary of the technical specifications for the WHIS-RAD unit (WHO/RAD/TS/95.1)

1. Background

WHO first specified a *Basic Radiological System* in **1975**. The basic X-ray unit included was further developed and evaluated at several WHO Advisory Group meetings. In **1985** *The technical specifications for the X-ray apparatus to be used in a basic radiological system* was published by WHO. It was called the **WHO-BRS**, and was originally intended for use in regions deprived of radio-diagnostic services for economic, or geographic reasons. The Basic Radiological System included manuals for radiographic technique, film processing, and image interpretation.

The BRS-concept was developed further, and the **World Health Imaging System for Radiography (the WHIS-RAD)** was presented at a consultation meeting on *WHO Basic Radiological Systems* in June **1993.** The meeting gathered 25 participants including representatives from the International Society of Radiology, the International Society of Radiographers and Radiological Technologists, the International Organization of Medical Physics, and several X-ray equipment manufacturers. New technical specifications were developed, and they were published in the WHO/RAD/TS/95.1.

The use of a WHIS-RAD unit would improve image quality and simplify work in any X-ray department. The unit can perform more than 80% of all general radiographic procedures made at teaching hospitals, and 95% of all X-ray examinations made in the world (1993).

The radiation doses are lower than with most other equipment, and the image quality is outstanding.

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

1. The X-ray image quality must be excellent.
2. The equipment must be safe for patients and personnel.
3. The equipment must be easy to install and use.
4. Equipment maintenance should be minimal.
5. It must be possible to use the equipment also with an unreliable mains supply.

2. General information and description of the WHIS-RAD unit.

The *examination stand* is designed to assure optimal imaging geometry, eliminating the negative influences of variable focus-film distance and angulation of the antiscatter grid. The X-ray tube and the cassette holder are mounted in *fixed imaging geometry* at opposite ends of a swivel arm, permitting angulation of the X-ray beam as with a pendulum arm. Any standard cassette format can be used.

Fixed imaging geometry is the most important reason for the resulting superior image quality:

1. Patient positioning becomes very simple and easy to learn,
2. exposure variations due to variable focus-film distance are eliminated, and
3. the lines of a correctly focused antiscatter grid are invisible at viewing distances over 30 cm. (Even small variations in focus-film distance and beam angulation in relation to the grid make the grid lines visible).

The WHIS-RAD unit is easier to operate than most conventional X-ray units, and can be powered from lead-acid batteries, or large capacitors.

The other very important reason for good image quality is that the X-ray generator is not directly connected to a 50/60 Hz AC main supply. Only **multipulse X-ray generators**[1], using inverter technology, are acceptable. The use of **energy storage** is preferred, because it makes it possible to use very weak power sources such as regular household wall outlets, stand-alone fuel-powered AC generators, or solar panels.

For acceptable radiography of lungs (chest) the *power* output from the generator must be at least 12 kW at exposure times shorter than 0.1 s. The total *energy* available for a single tube loading at 90 kV shall be in the range of 23 – 30 kWs within 2 s.

3. Technical specifications for the radiation source of the WHIS-RAD. Summary of WHO/RAD/TS/95.1.

These specifications are intended as a guide for manufacturers, purchasing agents, and end-users. They do not constitute an international standard.

[1] other names used are **multipeak generators** or **converter generators.**

3.1. HIGH TENSION GENERATOR

3.1.1. **Mains connection**

A *grounded* 50/60 Hz AC power, which can deliver 2.3 kW within 10% is required: either 230 V/10 A, or 115 V/20 A . *Use a slow fuse.*

3.1.2. **Energy storage**

The high tension generator must have an integrated energy storage unit. Tube loads close to 30 kWs at 90 kV may be required. Peak power loads in the range of 12 – 30 kW for 0.1 s, and 12 – 15 kW for 2 s can be expected.

NOTE: Maintenance free ***lead/acid*** **batteries** are preferred. *The energy available should be 2 – 4 kWh.* A large **capacitor** on the primary side of the high-voltage transformer is also acceptable.

Comment: Energy storage makes a generator insensitive to voltage variations in the mains supply, and results in very exact and reproducible tube loading factor (usually within 2%).

Only sealed maintenance free lead/acid batteries are acceptable. ***Nickel-cadmium batteries are not acceptable.***

3.1.3. **High-tension transformer frequency.**

Only high-tension generators using *multipeak inverter technology* are acceptable. Frequencies from several kHz to 100 kHz are satisfactory. The high-tension ripple shall be < 4% at 100 kV (kVp) and 100 mA.

Comment: A frequency close to 100 kHz is preferred, resulting in a very small transformer with small energy losses, and also good dose/mAs linearity at short exposure times.

3.1.4. **Generator control panel**

Only the following switches, or controls shall be available: *on/off, kV-selector, anode rotation,* and *exposure.* The actual tube loading shall be indicated with a sound and/or a light signal.

Comment: The five control functions mentioned are the only ones needed for a satisfactory selection of tube loading factors (exposure factors).

3.1.5. **Nominal X-ray tube voltage**

The nominal X-ray tube voltage (highest available kV) shall be 120 kV.

Comment: It is recommended to use an X-ray tube rated at 125 kV. The expected tube life is increased, if the maximum generator voltage is lower.

3.1.6. **Available X-ray tube current.**

The tube current shall be, or exceed 100 mA.

Comment: Tube current values below 100 mA bring no advantages.

3.1.7. **Electric power rating.**

The minimum acceptable power rating is 12 kW at 90 – 100 kV for a tube loading time of 0.1 s.

3.1.8. **Electric energy rating.**

The total energy available 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 (see item 3.1.9.d).

Comment: There is one exception to this. When a recording medium is used, which has a nominal speed of 500 or more at 90 kV, a nominal electrical energy of 12 kWs may be satisfactory.

3.1.9. **Selection of tube loading factors**

The selection of loading (exposure) factors is optimized in the WHIS-RAD unit, and limited to kV- and mAs-values. Shortest possible exposure time and highest possible mA-values are selected automatically for each mAs-value used.

a) **Values of X-ray tube voltage:**
For didactic reasons the choice of kV-values is limited to a small number of fixed steps. In practice this leaves a quite satisfactory choice of radiation qualities for clinical radiography.

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

NOTE: 100 kV is available for testing purposes only. A larger number of kV-steps, or continuously variable tube voltage is not acceptable. The selected kV-value must not fall more than 5% from initial value during a tube loading.

Selection of kV-values in practical use:
- 46/53 kV for examinations of peripheral extremities (no antiscatter grid).
– (60), 70, and 80 kV for examinations of bone, or using iodine contrast media.
– 90 kV for very dense objects, barium "double-contrast", and children's chest.
– 120 kV for chest (lung) examinations of adults, and for barium contrast studies.

b) **Values of X-ray tube current** shall be selected automatically, but not displayed. Minimum value shall be 100 mA.

Comment: Unless continuously falling tube current is used, other suitable values are 125, 160, 200, and possibly 250 mA.

c) **Values of loading time** (exposure time) do not need to be displayed. Shortest reproducible loading time (measured as the time during which the kV is 75% of the selected value) shall be 5 ms, or shorter. No loading time may be longer than 2.5s.

d) **Values of current-time product** shall be indicated in mAs, and shall be chosen as decimal multiples and sub-multiples from Renard Series 10 (ISO Standard 497/1973):

NOTE: It is not required that the entire range of mAs-values is available at all kV-values. Thus, it is acceptable that only 20 kWs is reached at 80 kV, and only 12 kWs at 120 kV.

R'10 = Renard Series 10:
1 – 1.25 – 1.6 – 2 – 2.5 – 3.2 – 4 – 5 – 6.3 – 8

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)

Comment: When the R'10 series is used, each exposure step has exactly the same size in the entire range (+ 26%). Film blackening should always be altered by mAs-variations, and never by kV-variations. Tube voltage (kV) variations are used to influence the image contrast.

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

NOTE: The mAs-values shown on the control panel shall represent the mAs-values available at the X-ray tube, not those measured at the centre-point of the transformer.

Comment: If the mAs-values on the control panel represent the values measured at the centre-point of the transformer, the current losses in the high-tension circuit will be included. The energy loss may be of the same magnitude as the energy used for the radiation output at very short exposure times. The apparent dose / mAs linearity may become very poor. The non-linearity of dose / mAs should never exceed 10%.

3.1.10. **Reproducibility, linearity, and constancy of radiation output.**
Multipeak X-ray generators with energy storage have a much better reproducibility and linearity than 50/60 Hz generators. The reproducibility and linearity of air kerma shall be within 10% for any combination of loading factors in the available range (10 mAs is used as the reference value).

3.1.11. **Agreement between indicated and measured values of loading factors.**
At a given measuring date, using the same measuring instrument, the permissible average error of indicated values of X-ray tube voltages shall not be greater than 2.5%. Under the same conditions the permissible average error of current-time products should not exceed 5%, or 0.1 mAs, whichever is larger.

Comment: These are much stricter requirements than in international standards, but are usually not representing any problems with multipeak X-ray generators using energy storage.

3.2. THE X-RAY TUBE

Due to the long *functional standstill caused by an X-ray tube failure* 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 promotes a long tube life. Anodes with large diameter, and a rhenium/tungsten surface are preferred.

Comment: "Normal use" may be a total tube load around 150 kWs in an average work day (50 exposures per day). RTM tubes (Rhenium – Tungsten – Molybdenum) are definitely preferred. The expected useful life of an RTM tube is four times that of a tube with pure tungsten anode.

3.2.1. Expected lifetime.

The X-ray tube should have an expected lifetime of 10 years with the type and mixture of examinations to be found in an X-ray department at a small hospital, or a primary care clinic. This may correspond to a total of up to 100,000 exposures.

NOTE: Distribution of examinations to be expected in primary care, or at the first referral level:
38 – 42% extremities; 35 – 40% chest (lungs); 10 – 15% spine & pelvis; 8 – 10% abdomen; 3 – 4% head/ neck.

Heat variations in the anode of an X-ray tube lead to small cracks in the target surface, reducing the radiation output. When the reduction reaches 20%, the demand on the X-ray generator power output has increased by 25%, which may prove critical for some examinations of dense body parts.

*Comment: A suitable **anode diameter** may be 75 – 100 mm, and the anode rotation need not be more than 2,800 rpm.*

The average tube load at normal working conditions is around 3 kWs/ loading, corresponding to 10 – 13% of the permitted maximum load. The actual tube load varies within a range from 0.25 kWs (normal PA chest) to 30 kWs (lateral view of a dense lumbosacral junction).

Comment: The maximum tube load ever used in clinical work at the WHO test site in Lund is 90 kV and 320 mAs (28.8 kWs), using a WHIS-RAD configuration.

3.2.2. Focal spot.

A rotating anode must be used, and the focal spot shall have a nominal size no larger than 1 mm.

Comment: Focal spots delivered with WHIS-RAD units are in the range of 0.8 – 1.0 mm.

3.2.3. Anode angle

The anode angle should be in the range of 12 – 15°.

3.2.4. Tube rating

The *high-tension rating* shall be 125 kV with < 4% ripple. The *nominal power rating* shall be in the range of 23 – 30 kW at 0.1 s. The *long-time power rating* (energy rating) shall be in the range of 12 – 15 kW at an exposure time of 2 s (total load 24 – 30 kWs).

3.2.5. Tube filtration

The total filtration (inherent and added) shall be within the range 3 – 4 mm Al, and should be measured on location with a penetrameter.

Comment: 4 mm Al is better than 3 mm.

3.2.6. X-ray beam collimator

Use a standard, multilevel light beam collimator. The collimator controls should have reliable indicators for 12, 18, 24, 35, and 43 cm for focus-film distance of 140 cm, so that it can be used in case of a light-bulb blow out.

The manual collimator controls should be located so that they also can be reached by a short operator when the beam direction is vertical.

*Comment: The tube housing shall have a 2 mm lead diaphragm (**beam stop**) close to the X-ray focus, limiting the irradiated field to 43 x 43 cm at a distance of 140 cm from the focal spot. It is also advantageous if the collimator has "near-port shutters" extending into the window cone of the X-ray tube, limiting extra-focal radiation.*

It should be possible to change the collimator light bulb without the use of special tools. The centre of the light field shall not deviate more than 14 mm (1% of the FFD) from the central X-ray beam. The limits of the light field may not vary more than 1% of the FFD from the limits of the X-ray field.

Comment: The rules for collimator adjustment are more strict than international standards require, but achievable with a well designed collimator. The aim is to keep the irradiated field within the area covered by the 50 x 50 cm lead plate in the back wall of the *cassette holder.*

4. Technical specifications for the WHIS-RAD examination unit

4.1. **The examination unit** (the stand) consists of a support for *a swivel arm, carrying* the X-ray tube and the cassette holder, and a patient trolley, which can be used as a floating-top table. The unit combines the functions of a chest unit, a vertical bucky, and a floating-top table with an overhead X-ray tube. It must permit the use of a horizontal, vertical, and angulated X-ray beam for examinations of lying, sitting, and standing patients.

4.2. **The design of the stand** must ensure that the X-ray tube is rigidly connected to the cassette holder in **fixed geometry.** The focus-film distance shall be 140 cm, and the arm design must permit examinations of a recumbent patient with a horizontal X-ray beam.

Comment: The X-ray tube and the cassette holder are mounted at the opposite ends of a swivel-arm, shaped as a "prone question mark". This design makes it possible to examine patients lying on a trolley with a horizontal X-ray beam.

The arm assembly shall be perfectly balanced in vertical and horizontal position. It must be possible to angulate the arm +/- 30° from both these positions, retaining the balance, and to use a horizontal X-ray beam in the minimum range of 50 – 170 cm above the floor.

Comment: If a WHIS-RAD unit is to be used in traumatology, it should be possible to tilt the beam 90° downwards (towards the floor), when the tube arm is horizontal. This may be required for radiography of patients that cannot be moved from the bed, or stretcher, on which they have arrived.

4.3. The **cassette holder** shall be fixed at right angles to the central X-ray beam, and shall accept any standard cassette size. It also must be possible to change cassettes easily when the X-ray beam is used in the vertical direction with the cassette holder under the trolley.

Comment: The length/height of the cassette holder shall be 50 cm. The distance from a horizontal plane through the central X-ray beam to the cassette holder arm should be 25 – 30 cm to provide space for a recumbent patient during radiography with a horizontal X-ray beam. (This is the justification for the existence of the "prone question mark" design).

The centre point of the X-ray beam, and the dimensions of the four most frequently used film sizes in the vertical position shall be indicated on the front wall of the cassette holder.

A **fixed antiscatter grid** shall be mounted immediately behind the front wall of the cassette holder. The distance between the front wall surface of the cassette holder and the X-ray film shall be 2 –3 cm.

The back wall of the cassette holder shall contain a protective screen with an equivalent thickness of 0.8 mm Pb at 100 kV within an area no smaller than 49 x 49 cm.

4.4. The **fixed antiscatter grid** must be focused at a distance of 135 – 140 cm, have a ratio of 10:1, and a line density of 40 – 60 lines/cm. The grid must cover an image area of 43 x 43 cm.

Comment: A Pb/Al grid with 40 lines/cm (e.g. line width 50 µm, space width 200 µm, information loss 20%) gives excellent results. The lines are practically invisible if the grid is correctly focused, and the viewing distance is 30 cm or more.

A Pb/graphite grid with 60 lines/cm is preferred in digital radiography, but does not use a 50 µm line width (30% information loss). A 33 µm line width gives only 20% information loss, but insufficient contrast with dense objects, unless the contrast is improved digitally.

Optional loose antiscatter grids:

A few projections make use of loose cassettes, especially in traumatology. Separate antiscatter grids with a ratio of 6:1, mounted on the front side of these cassettes, may then be required. Separate grids are needed for 24 x 30 cm, and 35 x 43 cm cassettes.

4.5. The **examination table** shall be a trolley with large wheels, used as a floating-top table. The width of the table top should be 70 +/- 1 cm, and the length 205 +/- 5 cm. The table top shall support a patient weighing 110 kg, sitting on the middle of the table, without appreciable sagging (< 1 cm). The equivalent radiation attenuation of the table top should be no more than 1 mm Al.

The distance between the table top and the plane of the film in the cassette holder, when used under the table, should not exceed 8 cm.

Comment: It is recommended to use a wheel diameter around 12 cm for the trolley.

5. Cassettes and fluorescent intensifying screens

5.1. RECOMMENDED SCREEN TYPES

It is recommended to choose the **basic screen-film system** described in section 5.2, if the choice of intensifying screens and X-ray films is limited. 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-film system** is preferred.

The detail resolution of advanced system is considerably better than that of the basic system in all screen types except in Detail/Fine category.

Comment: The basic screen-film system (the "blue system") is based on blue-emitting calcium-tungstate screens, and blue-sensitive X-ray film. It is available all over the world in three speed groups: 50, 100, and 200. In some countries blue-sensitive film is the only X-ray film easily available.

In order to reach the speed group 400/500 with blue-sensitive film, it is possible to use high-speed yttrium-tantalate screens (speed close to 500) in a few cassettes. They are kV-independent, and emit blue/UV light.

*Blue sensitive film tolerates **amber** darkroom light, with is easy to work with during manual processing.*

Calcium-tungstate intensifying screens emit **blue light**, and are available in three speeds:	
Detail/50	hands and feet
Universal/Paraspeed/100	head & extremities
Fast/HiPlus/200	everything else
Yttrium-tantalate/500 for very dense objects	

The speed (sensitivity) of gadolinium-oxysulphide screens is highest in the upper end of the clinically used kV-range (flat peak at 85 – 120 kV). The speed approximately doubles, going from 50 to 100 kV, reducing exposure times for dense objects (90 kV), and chest (120 kV). This is advantageous, because the sensitivity to scattered radiation becomes lower than to primary radiation *[in this kV range].*

*Comment: The advanced screen-film system (the **"green system")** uses green-emitting **gadolinium-oxysulphide screens** and **green-sensitive** (orthochromatic) **X-ray film.***

*The green system shows the best image quality, and requires a smaller radiation dose, but may not be available everywhere. The orthochromatic film is made for automatic processing, and tolerates high developer temperature, but requires **ruby red** filtration of the darkroom light. That may, however, be considered more difficult to work with than **amber**.*

Gadolinium-oxysulphide intensifying screens emit **green light**, and come in four speed groups (nominal speed figures refer to 75 kV)	
Fine/100	hands and feet
Medium/200	chest
Regular/400	everything else
Fast/800	*very* dense objects
The speed (light / µGy) varies with kV used. Maximum sensitivity at 90 – 100 kV	

Speed groups of intensifying screens

Speed of blue-emitting calcium-tungstate screens with blue-sensitive film	Speed groups of **green-emitting gadolinium-oxysulphide** screens	Relative speed with **green-sensitive film**					
		no grid		with Pb/Al grid, ratio 10:1			
used at 46 – 120 kV	used at (kV):	46	53	60	70	80	90 - 120
Detail/50	Fine/100	50	63	80	100		-
Univ./Paraspeed/100	Medium/200	100	125	160	200	225	250
Fast/200	Regular/400	-	-	320	400	450	500
	Fast/800	-	-	-	630	700	800

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

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

Comment: Do not replace a single damaged cassette alone, risking a change of screen speed (sensitivity).

5.2. CHOICE OF X-RAY CASSETTES

Cassettes must be available in four sizes:
- *small format*: 18 x 24 cm (not 13 x 18 cm)
- *intermediate format*: 24 x 30 cm
- *long format*: 18 x 43 cm (or 20 x 40 cm)
- *large format*: 35 x 43 cm (or 35 x 35 cm)

Comment: A suitable selection of cassette sizes with intensifying screens of different speeds is included in the attached form for request of tender.

CHOICE OF X-RAY CASSETTES	size (cm)	designation	speed group	quantity	use
Basic screen system	18x24	fast	200	3	grid
for blue-sensitive X-ray film:	24x30	fast	200	3	grid
A minimum supply of cassettes should	18x43 (15x40)	fast	200	3	grid
include those listed to the right, intended for **blue-emitting calcium-tungstate screens**:	35x43 (35x35)	fast	200	3	grid
* Alternative choice for extremities	18x24	detail	50	3	no grid
	18x24	universal	100	3	+/- grid
Yttrium-tantalate screens for very dense objects	24x30	fast detail (high speed)	500	3	grid
Advanced screen system	18x24	medium	100-200 ☼	3	+/- grid
for green-sensitive (orthochromatic)	18x24	regular	320-500	3	grid
film. If available, it is better to choose	24x30	medium	200-250 ♥	3	grid
green-emitting intensifying screens	24x30	regular	320-500	3	grid
as shown to the right:	18x43 (15x40)	regular	320-500	3	grid
(speed varies with kV, see above)	35x43 (35x35)	regular	320-500	3	grid
	35x43 (35x35)	medium	200-250 ♥	3	grid
☼ extremities, 46 – 70 kV ♥ chest radiography, 90 – 120 kV					

6. PROTECTIVE DEVICES

It is recommended to install the X-ray generator control panel behind a protective wall, or screen, separating an area from the X-ray room, large enough for two people (e.g. operator and interpreter, or parent/companion). The lead equivalence of the wall, or screen should be 0.5 mm Pb, or more. The wall, or the screen 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 screen, but should be at least 40 x 50 cm in a brick wall.

The back wall of the cassette holder contains 0.8 mm Pb (or equivalent). Thus, 12 cm thick walls of solid, baked bricks, or *8 cm* of concrete *(both equivalent to 1 mm Pb)* may be satisfactory for radiation protection around the X-ray room, provided the room is at least 18 m^2 in size, and no more than 2,000 examinations are made per year. *[This is valid for an average speed of 200 for the screen-film combinations used. If a 400 speed screen-film combination is used for everything but chest and peripheral extremities, the radiation protection is satisfactory for 4,000 examinations per year.]*

NOTE: Any radiation protection measurements shall comply with international and national regulations.

Comment: The original calculations for lead shielding were made for the WHO-BRS/85 (with 0.5 mm lead behind the cassette) by the Department of Radiophysics at the University of Lund, Sweden. The results were published in WHO/RAD/86.1: "Guidelines for the installation of WHO Basic Radiological Systems". The original figures have been modified by application of the "inverse-square" law on different room sizes.

Excerpt:

The maximum radiation level outside the X-ray room will be 5 mSv/year with walls of 5 cm concrete (0.6 mm Pb), a screen-film speed of 200, and...		
room size	central beam distance to nearest parallel wall	maximum number of examinations / year
3 x 4 m	1.5 m	2000
4 x 5 m	1.8 m	3000

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

7. FINAL COMMENTS

7.1. **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 manuals for installation, use, maintenance, and repair of their own equipment.

7.2. **Operational accessories**

(to be offered with a WHIS-RAD UNIT)

a) Two 15 x 32 cm lead **rubber sheets** (0.5 mm Pb equivalent) for subdivision of film *sizes* in cassettes, used directly on the top of the table. 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 film, or two times 12 x 30 cm for a forearm on a 24 x 30 cm film.

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

Comment: A caliper used by lumberjacks to measure timber, is the best, but hard to find.

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

d) Two **viewing boxes**, *with light areas about 36 cm wide and 44 cm high*, mounted side by side, or one viewing box about *72 cm wide and 44 cm high*, is a minimum requirement. Use 2 or 4-5 *(respectively)* standard *15 W (437 mm)* fluorescent tubes *mounted vertically* behind milky-white glass *or perspex. A suitable colour temperature is 3,600 – 4,000 K^o* (not "daylight" tubes). The luminance of the light surface should be in the range of *2,000 – 2,500 cd/m^2 when the tubes are new.*

Comment: The paragraph on viewing boxes is rewritten, and represent the current opinion. The light boxes should be located in the office of the X-

ray department, and represent a minimum number. The expected lifetime of the fluorescent tubes is 8,000 hours.

e) **Film marking equipment.** *X-ray films must be marked with patient identity, examination day, and name of hospital, or polyclinic before they are processed. Film marking is best made by a photographic marker, which is located inside or outside the darkroom. Film marking by hand after the processing is acceptable only if the film-flow is extremely small, and the same person makes the examinations and the marking.*

When the darkroom is separately manned, and the film flow is large, it should be required that the person who makes the examination also marks the film outside the darkroom.

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, it may be possible to justify the use of a small automatic processor. This would require a totally reliable mains supply *for 3 – 4 kW*, access to *plenty of clean water*, and *specially trained personnel* for daily use, and maintenance service.

Comment: Consult the WHO-BRS Manual of Darkroom Technique (1985). Manual processing requires more precision and attention from the darkroom technician than automatic processing does, especially if the air temperature is high, and the room ventilation poor.

To simplify the purchase of darkroom equipment, a detailed description of manual processing is given below.

Manual processing

(The following sequence of actions are required in a permanently manned darkroom)

1. Bring the exposed cassette from the through-the-wall cassette hatch to the dry bench.

2. Unload the cassette.

4. Mark the film with the name of the patient, date, and name of the X-ray department.

NOTE: Film marking can be made outside the darkroom with a photographic marker if cassettes with a window in the back wall are used. This will shift the marking job from the darkroom attendant to the radiographer making examinations, and will considerably improve the precision of the developing procedure, especially if the developer temperature is high (> 23° C), leading to short developing times (< 3 min), which are difficult to observe in a hurried work situation.

4. Mount the film into a stainless steel frame of correct format.

5. Place the film into the developing tank, and move it up and down at least once , eliminating air bubbles on the film, ensuring that the whole film gets in contact with the developing solution.

6. Start the darkroom timer (which must be pre-set for the appropriate developing time for the actual temperature of the solution). Normal range is 5 down to 3 minutes at 19 up to 23° C, respectively. With special precautions, the temperature range can be extended to 25° C, using 2 minutes. *Shorter developing times than 2 minutes cannot be maintained properly in routine work.*

7. Re-load the cassette with a new film, and return the cassette to the through-the-wall hatch.

8. *After ½ minute* in the developer, move the film frame up and down once or twice, and make space for another film frame to the left of the first one. *Do not check the film blackening!*

9. After the predetermined developing time (2 – 5 min), depending on the temperature), transfer the film frame to the stop bath (without checking the blackening!). Move it up and down two or three times during ½ minute, then transfer it to the fixing tank.

10. The fixing time is independent of the developing time, and is at least 3 minutes (for modern emulsions with low silver content), but preferably 5 minutes. Longer time will not damage the film. *It is permitted to view the film in white light after 2 – 3 minutes (the emulsion clearing time) in the fixer, provided that there is no film in the developing tank.*

11. Transfer the film to the rinsing tank, where it has to remain in running water for at least 30 minutes. Longer time will not damage the film.
NOTE: The rinse water temperature should be close to that of the fixer.

12. Films are best dried (in their hangers) in a drying cabinet with forced ventilation. If air is heated, a thermostat must control that the temperature does not exceed 35° C. The film dryer should be located outside the darkroom.

NOTE: A darkroom attendant may be able to handle 10 – 15 films per hour, depending on experience. If the films have been marked outside the darkroom, the capacity increases.

ANNEX

to the Consumer guide for the purchasing of X-ray equipment

PROPOSED FORM FOR TENDER

regarding a World Health Imaging System for Radiography (WHIS-RAD)

Equipment manufacturers, or agents are asked to follow this form in order to simplify fair comparisons with other offers. Differently arranged quotations make this more difficult.

DATE:

Name of radiographic system:	Country of origin:
Name of manufacturer:	
Mailing address:	
Fax number:	Telephone number:
Your reference:	Reference at WHO:

Working conditions for the equipment

The X-ray unit requested is intended for **stationary use** in a single examination room. It will be installed in one , or several **small X-ray departments,** located in primary health care centres, or small hospitals. It will usually handle a workload of 2,000 – 6,000 general radiographic examinations per year. Fluoroscopy, mammography, tomography, or serial radiography will not be made.

Special requirements for the X-ray generator and power source

The X-ray generator must have an integrated **energy storage**, and use **multipeak inverter technology**. It must be possible to operate the generator from a "household" **mains supply of 10 A at 230 V**, or from a fuel-powered AC generator. A wind powered generator, or solar panels may be acceptable in combination with lead/acid batteries.

Sealed, maintenance-free **lead/acid batteries** are preferred. A set of fully charged batteries shall provide at least 1,400 kWs for *X-ray production* (energy used during stand-by, for anode rotation, collimator light etc. not included). *NiCad batteries are not acceptable.* A **large-capacitor** on the primary side of the high-voltage transformer is acceptable if 15 kWs is available for a single tube load at 90 kV, and the image recording medium has a nominal speed of at least 400 at 90 kV.

Infrastructure

Specify the *infrastructure* required for proper functioning of your equipment in the space provided below, or use a separate sheet of paper.

• **Room dimensions**, including ceiling height, maximum cable lengths between control unit ("console"), X-ray generator, and X-ray tube.	
• **Indoor climate** requirements such as maximum temperature and humidity for satisfactory functioning. Will air-conditioning be required to neutralise heat dissipation from the X-ray unit and film dryer?	
• **Mains supply**, including impedance, fuse requirements, and permissible line voltage variations for: a) the complete X-ray unit; b) the film dryer and/or automatic film processor; c) air-conditioner, if any.	
• **Local support** required during installation, and the future local maintenance service.	

Installation

It is very important that the equipment design permits installation with a minimum of mechanical adjustments on site. The equipment should have been pre-installed and tested at the factory, and should only need re-assembly at the work site. It is unacceptable to rely on extensive mechanical alignment of the cassette holder and the X-ray tube at the installation site. It is important that the collimator and the antiscatter grid can be centered without the use of special tools at the installation site.

All cables must be pre-fabricated to correct length before shipping. Cable lengths may not be adjusted during installation. High quality multi-channel connectors should be used.

Ideally, the nearest large X-ray department, or a financing organisation with experience and knowledge of radiography in small X-ray units should take some responsibility for the planning of the premises in cooperation with the manufacturer. The premises must be correctly prepared and approved for clinical radiography with a WHIS-RAD unit before the arrival of an installation team. A competent local service engineer/mechanic (responsible for future service at minor breakdowns) should participate in the WHIS-RAD installation, and the installation time required by a qualified team of one engineer and one assistant (locally provided) should be no longer than 16 work hours. It is important that the local radiographer is present during the installation.

Specify the *installation time* you anticipate at well prepared premises, and what *kind of instructions* you can provide for the local staff of radiologists, radiographers/technicians, and hospital mechanics/engineers to guarantee a proper understanding of your equipment and its functioning.

Processing equipment

Film processing is the most difficult part of the radiographic procedure, and most radiographic errors originate in the darkroom. It is advantageous if the manufacturer of the WHIS-RAD Unit also accepts responsibility for the film processing equipment. Complete sets of tanks are available for purchase, and should not be built on location.

Prices are FOB, and may be quoted in your local currency, or in USD. Currency used: ....

I. Equipment constituting the X-ray generator and patient stand

Requested components and performance	Specifications, comments, and price of equipment
A. X-ray generator X-ray generator, including energy storage unit *(specify)*, and cables for installation • *Displayed loading factors:* **Voltage steps:** 46-53-60-70-90-120 kV (+ 100 kV for testing purposes). *Continuously variable kV is not acceptable.* **Current-time products:** 0.5 – 250 mAs in 26% increments (ISO Standard 497). • *Not displayed loading factors:* **Tube currents:** 100, 125, 160, 200, (250) mA (ISO Standard 497), or falling load, starting at 250 mA, or higher. **Exposure time range:** 0.005 – 2.5 s (ISO 497). • *Specify:* **Nominal power rating** in **kW** (at 0.1 s), and **maximum energy available** within 2 s at 90 kV in **kWs** (= energy rating)	Subtotal **A:**_______________
B. X-ray tube assembly B.1.: *X-ray tube with rotating anode* in housing. **Single focus**: 0.8 – 1.0 mm. • *Specify* anode material, diameter, and angle (12 – 15°), focal spot size, voltage rating (min. 125 kV), nominal tube load (min. 25 kW at 100 kV), and peak energy load at 90 kV (min. 25 kWs within 2.5 s). B.2.: *High tension cables.* • *Specify* cable length permitting a 5 ms exposure time (with more than 75% of the tube voltage) at 100 kV. B.3.: *Collimator.* • *Specify* type of collimator, maximum field size of beam stop (focus-near lead diaphragm related to the film plane), and total filtration (in the range of 3 – 4 mm Al).	Subtotal **B:**_______________

Requested components and performance	Specifications, comments, and price of equipment
C. Examination stand, FFD 140 cm (Compare with WHO/RAD/TS/95.1.) C.1.: *Examination stand:* column with swivel arm for tube and cassette holder in *fixed geometry* with offset cassette-holder arm ("prone question-mark" design). • *verify* that all standard cassette formats can be used up to 35 x 43 cm, longitudinally and transversally, that a horizontal X-ray beam can be used with a recumbent patient close to the cassette, and that the distance from cassette holder front wall to film is < 3 cm. • *specify:* angulation range of balanced swivel arm, height range above floor for horizontal X-ray beam, distance between central X-ray beam and nearest part of swivel arm, space available for trolley between cassette holder and column, and Pb-equivalence for cassette holder back wall. (Compare with WHO/RAD/TS/95.1). C.2.: *Fixed antiscatter grid.* • *Verify* dimensions (43 x 43 cm), ratio (10 : 1), focusing distance (135 – 140 cm). • *Specify* inter-spacing material and number of lines/cm. C.3.: *Mobile examination table (trolley)* with lockable wheels, flat table-top, and radiolucent foam plastic mattress. • *Specify* dimensions of table top, height above floor, and diameter of wheels.	Subtotal **C**:______________
D. Examination accessories 1 set of foam plastic positioning wedges. 2 lead rubber sheets (0.5 mm Pb) measuring 15 x 32 cm (used to make two separate exposures on one cassette). 1 set of sandbags (1 and 2 litres). 3 sets of L(eft) + R(ight) markers (or equivalent in the language preferred by the users) 1 set of **WHO-BRS Manuals** (radiographic technique; film processing; and film interpretation)	Subtotal **D**:______________

II. Equipment related to handling of X-ray film

Two alternatives are described. For an experienced buyer it is possible to select components from both of them to form an appropriate compromise. The essential differences between the alternatives are summarised below:

Alternative 1: Only one X-ray room is used. Less than 50 films are used per day (< 6,000 examination per year). **Blue-emitting intensifying screens** and **blue-sensitive X-ray films** are used. The film is **marked in the darkroom, processed manually,** and dried in warm air (best in a drying cabinet with forced ventilation). The processing solutions will require cooling if the room temperature is expected to be > 27° C. Blue-sensitive X-ray film permits **amber filters** for the darkroom light.

Alternative 2: One or two X-ray rooms may be used. More than 50 films are processed per day. More than 5,000 examinations are made per year. **Green-emitting intensifying screens** and **green-sensitive (orthochromatic) X-ray film** are used. The film is marked inside or outside the darkroom, and an **automatic film processor** is used (included a drier). The ambient temperature may be as high as 32° C. Orthochromatic film requires **ruby red filters** for the darkroom light.

E. Darkroom fittings, common for both alternatives

Requested components and performance	Specifications, comments, and price of equipment
a) **'Dry bench** *for film storage, film marking, and cassette loading:* Table top dimensions: 60 x 120 cm. Table height: 80 cm above the floor, or above the surface of wooden slats on the floor	Subtotal E:a:____________
b) **Film marking equipment** (specify) *- for use in the darkroom, or* *- for use outside the darkroom:* (both use photographic marking with light and trans-illuminated paper strips with typed or written information: name of clinic, date of examination, patient name and ID number)	Subtotal E:b:____________
c) **Water purifying unit** for re-circulation, de-ionisation, and filtering of rinse water (optional). *Specify:*	Subtotal E:c:____________
d) **Passbox for X-ray cassettes** with separate IN- and OUT-channels. The OUT-channel should possibly serve as storage for 18 cassettes. *(Required for a manned darkroom; optional if not permanently manned)*	Subtotal E:d:____________
	Subtotal E:____________

F. X-ray film cassettes

F: Alt. 1: Cassettes with blocker for marking in the darkroom, name: ....
Blue or blue/UV intensifying screens:
Standard *calcium-tungstate screens* (speed 50 – 200): name: ....

Special high-speed *yttrium-tantalate* screens (> 400): name: ....

Speed 50/100 for use without grid at 46 and 53 kV (**calcium-tungstate** screens).
Speed 200 for use with antiscatter grid at 60 – 120 kV (**calcium-tungstate** screens).
Speed 400 + for use with grid at 80 – 90 kV (**high-speed yttrium-tantalate** screens)

Requested components and performance			Specs, comments, and price of equipment	
Size and usage	*speed*	*qty*	**Cassettes (without window)** + screens	PRICE
18 x 24 cm, extremities	US 100	3		....
18 x 24 cm, general use	HS 200	3		....
24 x 30 cm, general use	HS 200	3		....
18 x 43/20 x 40 cm, general use*	HS 200	3		....
35 x 43, general use	HS 200	4		....
24 x 30 cm, very dense parts	? 400	2	(yttrium-tantalate)	....
* request and specify only one size	total	18	Subtotal **F:Alt.1:**	

F: Alt. 2: Cassettes with window for **marking** in daylight, name: ....

Green-emitting *gadolinium-oxysulphide intensifying screens:* name: ....

Nominal speed 100 at 75 kV (range 50 – 80 at 46 – 60 kV) for use without antiscatter grid.
Nominal speed 200 at 75 kV (range 200 – 250 at 90 – 120 kV) for chest (lung) radiography without grid.
Nominal speed 400 at 75 kV (range 320 – 500 at 70 – 120 kV) for general use with antiscatter grid.

Format, usage and kV-range ☼	*speed*	*qty*	*Screen identifications*	PRICE
18 x 24 cm, extremities, 45–60 kV	50-80	3		....
18 x 24 cm, general use, 60–90 kV	320-500	3		....
24 x 30 cm, general use, 70-90 kV	400-500	3		....
18 x 43/20 x 40 cm, general use, 70-90* kV	400-500	3		....
35 x 43, general use, 70-90 kV	400-500	4		....
35 x 43/35 x 35 cm, chest, 90-120 kV*	250*	2		....
☼ speed varies with kV * request and specify only one size	total	18	Subtotal **F:Alt.2:**	

G:Alt. 1: Darkroom and film processing equipment for manual processing

Requested components and performance		Specifications, comments, and price of equipment
a) *Darkroom lanterns* for **blue-sensitive film** NOTE: *Incandescent bulbs > 15 W will destroy the coloured filter*	2 darkroom lanterns with **15 W bulbs** and **amber filter** (one for the dry bench, one for the wet bench) 1 spare *amber filter* 10 spare **15 W** bulbs	Subtotal G:1a:________
b) *Processing tanks.* Stop bath optional NOTE: *Exact tank configuration open for discussions.* (temperature control heating/cooling?)	1 20 – 26 litre tank with lid, for developing (1 10 litre tank, option for stop bath) 1 30 – 40 litre tank with lid, for fixer 1 60 – 70 litre rinse tank	Subtotal G:1b:________
c) *Film hangers* (with pliers for best drying) *Alternative sizes ▶ specified by user ▶	Format (cm) — Qty 18 x 24 — 15 24 x 30 — 15 18x43/20x40* — 15 35x43/35x35* — 15	Subtotal G:1c:________
d) Wall-mounted *storage rack for film hangers*	minimum capacity for 40 hangers	Subtotal G:1d:________
e) *Additional processing equipment* NOTE: battery operated timer with at least ¼ **min accuracy**	2 mixing paddles (developer/fixer) 1 measure 1,000 ml 1 measure 2,000 ml 1 development tank thermometer (with hook) 1 darkroom timer 2 frame consoles for 15 – 20 film hangers	Subtotal G:1e:________
f) *Film drying equipment* (for at least 30 film hangers)	2 frame consoles **or** 1 **heated drying cabinet** with thermostat and forced ventilation (possible to use the fan only)	Subtotal G:1f:________
		Subtotal **G:Alt. 1:**________

G:Alt. 2. Darkroom and film processing equipment for automatic processing

a) *Darkroom lanterns* for **green-sensitive film** (orthochromatic) NOTE: *Incandescent bulbs > 15 W will destroy the coloured filter.*	2 darkroom lanterns with **15 W bulbs** and **ruby filter** (one for the dry bench, one for the wet bench) 1 spare *ruby filter* 10 spare **15 W** bulbs	Subtotal G:2a:__________
b) *Automatic film processor:* • *Specify* in detail on separate paper	Film width 36 cm, time in developer minimum 23 s, total processing time 1 ½ - 3 min.	Name:.................................. Subtotal G:2b:__________
c) *Additional processing equipment* • Separate mixing paddles for developer and fixer	2 replenishment tanks (DEV and FIX) 1 input water filter 2 mixing paddles (D/F) 1 measure 1,000 ml 1 measure 2,000 ml 1 thermometer	Subtotal G:2c:__________
		Subtotal **G:Alt.2:**__________

H. Film viewing equipment

a) *Film viewing boxes.* Use 437 mm long, 15 W, warm-white fluorescent tubes (colour temperature 3,600-4,000 K°). *Specify.* • Manual processing requires *drip-tray* on light box	2, light boxes with light area 44 x 72 cm (H x W) with 4 – 5 fluorescent tubes. *Specify.* 1 drip tray if wet films are viewed	Subtotal H:a:__________
b) *High-intensity light source* with milky white glass and iris diaphragm.	1 spot-viewer, table model. *Specify.*	Subtotal H:b:__________
		Subtotal **H:**__________

III. Radiation protection equipment (= J)

Best location for the *generator control* is in a separate **lead-protected cubicle** with direct access to the darkroom and the office. If not available, use a **lead screen** inside the X-ray room.

Requested components and performance	Specifications, comments, and price of equipment
J:a) *A protective lead screen* (1 – 2 mm Pb) carrying the generator control panel, should be offered if a separate control room is unavailable: min. width 120 cm, height 200 – 210 cm. A 30 x 30 cm (or larger) lead glass window shall be mounted at a convenient height for the operator. • **Observe local radiation protection rules!**	Subtotal J:a:__________
J:b) *Radiation protection aprons** with lead equivalence of 0.25 – 0.35 mm (need not cover the back, but shall cover sternum/chest): 1 shoulder to knee apron 100 cm 1 shoulder to knee apron 115 cm 1 *half apron*, 0.5 mm Pb equivalence, for chest examinations of pregnant women. 2 pairs of *protective gloves*, 0.25 mm Pb. Aprons and gloves delivered with hanger.	Subtotal J:b:__________
** Light-weight vinyl XENOLITE aprons with barium-tungsten-lead are preferred.*	Subtotal **J:**__________

OVERALL TOTAL PRICE FOR ITEMS A – J When a tender is invited, one, or both complete alternatives for film handling equipment could be asked for. Different combinations of items from both alternatives are possible.	Currency:__________
ALt. 1: Equipment using *manual processing* and *blue" screen-film system* (items A, B, C, D, E, F:1, G:1,H and J). F.O.B.:	Total:__________
Alt. 2: Equipment using *automatic processing* and *"green" screen-film system* (items A, B, C, D, E, F:2, G:2, H and J). F.O.B.:	Total:__________
Unconditional warranty for 1 year must be included in the price. Extension of the unconditional warranty up to two years would cost: Extension of the warranty to five years *pro rata temporis* would cost:	Percent addition .... % more .... % more
• Specify **total transportation costs** from manufacturing site (F.O.B.) to installation site by surface, or air (**including insurance**): ► • Specify any **charges for instruction of local staff** (if any): ►	Total:__________ Total:__________