Overview of Occupational Exposure Optimisation Challenges in Industrial and Research Uses

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1 Introduction

The Optimisation principle is the cornerstone of radiation protection, however, its practical application varies from one sector to another and has to fit within national safety cultures and infrastructures. The feedback from the experience of application is an important part of optimisation. This paper provides a brief review of the development of the understanding and implementation of the principle and the input of European Commission (EC) initiatives to this process. This workshop is one of those initiatives and the primary objective of this paper is to set the scene for the workshop by providing an overview of the uses and optimisation challenges in the Industrial and Research sectors.

2 History of Development

Since the advent of ICRP's Publication 22[(1)] in 1973 and Publication 26[(2)] in 1977, the understanding and practical implementation of the concept of Optimisation of Radiation Protection has developed considerably. This past progress can be split into three periods each with a dominant theme that contributes to current approaches. The first period, lasting up to 1982 was mainly focused on theoretical aspects and an evaluation of possible quantitative decision aiding techniques, with most emphasis being placed on cost effectiveness and cost benefit analysis. The second period from 1982 to 1987 was mainly devoted to the development of a structured approach to optimisation, the ALARA Procedure, within which decision aiding techniques, if required, could be used. This period also saw many case studies being carried out in a wide variety of installations both in relation to design and operational problems, but predominantly *a posteriori*. The third period from 1988 onwards saw the development of more structured approaches and "tools", which together with an *a priori* predictive approach have been integrated in operational radiological protection programmes with varying degrees of success.

Throughout these periods the National Radiological Protection Board (NRPB) and the Centre d'etude sur l'Evaluation de la Protection dans le domaine Nucléaire (CEPN), worked to provide a significant input to these developments and some of the results of this work have been published in book form[(3)]. Much of this was supported financially by the EC, and it is also on their behalf that since 1990 both organisations have been heavily involved in running training courses on optimisation. These courses were primarily focused on the nuclear sector and one of their strengths has been the input of lecturers from utilities across Europe who had experience of the practical implementation of ALARA. Another strength has been the wealth of practical experience that the participants themselves, from a range of countries and different backgrounds, have brought to these courses. One of the early lessons from these courses was that to benefit from the exchange of ideas and experience there also had to be an understanding of the different safety cultures and radiation protection infrastructures in each country in order to understand some of the driving forces. Undoubtedly the same will be true for this Workshop.

3 European ALARA Network

The progress of the international community in developing understanding of optimisation and its practical implementation can be traced through the proceedings of four European Scientific Seminars[(4-7)]. The last of these was in Luxembourg in 1993 and its structure was such that each session produced conclusions which have subsequently provided an input to shaping EC work in this area. Conclusions of particular relevance to this workshop were:

"..... the principal challenges for the future are

(a) to improve our feedback from past experience by developing databases,
(b) to improve the situation in the non nuclear sector ......".
"there needs to be a focussed effort on optimisation in certain areas of the non-nuclear industry ....".

This led to the establishment of an EC Concerted Action, the European ALARA Network (EAN). Its objectives are:

- to promote the wider and more uniform use of optimisation techniques in the various fields of application in Europe, ie, industry, research and the nuclear fuel cycle.
- to provide a focus and mechanism for the exchange and dissemination of information from practical experience, and
- to propose topical issues of interest that should be the subject of European meetings, workshops or research.

CEPN provide a coordinating function for the EAN and an Expert Group has been established to guide the programme of work and to provide contact points throughout Europe. A key element of its work has been the establishment of the twice yearly European ALARA Newsletter. This has been highly successful and is currently distributed to several thousand persons in over 20 countries. It is also accessible on the Internet; at http//www.ean.cepn.asso.fr. A regular feature of the Newsletter has been short case histories of incidents so that the lessons learned can be widely disseminated: practically all of these have been in the industrial and research sectors.

In 1997 EAN organised its first workshop at INSTN, Saclay, France on 'ALARA and Decommissioning'(8). This was highly successful and produced recommendations to inform EC work needed to be carried out in this area. The subject of this second workshop, "Good Radiation Protection Practice in Industry and Research" was chosen to assess the progress made since the area was highlighted in the conclusions of the 1993 Luxembourg Seminar(7) and in the light of current dose and incidents statistics.

4 Sector Characteristics

Assembling relevant and comparable data that allow us to characterise the radiological protection performance of the various sectors of use, whether at the national or international level, is fraught with difficulties. However such data is key to identifying problem areas and assigning priorities for allocating resources for improvement. The Wednesday morning session of the Workshop covers initiatives to provide the necessary data, both in respect of doses from routine operations and incidents, and how this data can be used as effective feedback. Many of the articles in the EAN Newsletter have been relevant to this and a flavour of the dose trends can be found in the dose data contained in these articles. Tables 1-4 reproduce examples of the data for Germany(9), Spain(10), France(11) and the UK(9) respectively. More recent UK data(12,13) is given in Table 5. As might be expected, different national patterns of exposure emerge that will be discussed in more detail in the Wednesday morning session; but it is clear that the industrial and research sector features significantly in the higher dose bands. This is reinforced by the "Learning the Lesson" case histories, also published in the Newsletter. However before focusing down on the Industrial and Research sector, it is perhaps worthwhile commenting on both the Nuclear and the Medical sectors, as there are relevant differences.

Nuclear

In the Nuclear sector, radiological protection is central to the operation of this international industry. It has a high media profile and pressure from public opinion is a factor that has an impact both on managements and the attention paid to the sector by the regulators. As a consequence, professional health physics expertise is readily available, occupational exposure dosimetry is generally very good and significant effort is put into training. Another characteristic is that the organisations involved are large, often covering many sites: thus once radiological protection issues are brought to the attention of senior management, coherent actions to address problems can be efficiently implemented across a large part of the industry.

Medical

In the medical sector the uses of radiation are also central to the work undertaken eg, radiotherapy, radiography and nuclear medicine, but the radiological risks are generally not high profile and the medical benefits of the uses sometimes tend to stifle objective questioning of occupational and patient exposures. However this situation may be changing. For example in France there is an increasing social demand concerning the justification of radiological diagnostic examinations, as well as requests to know the associated patient dose from any examination.

The dose data in Tables 1-5 indicates quite significant differences between countries. For example in France in 1995 there were 37 persons working in the Medical sector who received doses in excess of 50 mSv, whilst there were none in the UK. Here a variety of factors may be relevant; for example the degree of regulatory controls and enforcement, the structure of the heath service and the ready availability of health physics expertise. With regard to the last of these it is relevant to note that in France there are relatively few hospital health physicists, these being mostly in radiotherapy, whilst in the UK they are more widespread throughout the medical uses and have a strong professional body with significant influence.

Industry and Research

Unlike the previous two sectors, in Industry and Research the use of radiation is often not central to the activity being carried out and merely provides supporting technology. Here radiation is just one of the many risks that have to be managed. The sector is characterised by a large number of separate companies and organisations using radiation, each acting independently. It is very rare for all but the very largest organisations to have professional health physics expertise available from their own staff. Whilst the BSS Directives(14,15) would require many users to consult a " Qualified Expert", there is considerable variability across Member States in both the level of expertise that would be expected of a Qualified Expert and the extent to which they are used.

5 Uses and main risks

The range of uses of radiation in this sector is very wide. Appendix 1 provides an indicative list of types of use. A useful more in depth review of uses is given in IAEA Safety Series 102(16). However, in this brief overview of the issues involved we will concentrate on 5 general use areas, unsealed radioactive material, naturally occurring radioactive material (NORM), gauging systems, irradiation facilities and industrial radiography; together with some common themes. Within the text a number of questions are posed that are intended to stimulate discussion during the workshop and provide a focus for the final discussion.

Unsealed Radioactive Material

Techniques involving laboratory scale use of unsealed radioactive material are widespread tools of research. The levels of activity involved typically vary from kBq levels to GBq amounts, with the principal isotopes being H-3, C-14, S-35, Cl-36 and various isotopes of iodine.

Whilst the design of laboratories is important the nature of the work is such that controls over the spread of contamination and prevention of exposure depend heavily on procedural controls and the correct use of personal protective equipment. Inevitably, from time to time, there are failures in these controls, but often the consequences are limited.

Are controls effective and commensurate with the risk?

Are there effective mechanisms to learn from small scale incidents?

All the uses produce radioactive waste which is increasingly expensive to dispose of, and uncontrolled accumulations of radioactive waste over periods of time can pose problems.

Are there issues related to the accumulation and disposal of radioactive waste?

NORM

Certain minerals contain significant levels of naturally occurring radioactive material (NORM) in conjunction with elevated levels of elements for which these minerals are extracted and processed. These minerals, the by-products from processing and the processed product can provide exposure routes for both workers and members of the public. Examples can be found in the phosphate industry, the processing of metal ores, the extraction of rare earths and the oil and gas extraction industry. The principal radionuclides are Th-232, U-238, Ra-226, Pb-210 and K-40 with very wide ranges of concentrations, up to several hundred Bq g^{-1}. Both external and internal exposure routes are relevant and doses can be up to a few tens of mSv per year in some situations.

Do we have sufficient information to characterise the exposure routes from NORM?

Is sufficient dosimetric effort put into quantifying exposures from NORM?
Is there appropriate regulatory control both at the national and European level?

Gauging Systems

The two most common uses are for

(a) detecting the level of liquid or material in vessels, ranging in size from cans and bottles to large hoppers and reaction vessels in the petrochemical industry: typical sources would be

2-10 GBq	Am-241
2-80 GBq	Cs-137, Co-60
60-140 kV	X-rays

(b) measuring the thickness of material, predominantly in the paper, board and plastic film industries, but also for rolled materials: typical sources would be

40 MBq - 40 GBq	Kr-85, Sr-90/Y-90, Pm-147, Tl-204
0.4-40 GBq	Am-241, Cs-137

During normal usage, these gauges are fixed in position and amenable to engineering control eg, shielding or interlocked access controls. The principal potential problem areas relate to

· robustness of the designs for the environments in which they are used
· the control of engineering work, which often takes place with some engineering controls removed.
· source security during the life of the plant and appropriate disposal at the end of the useful life of source.

Is sufficient attention given to controlling maintenance procedures both by managements and regulators?

Two other principal groups of gauging uses are Borehole logging and Nuclear Density Gauges. Both are designed to profile strata, the first in the oil and gas industry, the second in road construction. Typical sources are:

1-800 GBq	Am-241 / Be
0.4-20 GBq	Cs-137

These sources are mobile in nature and can be used in almost any environment but are often used in challenging environments such as offshore oil platforms and on road construction sites. The principal problem areas are

· robustness of designs for the working environment
· source security
· effective demarcation and use of controlled areas.

There is a steady stream of incidents with these uses.

- **are we seeing all the incidents that occur?**
- **what could be done to reduce the frequency?**

Irradiation Facilities

These are used for the production of isotopes or for altering the physical or chemical properties of material eg, polymerisation, sterilisation of products. They can vary from laboratory sized units which can only accommodate small samples to large facilities with a product transport system to continuously pass the product through an irradiation position where dose rates in excess of $Sv.s^{-1}$ can exist. World-wide there have been at least 5 radiation fatalities in irradiation facilities. These have been reported in detail in IAEA publications[17-20].

There have been many more serious incidents that, though not fatal, have resulted in deterministic effects, one of which, the Forbach accident is covered in a presentation at this workshop.

Do existing installed safety systems provide 'defence in depth'?

Many of the accidents have come from workers not following procedures: is appropriate training provided?

Industrial Radiography

The range of sources typically used is

0.1 - 10 TBq	Ir-192
0.2 - 100 TBq	Co-60
60 - 300 kV	X-ray sets
1 - 8 MV	linear accelerator

Industrial radiography is undertaken:

(a) in fixed facilities with engineered safety systems: the principal problems are

- poor design of safety systems
- poor maintenance and degradation of safety systems
- lack of monitoring

(b) using mobile sources in what is known as "site radiography": the principal problems are

- the work is often undertaken in remote/ difficult/ hostile environments
- supervision is poor
- it is a highly competitive business

In gamma radiography a variety of remote exposure systems are available; the most common being with the source attached to a cable which allows the source to be moved between its shielded container and its exposure position. A common failure mode is for the source to become detached from its cable and for this not to be detected immediately due to poor, or non-existent monitoring. In short, in addition to possible high routine doses, there is the potential for equipment and procedural failures; a potentially lethal combination. Each year industrial radiography gives rise to a number of accidents where one or more dose limit is exceeded. Once sources are out of control they can enter the public domain. Table 6 lists the fatal industrial radiography accidents reported to IAEA[(21)], and it will be seen that the fatalities are dominated by members of the public.

There is the potential for significant under reporting of accidents and routine doses. In the UK in 1992 an industrial radiographer died of acute myeloid leukemia after, over an 8 year period presenting lesions on both hands and having a finger amputated. An investigation[(22)] showed that he had received a whole body dose of 15 Sv probably over many years from chronic poor practices.

Are there appropriate feedback systems so that the lessons from accidents can be effectively used in training?

What initiatives should be pursued to optimise radiation protection in industrial radiography?

Common Issues

It is clear that there are some issues that are common to various areas of use. The objective of this Workshop is to identify and prioritise these issues as an input to national and EU radiation protection programmes and to also provide a forum for exchange of information so that we can learn from each other. As an aide to focusing discussions, the following areas may be worthy of discussion:

Regulatory enforcement programmes.
Commitment of managements and employees (safety culture).
The role and standard of qualified experts.
Category A and B workers and relevant personal dosimetry.
Possible conflicts between medical confidentiality and optimisation.
Source security.
Databases and mechanisms to disseminate information.
Training.

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Table 1 German dose data for 1994

Categories of facilities	% of Persons exposed to doses >15 mSv	Collective Dose (man.Sv)
Medical Practices	0.04	7.25
Dental Practices	0.02	0.11
Hospitals, clinics or sanatoriums	0.02	14.70
Other medical facilities	0.04	0.69
Research, science	0.02	0.63
Industrial radiography	3.43	7.80
Reactor operation (excluding contract personnel)	1.34	23.70
Operation of installations of the nuclear fuel cycle	0.11	0.54
Technical control, governmental supervision, experts working in the field	0.46	0.98
Other facilities (including contract personnel for NPP)	1.94	45.30

Table 2 Selected Spanish occupational data for 1989 and 1995

OCCUPATIONAL CATEGORY	**Total number of workers**		Average annual individual dose (mSv)		Collective dose (man.Sv)		Number of individual dose >20 mSv	
Medical Sector	**37750**	**56570**	**0.86**	**0.55**	**47**	**27.4**	**90**	**22**
Diagnostic radiology Radiotherapy Nuclear Medicine Dental Radiology Other	33036 1041 924 1294 ------	41583 1614 1546 4631 7196	0.82 0.91 1.93 1.29 ------	0.53 0.57 1.35 0.60 0.42	24.4 0.9 1.6 1.6 ------	19.7 0.9 2.0 2.1 2.7		15 1 1 2 3
Non-Nuclear Industry	**3031**	**5070**	**1.6**	**1.3**	**5.3**	**5.6**	**17**	**13**
Radiography Gammagraphy Process control Metrology Manufacturing Other	650 169 672	440 327 1871 350 1045 1037	1.10 4.52 1.58	2.46 2.59 0.99 1.32 1.14 1.26	0.6 0.7 0.9	0.7 0.7 1.6 0.4 1.1 1.1		0 4 2 0 0 7
NPPs	**10807**	**8765**	**2.7**	**3.1**	**20.6**	**16.0**	**88**	**93**
Fuel Cycle	**757**	**807**	**1.2**	**0.3**	**0.6**	**0.1**	**0**	**0**
Research/Transpor t	------	**4778**	------	**0.7**	------	**2.7**	------	**4**
TOTAL	**52345**	**75990**			**73.5**	**51.8**	**195**	**132**

Table 3 Number of monitored workers, collective dose, annual individual doses over 20 mSv and over 50 mSv by activity sectors (external exposures only, France, Year 1995)

OCCUPATIONAL CATEGORY	No. of Monitored Persons (category A & B)	Collective Dose (man.Sv)	Individual Dose >20 mSv/y	Individual Dose >50 mSv/y
1 - Defence	6027	2.02	0	0
2 - Medical and Veterinary Uses	132692	18.25	127	37
3 - Transport of sources	*n.a. (item does not appear in French published statistics)*			
4 - Industrial Uses	20943	15.47	120	9
5 - From natural sources	*n.a. (often not monitored)*			
6 - Military Nuclear Cycle	4796	0.53	0	0
7 - Civil Nuclear Fuel Cycle - Utilities	33866	24.46	46	0
8 - Civil Nuclear Fuel Cycle - Contractors	30537	78.40	614	0
9 - Research and Teaching	17301	1.04	2	0
10 - Non Identified Employers	4456	0.48	0	0
Total	**250618**	**140.65**	**909**	**46**

Table 4 Selected UK occupational dose data for 1986 and 1994

Occupational Category	**Collective Dose (man.Sv)**		**Number of Individual Doses >15 mSv**	
	1986	**1994**	**1986**	**1994**
Nuclear Industry	77.2	27.8	1243	4
Industrial Radiography	7.5	2.7	57	29
General Industry	15.8	7.1	169	1
Mining Underground	6.6	4.3	224	140
Other	19.9	9.5	218	9
Total (man.Sv)	**127**	**51**	**1911**	**183**

Table 5 Numbers of classified persons who had doses in 1996 above specified levels*

OCCUPATIONAL GROUP	NUMBER WITH DOSES							
	>10 mSv		>15 mSv		>20 mSv		>50 mSv	
Non-coal mining	199	(170)	166	(100)	122	(43)	0	(2)
Industrial radiography	28	(72)	9	(37)	6	(20)	5	(3)
Nuclear fuel	64	(550)	2	(103)	1	(7)	1	(1)
Nuclear power	18	(636)	1	(194)	0	(76)	0	(0)
Nuclear - miscellaneous	2	(18)	2	(3)	0	(0)	0	(0)
General industry	1	(79)	1	(15)	1	(5)	0	(0)
Others	16	(156)	2	(36)	2	(11)	0	(1)
All persons	328	(1681)	183	(488)	132	(162)	6	(7)

*Figure in brackets is for 1990

Table 6 Fatal industrial radiography accidents reported to IAEA

Year	Location	Fatalities	
		Workers	Public
1962	Mexico	-	4
1978	Algeria	-	1
1981	USA	1	-
1994	Morocco	-	8

APPENDIX 1

List of Equipment Uses

The list below is that used in the UK. Ionising Radiations Incident Database (IRID)[23]. For completeness the medical uses have been left in as some of these can be found in research organisations. The code numbers quoted are those that are used in Field 14: Equipment Use, of the database.

MAIN CODES:

01	=	Diagnostic X ray
02	=	Veterinary X ray
03	=	Teletherapy
04	=	Brachytherapy
05	=	Nuclear medicine (therapy and diagnostic)
06	=	Baggage inspection/security
07	=	Gamma radiography site
08	=	Gamma radiography facility
09	=	X-ray radiography site
10	=	X-ray radiography facility (including cabinets)
11	=	Irradiation facilities (X, gamma and electron)
12	=	Thickness gauges
13	=	Level gauges
14	=	Density/moisture gauges
15	=	Analytical equipment
16	=	X-ray optics
17	=	Electron beam equipment
18	=	Unsealed radioactive materials (not covered elsewhere)
19	=	Smoke detectors
20	=	Consumer products
21	=	Static eliminators
22	=	Laboratory/calibration sealed sources
23	=	Yield monitors on agricultural equipment
24	=	Radioactive waste treatment plant
25	=	Environmental tracer work
26	=	Processing of ores and scrap materials
27	=	Other

OPTIONAL CODES:

Diagnostic X ray
01 = Dental intraoral (standard)
02 = Dental OPG
03 = Dental cephalostat
04 = Mobile radiography
05 = Mobile image intensifier
06 = General radiography
07 = Installed image intensifier
08 = Mammography
09 = Computed tomography
10 = X-ray bone mineralisation
11 = Gamma bone mineralisation

Teletherapy
01 = Gamma
02 = Megavoltage
03 = Orthovoltage
04 = Superficial voltage
05 = Electron
06 = Neutron
07 = Therapy simulator

Brachytherapy
01 = Interstitial implants
02 = Applicators
03 = Remote after loading
04 = Intercavity implants

Nuclear medicine
01 = Therapy
02 = Diagnostic

Baggage inspection/security
01 = X-ray cabinet (batch)
02 = X-ray cabinet (conveyor)
03 = X-ray portable
04 = Explosives detector (^{63}Ni)
05 = Explosives detector (Neutron)

Gamma radiography site
01 = Torch container
02 = Shutter container
03 = Projection container

Gamma radiography facility
01 = Torch container
02 = Shutter container
03 = Portable projection container
04 = Installed projection container (mechanical drive)
05 = Installed projection container (electrical drive)
06 = Installed projection container (pneumatic drive)

Irradiation facilities
01 = Laboratory/research (inaccessible gamma) [IAEA Cat I]
02 = Industrial air cooled (restricted access gamma) [IAEA Cat II]
03 = Industrial water cooled (inaccessible gamma) [IAEA Cat III]
04 = Industrial water cooled (restricted access gamma) [IAEA Cat IV]
05 = Laboratory/research (inaccessible electron beam) [IAEA Cat I]
06 = Industrial (restricted access electron beam) [IAEA Cat II]

Thickness gauges
01 = Gamma thickness
02 = Beta thickness – transmission
03 = Beta thickness – backscatter

Level gauges
01 = Gamma hopper
02 = Gamma packaging
03 = Gamma portable
04 = X-ray packaging

Density/moisture gauges
01 = Neutron density (construction)
02 = Gamma density
03 = Beta density
04 = Gamma moisture
05 = Neutron moisture

Analytical equipment
01 = Gas chromatograph
02 = Leakmeter
03 = Static meter
04 = Dewpoint meter
05 = Betascope
06 = Sediograph

X-ray optics
01 = Spectrometer
02 = Crystallography

Unsealed materials
01 = Laboratory studies (eg tracer)
02 = Industrial studies (eg tracer)
03 = Isotope production
04 = Low Specific Activity materials

Electron beam equipment
01 = Electron microscope
02 = Electron beam welding
03 = Ion implantation