RISKS IN MOBILE INDUSTRIAL RADIOGRAPHY

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Abstract

The most important factors in mobile radiography that tend to increase the radiation dose absorbed by the population, the workers and the environment are dealt with. The discipline and motivation of radiographers are considered of utmost importance in the application of the ALARA principle. (As Low As Reasonably Achievable)

Methods are presented to maintain this discipline in an area of tension between safety considerations and economic pressure.

On the one hand supervision by superiors and independent parties is required together with a policy of sanctions when rules are infringed, on the other hand the radiographer must be able to carry out his task properly. He shall have done a theory course and shall have gained sufficient experience. He must have enough equipment to absorb spilt radiation. Proper job preparation is necessary. The radiographer must know beforehand what locations are to be visited and the objects to be examined.

The rules themselves, to which a radiographer must adhere, shall be practical and understandable. Therefore, the regulations as recommended by ICRP and required by the Basic Safety Standards drawn up by Euratom (directive 96/29), and IAEA are translated into simple rules for radiographers. A set of standard equipment for safe working is presented. In the ideal situation the radiographer carries this set permanently in his car.

Personal protection means for the radiographer are dealt with. Malfunctioning of these protection means may never be an excuse for too large a dose equivalent absorbed. Precautions must be taken against failing equipment and against human senses that may be insufficient for indirect detection of an overdose of absorbed radiation.

Contents

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1 Introduction

The risks in mobile radiography are synonymous to the risks of unnecessary exposure of workers and population to ionising radiation. These are related to the following subjects in a sequence of importance according to the experience of the author.
-Motivation of the radiographer
-Knowledge and experience of the radiographer
-Means of protection of the radiographer and the population.

2 Motivation of the radiographer.

The radiographer is always in a position of conflict. He is usually employed by a company or self-employed. His activities belong to an industrial, commercial branch in which profit and loss can be made. Therefore he or his boss is interested in a productionrate as high as possible. The major parameters that can be influenced are the time to make the set-up of radiation equipment and the object, the time to make a controlled area, the power with which the exposure takes place and the width of the beam used with the exposure. All these parameters are such that timesaving works against good and safe workmanship i.e. expose only the film with as small a dose as possible.

If however the radiographer is well equipped with tools and aids that make his work fast and much easier he may be more motivated to take care for safety. Then he may dedicate the time gained because of the aids and tools to more attention for the radiation safety.

2.1 Supervision

Especially for those who execute regularly the same routine of activities, certain blindness for the risks they are dealing with may occur. Radiographers have such a routine and there is easily a tendency to take it easy when dealing with the efforts required to comply with the rules. For them it is a fatigue to carry more lead for the absorption of radiation, to walk more to make a larger controlled area, to bend and kneel more often if the direction of the beam is pointed towards the ground.

Therefore the only way to force these people into proper working according to often apparently senseless rules, is to survey them permanently or to keep them aware that at every moment an unexpected check may occur. In the recent past this was very well possible because the radiographers would receive their orders in the morning and remain without contact out of the office all day long. Nowadays the radiographers have potential contact with their offices due to the mobile telephones through which every unexpected arrival of an inspector will be announced.

A remedy for this is found. If all those who co-ordinate the daily activities submit their daily planning's every morning by fax to the central inspection the latter have all the information for that day and without further information the sites to be controlled can be selected. The method is without extra cost because the planning data are also necessary for further invoicing and are therefore already available.

The most serious and regularly occurring infringements are the omission of the application of the radiation survey meter, the construction of the controlled area and the doserate at the border of the controlled area.. There must be a sanction for these infringements. The first time a severe warning should be given and the second time the contract must be terminated.

2.2 Equipment set-up

Objects in all dimensions and weights are subject to radiography. In general two possibilities exist. In the first the objects are so heavy and /or large that these remain fixed and the radiation generator and films are positioned around it for the exposure. In the second case the objects can be handled easily and then the generator is fixed and the objects are placed in the proper position.

When the object cannot be moved less freedom exists for the radiographer and thus it is more difficult to work safely. The most important recommendations are the following:

- Do not work with the beam pointed in the sky. The amount of "skyshine", scattering of radiation by the airmolecules is always surprisingly great.
- Keep the beam so narrow that it just illuminates the object to be radiographed.
- Preferably point the beam towards the ground or a pile of sand or similar.

- Keep the focal distance as small as possible.

When the generator is in a fixed position the same arguments are valid. In this situation preferably the generator must also be pointed to the earth or towards a pile of sand.

2.3 Controlled area

According to laws and regulations there must always be a controlled area when applying ionising radiation. This is not much of a problem with a fixed installation where wallthickness and material can be chosen such that a low, controlled doserate exists outside the installation. However in mobile radiography this problem is much larger.

In practice the radiographer meets a variety of situations. For some of these situations it is more obvious than in others that a fence consisting of plastic ribbon increases the safety. For example everybody will agree that a controlled area is necessary in a densely crowded area like a town. But in the desert everybody will agree that such a fence will not add to safety. However it would be bad policy to let the radiographer decide depending on the situation. Therefore the only consequence is a regulation that prescribes that a controlled area must always be made.
The controlled area consists at least of one plastic ribbon, yellow with black stripes, suspended on sticks at least .5 meter above the ground with the end and begin connected. Just sticks with flags are considered insufficient.

The boundary of the controlled area must be surveyed permanently during radiation and therefore one man is required apart from the operator who serves the equipment.

2.4 The doserate at the boundary of the controlled area

The limit of annually absorbed equivalent dose due to other sources than natural radiation of members of the population is 1 mSv. This is a summation of various contributions like medical, dentist, radon etc. The Dutch regulation assumes that the annually absorbed dose consists of 10 different contributions of which mobile radiography is one. As a consequence the limit of annually absorbed equivalent dose due to mobile radiography must not exceed 100 micoSievert.

An instruction given to the operator must be simple and clean. The only experimental data the operator has, are the dose rates as measured with the survey meter. By instruction the doserate at the boundary of the controlled area must not exceed 10 microSievert per hour.
We estimate the annual dose in one place of the border under the following assumptions.

Four radiographs made in one hour.
Exposure time per radiograph: 2 minutes
One out of 4 exposures in the direction of the particular spot of the boundary.
40 working hours a week
50 working weeks in a year.

These assumptions lead to an annual dose on one spot of the boundary of 1 mSv.

For the estimation of the absorbed dose by members of the population we must recognise two situations. In the first situation the set up is really mobile and is rarely set up in the same place. If one person would be fixed to the ribbon he would incur 1 mSv in one year. In reality this is never the case and people only pass by occasionally and then further away. So it is very likely that nobody absorbs even one tenth of the amount.

In the second situation a radiographer works always or often on the same spot like outside the buildings in the backyard of a customer. Then the barricade can coincide with the boundary of the property of the customer and an amount of radiation is sent out of the property. Members of the population may stay considerable time in that area like in the case of living or working. Then a plan must be made that takes into account the exact positions, the radiation level and the duration of exposure or the number of radiographs made annually.

If it is impossible to make a controlled area with a certain doserate (we recommend 10 microSievert per hour) a radiography plan must be made for every particular situation. This plan must contain a calculation of the estimated absorbed dose by members of the population. Examples are situations close to motorways and bridges where both cars and ships pass, the traffic cannot be stopped and people are likely to be only during a short period in an area of enhanced radiation.

A particular situation arises in the case of pipeline construction. Often the activities take place in a wide-open area with no people in the neighbourhood. The access to the work is usually a muddy path along the pipeline. In such a case a controlled area with ribbon around the place of radiation does not enhance the radiation safety and the requirement of it is just demotivating the radiographer. In that case our procedure requires a ribbon that blocks the access paths and a free overview of the area including a virtual 10 microSievert per hour boundary.

2.5 Beamwidth

The principle of radiography is that differences in absorption of a beam of photons are made visible on a plate with photosensitive material. Therefore the beam is absorbed in the object and the object is thus the first shield against radiation arriving in the environment. Thus radiation passing aside the object is not absorbed and therefore spilt, has no purpose and arrives unattenuated in the environment. Therefore the beam should not extend over the surface of the plate to be exposed. This can be achieved by the following methods.
A small distance from the focus to the object. This distance influences the "geometrical unsharpness" together with the dimension of the source from which the beam arises. The "geometrical unsharpness "must be so small that it does not affect adversely the quality of the radiograph. Thus there is a minimum distance (focal distance) that may be applied. This minimum can be smaller when the focal spot is smaller. (see par. 4.3.2)
A second advantage of a smaller distance between focal spot and film is that the time of exposure can be less due to the intensity of the radiation. The simple quadratic law tells that if the distance is halved, one needs only a quarter of the exposure time.
If, after optimisation of the foal distance, radiation is still spilt, aids may be used.
In an X-ray tube a collimator must be inserted into the window of the tube. This is a disk of lead or tungsten with a hole that reduces the beam angles. These collimators must be applied and the use must be checked in the unexpected inspections. Lack of application of collimators must be considered as an infringement.
In gammagraphy in which a small spherical source that radiates in all directions is applied, a collimator must be used to reduce the radiation of a beam. Nowadays collimators are preferably made out of tungsten. There should be a collimator for various angles. Lack of application of the right collimator must be considered an infringement.

3 Knowledge and experience of the radiographer

The following instruction must be part of the toolkit of the radiographer.

- Theory. In the system EN (European Norm) 473 the requirements for the level 1,2 en 3 radiographers according to European model are listed. In the ASNT system similar requirements exist. In most countries the radiation safety is a small part of the radiographers course.

In the Netherlands the radiographer must follow a dedicated course on radiation safety. This is called level CI 5A for encapsulated sources. Without the diploma of this course one is not allowed to execute radiography.

The course takes five days of theory and practice and a distinction is made for handling open and closed sources. The course and examination are under supervision of the Netherlands government.

The radiographers are certified according to EN 473 with the purpose to guarantee that the knowledge and experience remain at a suitable level.

Experience is as important as theory. In order to obtain and maintain the certificates Level 1, 2 and 3 proven continuous experience is required. In practice the employer must be conscious and selective when sending out apprentices with experienced radiographers. A practice for safe and fast working can only be learned from good examples.

4 Means of protection

4.1 Human Senses

Unfortunately the human being has no sense for ionising radiation. Still there is risk involved and it is necessary that a radiographer continuously knows in what strength of radiation field he and other people are.
A replacement of a human sensor is an electronic device that measures the radiation dose and/or doserate and translates this into signals that are appropriate for the human senses. The most applied senses are the eye and the ear. These functions are different by principle.

The eye is very specific in the sense that it can focus on one visual signal and filters out all other signals. If there is a signal on the measurement device because of a doserate, it can be observed and if the readout is zero, this means there is no radiation.

The ear is non-specific in the sense that at the same time it absorbs a manifold of signals. If the audible signal from an alarm survey meter is present but less in strength than other signals or if the signal is blown away by the wind, no signal is observed but in reality there is certainly a non-negligible doserate. From this it must be clear that audible means are much less reliable than visual means and that therefore audible means must be avoided.

4.2 Personal protective means.

The protective means when working with radiation are the following.

4.2.1 The radiation survey meter.

The simple survey meter is a doserate meter that must have a sensitivity of at least 1.0 microSievert per hour. As indicated above the main purpose of the survey meter is to act as an extended human sense and to tell continuously the strength of the radiation field in which the radiographer is working. Moreover it is used to measure the value of the doserate at the boundary of the controlled area. This must be smaller then 10 microSievert per hour.

When making exposures the radiographer must follow the signals on his survey meter permanently. When he turns on the power of the X-ray tube or removes the source from the gammacontainer, he must follow the signals on the survey meter as well as when the radiation is stopped. If he changes the situation and observes no changes on the survey meter, the survey meter is probably defective and he must directly bring the equipment in the non-radiating position again. The failure mode of a survey meter is that no signal is given at the output even if a doserate is present at the input. Proper working with the survey meter implies that even if the survey meter is defect no radiation incidents occur.

It must be clear that the use of the survey meter is very important and it must be considered a serious infringement if somebody does not use the survey meter.

4.2.2 The pendosis meter.

The purpose of the pendosismeter for a radiographer is as follows:

- Measure the accumulated absorbed radiation after one day of work. Insufficient care to avoid radiation will give a considerable reading. The readings should be registered and a regular review can yield an extrapolation to the future. If the cumulative readings show any irregularity or that the limit of the annual dose will be reached, preventive measures can be taken. As a preventive measure the radiographer might need extra training or extra instruction.

- Back-up for the case that the survey meter was not in use or the survey meter was oversteered due to a large signal.

- If there is a suspicion of a radiation incident this can be verified immediately.

The pendosismeter measures the cumulative dose over a period of time. It is a simple passive device that every radiographer or even everybody who is in an area where he may absorb some radiation must wear. The range is 1000 or 5000 microSievert and it is possible to measure the absorbed dose every day routinely. If there is doubt whether or not an incident happened this may be observed directly with the pendosismeter.

The pendosismeter consists of a capacitor that must be loaded regularly. Radiation unloads the capacitor. The failure mode is a full-scale reading when the capacitor is for some reason unloaded. When there is a full scale reading this can either mean that a radiation incident occurred or that the pendosismeter has a defect.

4.2.3 The thermo luminescent dosimeter. (TLD meter)

The purpose of the TLD meter is as follows.

- The measurement of the accumulated radiation dose over a longer period of time for the determination and registration of the annual dose. This registration is a legal requirement in many countries. The annual dose is determined by the sum of the monthly dose readings. The readings are corrected for the background radiation.

- In the case of a radiation accident, the total absorbed dose is registered in the meter. Usually the pendosis meter gives a full reading. Therefore the pendosismeter is not suitable in a radiation incident except for the indication that probably an accident. occurred.

4.3 Means of reduction of the dose absorbed by workers and others.

In the philosophy of the application of the ALARA Principle (ALARA = As Low As Reasonably Possible) the deduction of the possibilities to reduce absorbed radiation is derived from the fact that the photosensitive film needs to comply with the requirements that are part of the purchase order. In practice this means a criterion for density and a criterion for resolution. The target must be that the required dose is so small as possible and that all radiation that is not used for the exposure of the film is absorbed in appropriate means.

4.3.1 Filmsensitivity

The sensitivity of a film or the filmspeed is related to the time of exposure required to achieve a certain density. No normalisation exists for the sensitivity in industrial Roentgen films. Therefore manufacturers have a system of their own to classify films.

A correlation exists between the size of the details that have to be made visible, the type of film and the required time of exposure. The smaller the details the longer the exposure time.

Often lead foil is applied on one or either side of the photosensitive material. This improves the quality of the radiograph. The time of the exposure remains more or less equal.

In processes where an extremely high speed is required special films are applied with salt screens. These require much less exposure time than the normal films. The quality of the radiographs suffers considerably.

The ratio of exposure times between the fastest and slowest film with or without lead foil amounts about 15. If films with salt screens are included, this ratio is about 80.

In view of the radiation protection and ALARA, it is recommended that films be applied that require a smaller dose to achieve a certain density.

4.3.2 Focal distance

For three reasons the distance between the radioactive source or the focus of the X-ray tube to the film (focal distance) must be as small as possible.

- The doserate on the film is larger and the exposure time is correspondingly shorter.
- The dose of radiation that falls besides the film is smaller for geometrical reasons.
- The dose of the radiation falling besides the film is smaller because of shorter exposuretimes.

The smallest possible distance is determined by the geometrical unsharpness. This must not be the limiting factor of quality. The geometrical unsharpness amounts:

Ug= SB/A where:

Ug the geometrical unsharpness
S diameter of the source / focal spot
B thickness of the object
A distance between source and object

4.3.3 Shielding screens

The radiation that is not absorbed in the film or in the object to be investigated may be divided in three groups.
- The radiation of the direct beam that remains after attenuation by the object and the film.
- The radiation that passes besides the object and/or the film.
- Indirect radiation scattered by the object and the surrounding air.

Screens of lead must be used for the absorption of this radiation. A plastified variety of 6-mm lead exists with handles to carry these.

4.3.4 Collimators in the generator

Collimators are disks out of lead or another heavy metal. These are meant to reduce the beamwidth to the smallest possible dimensions. The outer shape of the collimator is a circle that fits in the window of the X-ray generator and inside the disk is a hole of the appropriate form. This has usually a rectangular shape with the length – width proportion of the film. The dimensions to be used depend also on the film-focus distance. Care must be taken that the beamwidth on the film is not critical as this leads easily to unexposed edges of filmmaterial. Many clients don not accept these and the result is that the exposure has to be made again. This works against the radiation safety because the same dose has to be applied twice. Moreover it is not attractive because it costs more time and material.

4.3.5 Filters

Filters are used to absorb the lower part of the spectrum of radiation of an X-ray generator. This part adds usually little to the density of the film but it can cause a considerable dose to be absorbed in the environment.
In the respect of emitted spectrum two type of X-ray generators exist, distinguished by the type of rectifier applied.
The most frequently applied type is the one where the valve itself acts as a diode. In that case three is single phased rectification. Then the voltage varies every cycle between zero and the maximum value. Within every cycle the spectrum varies from very low energy to the maximum and only the region of the maximum adds to the exposure of the film.
In the case of a double phased rectifier the voltage remains high during the cycle with a ripple. These X-ray generators are called "constant potential". Due to the ripple however a spectrum is generated with low frequency components.
A filter consisting of a beryllium window should be permanently installed on the X-ray generator except for exposures at 40 to 60 keV as used for plastics. It must be fixed in such a way that it can be removed only in the workshop.
In situations where the film has to be shielded from indirect radiation or backscatter, a thin plate of copper or steel can be applied. This is the case with the objects close to the ground where the backscatter causes an additional density of the film and therefore a loss of contrast.
Due to the spectrum of radioactive isotopes, filters are not used in gammagraphy.

Whereas the common types of x-ray generators transmit a beam because of the construction of the insert, the radiation pattern of radioactive sources is omnidirectional. Beamshaping has to be realised with a collimator consisting of tungsten, lead or depleted uranium.

4.3.6. Inventory of the vehicle for mobile radiography.

Requirements have to be formulated for the vehicle with which the radiographer goes to his job to carry out his duties. When transporting radioactive sources in type B(u) or type A containers care must be taken that the level of radiation is sufficiently low. Even when respecting the limits according to the ADR requirements for transportation – 2mSv on the surface of the package- the driver may still receive an unacceptable dose. During transportation the container must be at least a few meters away from human beings. Effectively the consequence is that only vans are suitable for mobile radiography.

The standard inventory of the radiographers van should contain the following:

- Three (3) yellow-white placards for radioactive material.
- Two orange placards for dangerous goods.
- One valid document for transportation
- Two fire extinguishers
- Two orange accident lamps or reflecting cones
- Tools and a wedge
- One first aid kit
- Provisions to fix containers properly.
- One lamp

Means to construct the controlled area:

- Six sticks to support the ribbon
- Sufficient yellow-black ribbon and a spare box.
- Ten radiation flags

Shielding material
One collimator with support
One plastified plate of lead of 30 x 40 cm
One plastified plate of lead of 40 x 60 cm