The Success of the ALARA Principle – the View of an Inspector

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Introduction and Content

In the Recommendations of the International Commission on Radiological Protection, ICRP, Publication 26 [1], which were adopted in January 1977 and published the same year; the principle of optimisation (ALARA principle) represented a transition from limitation of individual doses alone to reducing doses to an optimum level. In ICRP's 1991 recommendations, ICRP 60 [2], the optimisation principle was further expanded so that also the likelihood of being exposed should be considered during optimisation.

In this presentation we offer our personal views on the application of the ALARA principle within the Swedish nuclear industry. We will outline some positive effects of the application of the ALARA principle, including work procedures, job satisfaction and the quality of the performed work.

The SSI inspection of ALARA and the nuclear industry's self-assessment is reviewed. Indicators of good dose reduction work and present inspection concerns are shortly described.

We will finally summarise by an attempt to see what can influence and change the future ALARA work. It is noted that in new draft ICRP recommendations [3] the principle of optimisation is under review. Planned power upgrades and increased staff turnover at the nuclear facilities are other factors, which could be of importance.

Optimisation and ALARA

Although the ICRP introduced the optimisation principle already in the 50's and in consecutive publications formulated this as "the lowest possible level" 1954, "as low as practicable" 1959, "as low as readily achievable" 1966, the major step forward and the origin of the acronym ALARA came with the clear formulation of the basic principles in radiation protection from the basic recommendations ICRP 26 [1]:

a) '*No practice shall be adopted unless its introduction produces a net benefit;*
b) *All exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account; and*
c) *The dose equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances by the Commission.*'

A further refinement of the optimisation principle was taken in ICRP 60 [2] when this was formulated as:

> '*In relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where*

these are not certain to be received should all be kept as low as reasonably achievable, economic and social factors being taken into account. This procedure should be constrained by restrictions on the doses to the individuals (dose constraints), or to the risks to individuals in the case of potential exposures (risk constraints), so as to limit the inequity likely to result from the inherent economic and social judgements. (The optimisation of protection)

The subdivision of the earlier "*all exposures*" into "*the magnitude of individual doses, the number of people exposed"* accounts for the individual detriment and the societal detriment - Even if the individual doses are lowered, an increase in the number of people that are exposed could outweigh the lowered individual doses and increase the detriment – all as a consequence of the linear, non-threshold assumptions for the dose-response curve for low LET radiation. It was also recognised and underlined that the risk for exposure should be accounted for in the optimisation process. The optimum choice might not be the one connected with the lowest projected dose – it could be the one with the lowest projected risk for achieving radiation dose!

In fact, in major epidemiological studies (such as LSS [4] and others [5]), it is the collective harm or detriment that can be estimated. The individual detriment (risk) is more elusive and must be derived on the basis of such "collective detriment estimates". Bluntly put, it is the collective dose and the collective detriment we estimate first –dose-response curves for "average" individuals are at least secondary quantities.

There has lately been a tendency to focus more on the individual and less on the collective. This is a reflection of the egocentric development in the society and changes in value judgements. In the peak of the 'cost-benefit analysis period', in the 80's and beginning of the 90's, it was popular to exemplify how optimisation could be achieved by analysing different options and comparing those with an α-value, related to the willingness to pay for an averted dose. In such comparisons, the minimum α-value chosen should at least cover the cost of medical care and loss of production capacity. In the Nordic countries this was estimated to about 33,000 US$ per averted mansievert in 1991 [6]. In the same statement an upper α-value of 100,000 US$/manSv was advocated. In the Swedish nuclear industry, a monetary value of 4,5 million SEK/manSv is presently used (2005) which equals about 600, 000 US$/manSv.

The implementation of ALARA – some issues noted

The willingness to reduce radiation doses and ALARA work has been performed at the Swedish nuclear facilities since the 70's/80's. Several good and practical advices about planning work, performing work and follow-up of work is found in the literature. From the very start of these activities, the work had a technical (water chemistry, reduction of Co-60, mock-ups, robotics, etc.) and an administrative side (education, planning, follow up, exchange of information). An example of this is found in [7] where 47 technical actions to reduce radiation doses at the Swedish PWR nuclear power station Ringhals 2 during the years 1975 – 1984 are listed. In the same documents lists of points to consider during pre-planning, dose projection work, and the planning and execution phase are given.

The practical ALARA work was greatly facilitated with the introduction of electronic dosemeters with direct read-out of dose and pre-set alarm levels. Now each worker had access to and ability to watch over his own radiation dose in a readily fashion. It both motivated the work staff and transformed the abstract radiation dose into a real, tangible phenomenon. It also gave the health physicists' and team-leaders the ability to continuously follow-up and control occupational doses.

The SSI introduced new regulations; requiring improved radiation protection education and a more formalised structure of the ALARA work in 1994 [8]. At the same time the annual individual dose limit for workers of a maximum effective radiation dose of 50 mSv in a year was complemented (on the basis of the recommendation from ICRP 60) with the additional individual dose limit of a maximum effective radiation dose of 100 mSv in 5 consecutive years. These new regulations were introduced in the beginning of the 90's since there was a trend of year-by-year increasing radiation doses at most of the Swedish BWR reactors.

The effect of these changes, coupled together with research and investment efforts by the nuclear industry paid off in the years to come with both decreasing radiation levels and reduced collective radiation doses [9]. The average collective radiation dose at the Swedish nuclear power plants in the last five year period (2001-2005) was 9,2 ± 1,3 manSv and the average number of workers with an individual dose exceeding 20 mSv was 4,6 ± 2,4. The average individual dose (to persons with recorded doses) was 2,3 ± 0,2 mSv. These mean values can be put in perspective by recognizing that in the year 1993 (although with twelve operating units instead of the present ten) the collective dose was 28 manSv and more than 200 persons received doses above 20 mSv.

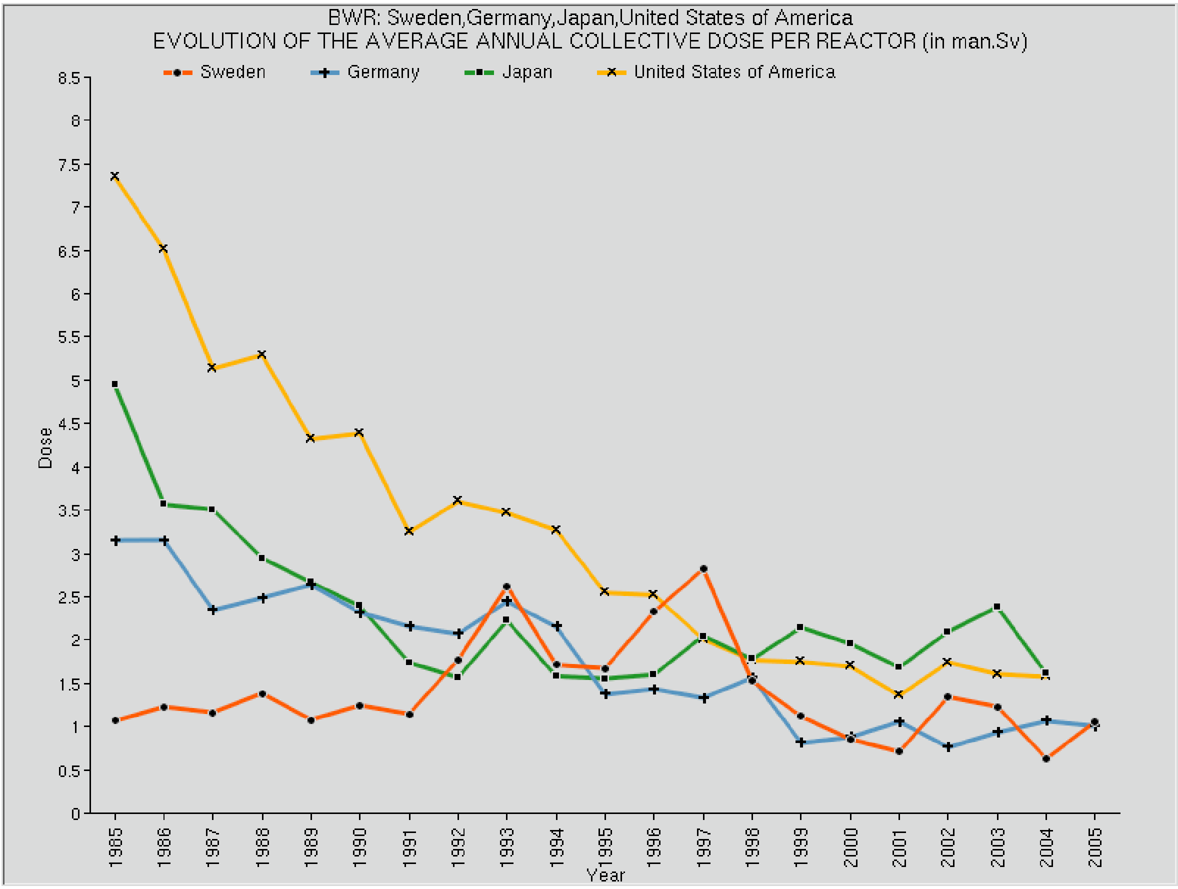

Figure 1: Evaluation of the average annual collective dose per BWR reactor in mansievert (manSv) in Sweden, Germany, Japan and the United States of America (Source: ISOE data base 2006).

In 1990 a good overview of the importance of the ALARA work in the nuclear industry and the achieved results was presented by the OECD/NEA in ref. [10]. An overview of the situation and the trends of collective and average individual doses in the NEA member states were presented. Especially for BWR, but also for PWR, a decreasing trend of the collective doses was observed. The major elements of occupational dose control management were identified (control of sources, control of exposure duration, nuclear safety requirements, and ALARA programmes). Focus was put on learning from experiences and benchmarking. A shift from monitoring and control to management of doses was stressed and comparison with a formal management system was made (objectives, measurements of performance, comparisons, identification of causes, implementation of corrective actions, follow-up, new objectives etc…). This approach has also been called the approach of '*a learning organisation*' and the SSI has advocated this idea in the implementation of its requirements of ALARA-programmes at Swedish nuclear facilities.

Figure 1 displays a comparison of the average collective dose per reactor for boiling water reactors (BWRs) in Sweden, Germany, Japan and the US – the four countries with most operating BWR reactors. The data is taken from the ISOE system [11], a database and information exchange system for occupational exposure data at nuclear power plants. It was started in the year 1992 by the OECD/NEA and is now also supported by the IAEA. It is a helpful tool for exchange of information for the operators and is also useful for authorities for benchmarking and illustrative purposes.

The increase of the average annual collective dose per reactor in Sweden during the beginning of the 90's was due to three main different effects. Firstly, requirements for increased non-destructive testing were implemented and this lead to major repair and substitute work (change of piping and other system parts) in areas of the reactor were earlier less outage work had been done. As exemplified in Figure 2, little attention had earlier been given to the fact that in some of these areas the radiation levels had continued to increase from the start-up years of the reactors. Source-term reduction and optimising water chemistry in order to reduce radiation levels became a prime objective in many of the Swedish boiling water reactors.

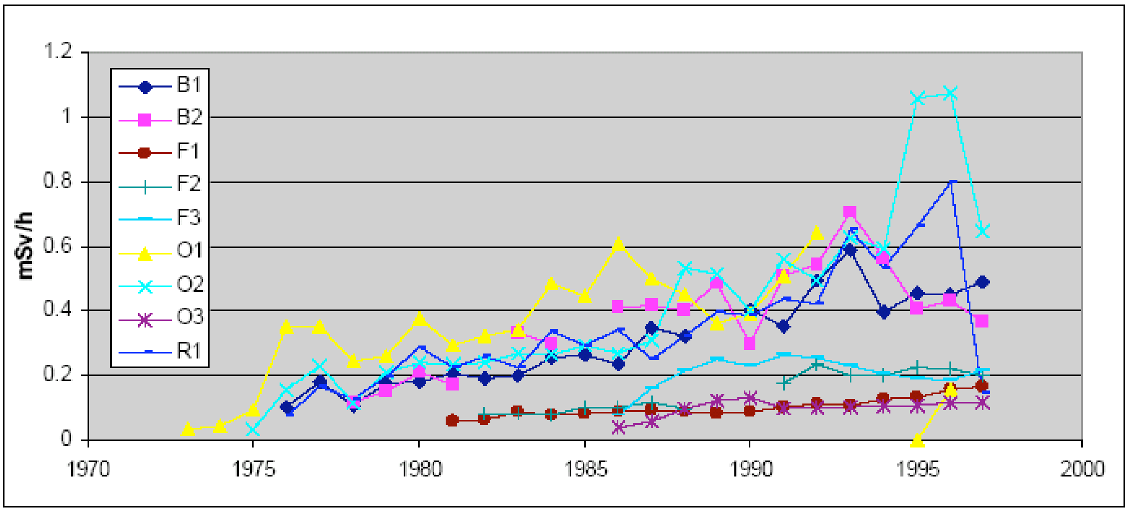

Figure 2: Recorded radiation levels (mSv/h) near cooling systems at Swedish Boiling Water Reactors between 1973- 1997.

Secondly, in pursue of prolonging the lifetime of the oldest boiling water reactors (the Swedish law does not allow the construction of new nuclear reactors) large refurbishment projects at some of the oldest reactors (e.g. Oskarshamn 1, Ringhals 1) were carried out. And thirdly, due to safety reasons, a large amount of insulation material was changed to 'metal insulation' during the years 1992-1993. These activities were required following an incident with clogged strainers in the water inlet of safety injection system at the now closed reactor Barsebäck 1 in August 1992. It is estimated that the incurred collective dose for the effort totalled 7 mansievert at the five oldest boiling water reactors.

Note the 'memory effects' – actions taken that increase or decrease radiation levels at the nuclear power stations usually are visible during the years to come – the effects are usually not immediate but show up in the future. Also, the major effect of the ALARA-actions taken by the Swedish nuclear industry, partly due to the regulatory requirements by the SSI and it's endorsement of active work with water chemistry and Stellite reduction, cannot be seen in Figure 1 – these doses are averted doses! [12]

Social aspects of the implementation of the ALARA-principle

In many cases, the success of the implementation of the ALARA-principle is measured by data on decreasing radiation doses, both collective as well as individual. This is of course an appropriate method since the effective dose, as 'estimated' by recording personal dosemeters, are measures of the detriment of the ionising radiation. There are however other mechanisms that directly and indirectly contributes to reduction of doses, which cannot be illustrated merely by graphs and figures. We would like to highlight a few of these.

As mentioned above, the averted doses during operation of the Swedish reactors cannot be seen in Figure 1, only the received dose is visible. If the efforts to reduce doses had not been implemented, how much higher would the doses have been? On this we can only speculate but it was clear both to the SSI and to the reactor owners that a continued increase of the radiation doses would not have been acceptable by the society. The required increased safety measurements were thus complemented by a commitment to ALARA at the top management of the utilities. This was underlined by the inclusion of radiation protection objectives in the top management steering programmes at the utilities. In the 90's the importance was also stressed by high-level management staff presence at the SSI-inspections and by firm support to the reduction of radiation levels and radiation doses in internal and external communications. Furthermore, the Swedish Nuclear Power Inspectorate, the SKI, underlined the importance of improved radiation conditions at the stations as an important factor in the safety work – lower radiation levels and improved working conditions would lead to enhanced safety (improved non-destructive testing and inspection conditions). A determined effort to reduce radiation doses was started and an unambiguous message was sent to the involved personnel.

To care not only about your own radiation dose but also the doses to others is a compassionate and social behaviour. The efforts made to decrease radiation levels, improve work preparation, work activities and the communication between working teams created a better understanding among all involved parties of mechanisms that could lead to improved conditions. Staff with different tasks and competence co-operated in preparatory work for outages and refurbishment activities. Ideas and solutions were identified by this multidisciplinary approach which otherwise could not have been found. Collaboration and co-operation between persons that earlier was not self-evident was established.

It is a fairly obvious statement that work quality and work efficiency benefit from well-being and pleasure in one's work. We are convinced that this was the case for many health physicists, both permanently employed and contractors, during these very active years. By having common objectives, taking part in the early work planning, and by carrying out activities, which felt meaningful and appreciated by others the general contentment, as testified to us in several cases, increased. This was also true for other specialists, such as chemists and engineers who worked with issues like source term reduction, mock-up facilities and improved tools. Some of this work is still carried out.

Some health physicists took part in new, dedicated education programmes. In 1994 the SSI required improved radiation protection education of the staff at the power plants. This resulted in collaboration between utility personnel and resulted in the creation of instruction and training programmes, course material and common tests. This work continues and presently the use of computers and access to information material via the web is in focus. Some of the national courses for health physicist at nuclear power plants have also been reconstructed in order to meet today's requirements and the existing work conditions. The SSI is presently reviewing the existing conditions and considers reformulating the existing requirements in order to further underline the importance of good teaching and personal contact with stimulating instructors for personnel that is new to the working conditions at nuclear facilities.

At the Swedish power plants, contractors have since many years back complemented the permanent staff during outage periods. In fact, they receive the major fraction of the collective dose. The collaboration between the utility staff and the contractors is not always optimal. Usually the differences in work culture and opinions, after initial difficulties in co-operating and even after radiation incidents, are resolved and work conditions bettered. In some cases however, individuals have been dismissed or sent home when common protection requirements were repeatedly ignored. In most cases however, the co-operations between contractors and utility staff work very well. We sometimes ask contractors and foreign personnel how they are being received at the Swedish utilities and in most cases we only are given positive accounts.

The SSI-efforts: promotion and control of self-assessment

In general, the SSI inspections focus on the licensee organisation, administrative routines, co-ordination within the organisation, division of responsibilities and competence. The aim of system inspections is to obtain good knowledge of the management system of the licensee. A vital ingredient in the control and follow-up of the ALARA process is the self-assessment of the operator. In the regulations SSI FS 2000:10 the SSI requires annual reports detailing the licensee's evaluation and follow-up of their activities, objectives and work. Considerations should be put on the reduction of radiation doses on both short-term as well as long-term. In the year 2002 the SSI performed special thematic inspections at all Swedish nuclear facilities. Major organisational changes at the facilities had occurred or were implemented and the SSI feared that this would negatively impact the quality of the radiation protection work. The general conclusion from the inspections was that the facilities either fulfilled or had the opportunity to fulfil the regulatory requirements in this area.

Good "ALARA indicators" are much sought after by operators and authorities alike. It is of course evident that trends in dose and dose rates, number of exposed persons, the distribution of individual doses etc. are valuable data in the evaluation process. The available resources within the ALARA process, in means and appointed persons, are other countable quantities. Since the work performed during any single year can vary considerably at any specific reactor these figures alone does not suffice. New safety requirements and identified weaknesses in the defence-in-depth system of the reactors have often necessitated reconstruction work at controlled areas. The SSI thinks that less well quantifiable quantities such as management commitment, willingness to participate in the ALARA process, shared common values, individual ideas and manifestations – in short the "work culture" at the facility, are/is equally important. The SSI promotes visible and proactive safety and radiation protection work at all levels of the facility organisation – endorsed and led by the top management.

Since a few years, the SSI has increased the systematic control of the every day radiation protection issues. In the wake of the efforts to reduce dose rates and the 'ALARA-activities' of the 90's, a little less attention was given to some of the 'bread and butter' issues. In the period 2001 – 2005 more attention has been given to dosimetry issues, measurement equipment, arrangement of and passage in-and-out of controlled areas, whole-body measurements, internal transports, etc.

It is important to have frequent visits at the plants and contacts with the licensees and their staffs. The visibility of the SSI inspectors during outage periods and at different meeting, apart from filling the operational duties of the inspections, sends a message of presence, continuity and interest to the personnel. During a walk-through at the facility, there is usually some possibility, albeit not in high dose rate areas, to talk with workers and get their impression of on-going activities and radiation protection issues. These contacts are valuable for the SSI inspectors and form one important part of our evaluation and supervision work.

The information flow and feedback from the everyday work is important. If errors are detected or mistakes are made these should be immediately reported and actions should be taken to rectify errors and re-establish normal conditions. The lessons learned should be reported within the organisation and sometimes, depending on the type and scope of the incident/observation to outside interested parties. In order for this "flow of information" to work it is important that the facility management, as well as the national supervision authorities, are careful with punishments and does not apply a penalizing attitude. It should be seen as positive when identified errors and incorrect actions are promptly reported so that corrections can be made.

There is however unfortunately at present a trend in the society for less carrot and more stick – something that must be opposed. The increased influence of the media world and the swift and pronounced 'hunt for news' dulls the intellect and official organisations and bodies seem to think that they have to be seen as determined and able to take quick and resolute actions – something that could result in rash actions and chastising rather than dialogue and an open attitude. In the prolongation this could furthermore lead to that errors are not reported and that the vital information for the continued safety work will be missing [13].

An Outlook

The ICRP are presently in the process of establishing new fundamental recommendations to replace the ICRP Publication 60 [2]. In the present draft [3], available for comments on the ICRP home page, it is noted by the ICRP that among the major features are:

> *'Maintaining the Commission's three fundamental principles of radiological protection, namely justification, optimisation and dose limitation, and clarifying how they apply to radiation sources delivering exposure and to individuals receiving exposure. This includes establishing source-related principles that apply to all controllable exposure situations, which the revised recommendations now characterise as planned, emergency and existing exposure situations;*

Furthermore, and the header Optimisation of Protection it is declared:

> *(192) The principle of optimisation of protection and constraints is central to the system of protection applying to all three exposure situations: planned situations, emergency situations and existing exposure situations. This principle has been applied very successfully in planned situations (specifically practices) where protective actions can be initiated at the design stage. The Commission's intention is to extend this experience to the other two types of exposure situations. (193) The principle of optimisation is defined by the Commission as the source related process to keep the magnitude of individual doses, the number of people exposed and the likelihood of occurring exposure where these are not certain to be received, as low as reasonably*

achievable below the appropriate dose constraints, economic and societal factors being taken into account.

From this draft text we make the preliminary conclusion that the new ICRP recommendations will not in any drastic way change the foundation on which the present 'optimisation work' at nuclear facilities is carried out. This is, in our view, a most welcome conservatism: Do not change when change is not warranted.

At present, the owners and licensees of many of the Swedish nuclear power plants are planning power up rates. The permission to increase the thermal power is given by the Swedish Government. If approved, the power up rates will increase the installed thermal power from Swedish NPP with about 2,5 GW and the electrical power with about 1,1 GW. The power up rates will be accomplished by increasing the thermal power and by modernization of the turbine/generator system. In this process, it is the task of the SSI to ensure itself that the present radiological conditions of the power plants are not unduly negatively impacted by the planned power up rates.

The SSI has contracted an Austrian/Swedish consortium to investigate the radiological consequences of worldwide power up rates at light water reactors. Changes in a nuclear power plant due to the power up rates that have affected occupational doses or otherwise were important for the exposure situation will be discussed. Specifically, the radiological situation before and after up rates will be analysed. The information gained from the investigation will first be used as background and reference material in the review process of the applications, thereafter in the survey of the power up rates themselves and finally in the assessment of the after effects of the up rates.

The SSI anticipates a continued use of contractors and external personnel at the Swedish nuclear power plants. It is however important that in the process of replacing retired persons and existing vacancies that the quality and competence of the personnel is not lowered. There is in today a trend that people change their job more often than before and experience is not always possible to attain quicker than before…There is a risk that temporary, less educated or experienced personnel will be entrusted with tasks that earlier was carried out by 'old hands' if not a fairly constant supply or work opportunities is available to the contractors and the external firms. To some extent this could be counteracted by in sourcing of key competence and that the nuclear facilities somehow supports an external "competence buffer". These issues are however outside of the regulatory scope of the Swedish Radiation Protection Authority as long as the radiation protection regulations are obeyed and the radiation doses are kept as low as reasonably achievable, economic and societal factors being taken into account.

References

[1] ICRP Publication 26. *Recommendations of the International Commission on Radiological Protection*, Pergamon Press, Oxford, Annals of the ICRP **1**(3) 1977.
[2] ICRP Publication 60. *1990 Recommendations of the International Commission on Radiological Protection,* Pergamon Press, Oxford, Annals of the ICRP **21**(1-3) 1991.
[3] ICRP *Draft Recommendations of the International Commission on Radiological Protection*, 02/276/06 – 5 June 2006. Available for comments at: www.icrp.org.
[4] Preston D.L., Shimizu Y., Pierce D.A., Suyama A., Mabuchi K., 'Studies of mortality of atomic bomb survivors. Report 13: Solid cancer and non-cancer disease mortality: 1950-1997', RERF Report No. 24-02, *Radiation Research,* 160(4): 381-407, 2003
[5] Cardis, E. et al. (51 co-authors), 'Risk of cancer after low doses of ionizing radiation: retrospective cohort study in 15 countries*', BMJ*, doi:10.1136/bmj.38499.599861.E0, 29 June 2005
[6] 'The monetary value of collective dose reduction (α-value)*',* Statement from the meeting on Nordic Radiation Protection Authorities (Denmark, Finland, Iceland, Norway and Sweden) at Reykjavik 14 June, 1991, *SSI-report Strålskyddsnytt,* no.4 1991

[7] Erixon O., 'Practical radiation protection' (In Swedish), Compendium & Course literature, Rådet för Kärnkraftsäkerhet, October 1984, Stockholm
[8] Godås T., 'ALARA IN PRACTICE: A Regulatory Perspective from Sweden', *European ALARA Newsletter,* Issue 1, July 1996
[9] Lund I. et al., 'Occupational Radiation Protection at Swedish Nuclear Power Plants: Views on Present Status and Future Challenges', *Proceedings from 4th IOSE European Workshop on Occupational Exposure Management at NPPs*, Lyon, France, 24-26 March 2004.
[10] Viktorsson C., Lochard, J. Benedittini M., Baum J., Khan T.A., 'OCCUPATIONAL DOSE CONTROL in Nuclear Power Plants', *OECD/NEA Report*, Paris, 1990
[11] ISOE-system database is found at www.isoe.net (password-protected database for use of the participating organisation [power plants, authorities])
[12] Malmqvist L. et al. , 'Strålskydd vid svenska kärnkraftverk under perioden 1994-2002, samt reflexioner om kommande utveckling' (In Swedish) *SSI-report 2003:23*, December 2003
[13] Svensson G., 'Punishemnt or learning?' *8th EAN Workshop: Occupational Radiological Protection Control through Inspection and Self-assessment",* Uppsala, Sweden, September 2004