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Radiological Protection in Geological Disposal of Long-Lived Solid Radioactive Waste

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Radiological protection in geological disposal of long-lived solid radioactive waste

ICRP Publication 1XX

Abstract –This report updates and consolidates previous recommendations of ICRP related to solid waste disposal (Publications 46, 77, 81). The recommendations given in this report apply specifically to geological disposal of long-lived solid radioactive waste. The report explains how the 2007 ICRP System of Radiological Protection described in ICRP Publication 103 can be applied in the context of the geological disposal of long-lived solid radioactive waste. The report is written as a self standing document.

The 2007 ICRP System of Radiological Protection maintains the Commission's three fundamental principles of radiological protection namely justification, optimisation, and the application of dose limits. The Recommendations evolve from the previous process-based protection approach using practices and interventions by moving to an approach based on the exposure situation. They maintain the Commission's current individual dose limits for effective dose and equivalent dose from all regulated sources in planned exposure situations. They re-enforce the principle of the optimisation of radiological protection. The Recommendations also include an approach for developing a framework to demonstrate radiological protection of the environment.

This report describes the different stages in the lifetime of a geological disposal facility and addresses the application of relevant radiological protection principles for each stage depending on the various exposure situations that can be encountered. In particular, the crucial factor that influences the application of the protection system over the different phases in the lifetime of a disposal facility is the level of oversight that is present. The level of oversight affects the capability to reduce or avoid exposures. Three main timeframes have to be considered for the purpose of radiological protection: time of direct oversight when the disposal facility is being implemented and active oversight is taking place; time of indirect oversight when the disposal facility is sealed and indirect oversight is being exercised to provide additional assurance on behalf of the society; time of no oversight when oversight is no longer exercised because memory is lost.

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Preface

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On February 12, 2010, the Main Commission of the International Commission on Radiological Protection (ICRP) approved the formation of a new Task Group, reporting to Committee 4, to develop a report which describes in plain language how the recommendations given in ICRP Publication 103 can be applied in the context of the geological disposal of long-lived solid radioactive waste. The report covers both the protection of humans (workers and the public) and the environment and discusses key issues like the transition from a planned to an existing exposure situation in case of a loss of control of the waste system as well as the applicability of dose calculated for the far future for decision aiding. The report updates ICRP Publication 81.

The report provides guidance on:

- the basic concepts and terms, eg. the radiation protection principles, the different types of situations (including human actions), dose and risk constraints;
- the nature and role of optimization (stepwise approach, short term vs. long term, best available technology);
- the use and application of dosimetric units and concepts (dose and risk constraints, potential exposures, collective dose, different time frames);
- the role of stakeholder involvement in different stages of planning and development.

The membership of the Task Group was as follows:

W. Weiss (Chair)	C.-M. Larsson	Chr. McKenney
J.-P. Minon	S. Mobbs	T. Schneider
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The corresponding members were:

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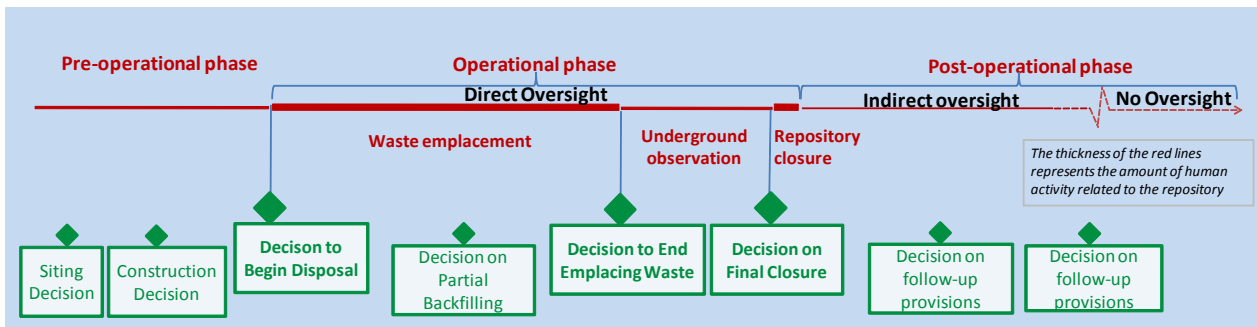
The Task Group wishes to thank those organizations and staff that made facilities and support available for its meetings. These include BfS, ARPANSA, NRC, NIRAS, HPA, CEPN, JAEA, EC, OECD/NEA, IAEA.

The report was approved by the Commission in XX in 2011.

164 **Executive summary**

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(a) This report provides advice on the application of the Commission’s 2007 Recommendations (ICRP Publication 103) for the protection of humans and the environment against any harm that may result from the geological disposal of long-lived solid radioactive waste. It illustrates how the key protection concepts and principles of ICRP Publication 103 are to be interpreted and how they apply over the different timeframes over which a geological disposal facility for long-lived solid radioactive waste would have to provide radiological protection (see Figure).



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(b) The goal of a geological disposal facility is to isolate and contain the waste in order to protect humans and the environment for time scales that are comparable with geological time scales. At great distance from the surface, changes are particularly slow. With distance from the surface, and having chosen appropriate sites the potential for human intrusion will be limited. Radioactivity will decrease with time, and any release would be slowed down and diluted further by a properly chosen geological formation. Geological disposal is recognized by the international organisations as especially intended for high level radioactive waste or spent fuel where long term isolation and containment is required. Geological disposal may also be used for other long-lived wastes since a similar need for long term protection applies.

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(c) The design of a geological disposal facility addresses a series of developments with different probabilities that may be defined by regulation. Besides these design-basis developments, the developer / implementer and the regulator may want to assess evolutions in non-design-basis conditions in order to judge the robustness of the system.

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(d) These ICRP recommendations describe the radiological concepts and criteria that ought to be used by both the designer and/or operator of the facility and the regulator. For the assessment of the safety and radiological protection of a geological disposal facility for long-lived radioactive waste various dose and risk constraints are used. Optimisation deals with the main aim of a disposal system, i.e., the radiological protection of humans and the environment. Optimisation of protection is the central element of the step-wise construction and implementation of a geological disposal facility. It has to cover all elements of the system, including the societal component, in an integrated way. Important aspects of optimisation of protection must occur prior to waste emplacement, largely during the siting and design phase. The optimisation efforts can be informed by, and construction supplemented with, consideration of best available technique (BAT) as applied to all stages of disposal facility siting and

206 design. During the implementation phase, some further optimisation is possible but
207 very little can be done to further optimise the performance of the engineered features
208 after waste emplacement has occurred. In the long term optimisation of protection
209 can only be achieved if oversight is maintained.
210

211 (e) In the distant future the geological disposal facility might give rise to some
212 releases to the accessible environment and the “safety case” has to demonstrate that
213 such releases, should they occur, are compatible with regulation and radiological
214 protection criteria. In application of the optimisation principle, the reference
215 radiological impact criterion for the design of a waste disposal facility recommended
216 by ICRP is an annual dose constraint for the population of 0.3 mSv in a year [ICRP
217 103], without any weighting of doses in the far future. For less likely events resulting
218 in potential exposures, the Commission continues to recommend a risk¹ constraint for
219 the population of $1 \cdot 10^{-5}$ per year. However, ICRP Publication 103 also warns that,
220 given the long timeframes considered in waste disposal, the evolution of society,
221 human habits and characteristics is such that effective dose loses its direct
222 connection to health detriment after the time span of a few generations. At the same
223 time, in the distant future, the geosphere and the engineered system and, even more,
224 the biosphere will evolve in a less predictable way. The scientific basis for dose and
225 risk assessments at very long times into the future then becomes questionable and
226 the strict application of numerical criteria may be inappropriate. Hence, the annual
227 dose constraint of 0.3 mSv in a year is to be used for the sake of comparison of
228 options rather than as means of assessing health detriment.
229

230 (f) In particular, a crucial factor that influences the application of the protection
231 system over the different phases during the lifetime of a geological disposal facility, is
232 the level of oversight that is present. The level of oversight directly affects the
233 capability to reduce or avoid some exposures. Three main timeframes have to be
234 considered: the time of direct oversight when the disposal facility is being
235 implemented and active oversight is taking place (operational phase); the time of
236 indirect oversight when the disposal facility is partly (backfilling and sealing of drifts)
237 or fully sealed (post-closure period) where direct regulatory oversight might be
238 supplemented or replaced by institutional oversight (e.g. restriction of land use) and
239 the time of absence of oversight (post-closure period in distant future) in case
240 memory is lost, although the primary objective is to keep memory of the site.
241

242 (g) The exposures arising from the design basis evolution of the geological disposal
243 facility are planned exposure situations as defined in ICRP Publication 103. They
244 include potential exposures from events with low probability which have to be
245 considered as part of the design basis. If severe disturbing events outside the design
246 basis occur while there is still oversight (direct or indirect) of the disposal facility and
247 which result in doses largely exceeding 0.3 mSv in a year, the ensuing situation will
248 be considered as an emergency exposure situation followed by an existing exposure
249 situation in case this emergency is resulting in a long lasting contamination of the
250 environment. If a severe disturbing event occurs when there is no longer any
251 oversight of the disposal facility, there is no certainty that a competent authority
252 would be able to understand what is the source of the exposure and therefore, it is

¹ Risk is used in this document always to mean **radiological risk** as defined in ICRP Publication 103.

253 not possible to consider with certainty the implementation of relevant
254 countermeasures to control the source. However, there is a need to evaluate the
255 consequences within the scope of an existing exposure situation.
256

257 (h) For the “design basis” evolution, the dosimetric criteria relevant to planned
258 exposure situations will be considered for assessing the safety and robustness of the
259 disposal facility. For a severe disturbing event, the reference level to be considered
260 for emergency exposure situation would apply when relevant (i.e. reference level in
261 the range of 20 to 100 mSv for the first year). It is also necessary to evaluate the
262 possible consequences of the occurrence of such events on the basis of the
263 dosimetric criteria relevant for existing exposure situation as defined by ICRP (i.e.
264 reference level of a few mSv per year).
265

266 (i) The safety case of a geological disposal facility, by including events that are not
267 expected to occur with high certainty, includes automatically considerations on how
268 to deal with potential exposures as defined by ICRP Publication 103 (section 6.1.3).
269

270 (j) ICRP recommends that dose or risk estimates derived from these exposure
271 assessments should not be regarded as direct measures of health effects beyond
272 timescales of around several hundred years into the future. Rather, they represent
273 indicators of the protection afforded by the geological disposal system.
274

275 (k) The application of the three exposure situations and of dose limits, constraints
276 and reference levels as defined in ICRP Publication 103 during these timeframes is
277 indicated in Table 1.
278

279

RADIOLOGICAL EXPOSURE SITUATIONS AS FUNCTION OF DISPOSAL FACILITY EVOLUTION AND PRESENCE AND TYPE OF OVERSIGHT			
Disposal facility Status	Type of Oversight		
	Direct Oversight	Indirect Oversight	No oversight
Design-basis ¹ evolution	Planned Exposure Situation ²	Planned Exposure Situation ²	Planned Exposure Situation ^{2,3}
Non-design basis evolution involving significant exposures to people and the environment	Emergency Exposure Situation at the time of exposure, followed by an Existing Exposure Situation ⁴	Emergency Exposure Situation at the time of exposure, followed by an Existing Exposure Situation ⁴	Emergency and/or Existing Exposure Situation
Inadvertent Human Intrusion	not relevant	not relevant	Emergency and/or Existing Exposure Situation

280 ¹ The design basis is the envelope of both expected and less likely (potential) events that are used in planning the
 281 facility.

282 ² At design: 20 mSv in a year dose limit to worker and dose constraint to be specified by operators; 1 mSv in a
 283 year dose limit and 0.3 mSv in a year dose constraint for the public, in the case of less likely events within the
 284 design basis a risk constraint of $1 \cdot 10^{-5}$ per year for the public is suggested.

285 ³ No worker dose is foreseen during the period of no oversight

286 ⁴ For an emergency exposure situation a reference level between 20 and 100 mSv per year is recommended; for
 287 an existing exposure situation a reference level should be selected in the lower part of the band between 1
 288 and 20 mSv per year, eg., in the range of a few mSv per year.
 289

290 1. Introduction

291
292 (1) In the context of the Commission's recommendations, waste is any material for
293 which no further use is foreseen. Waste, as generated, includes liquid and gaseous
294 effluents as well as solid materials. Waste storage is the temporary retention of
295 waste. Waste disposal is the permanent isolation and containment of waste in an
296 appropriate facility. Waste management means the whole sequence of operations
297 starting with the generation of waste and ending with disposal.

298
299 (2) This report deals with geological disposal of long-lived solid radioactive waste
300 which is intended to isolate and contain especially high level waste, spent fuel and
301 intermediate level wastes containing radionuclides with long half lives. These are
302 concentrated wastes which contain high specific activities; they need to be handled
303 remotely, for hundreds or thousands of years. The report does not address near
304 surface disposal facilities because they differ from geologic disposal facilities in two
305 key aspects: the isolation and containment function and the waste for which they are
306 intended.

307
308 (3) Technical solutions for the permanent isolation of long-lived, solid radioactive
309 waste at distances from the surface of hundreds of metres in geological formations
310 are being developed and pursued in a number of countries. Geological disposal is
311 currently recognized by international organisations in charge of radioactive waste
312 management as especially suited for high level radioactive waste or spent fuel where
313 long term containment is required. Geological disposal may also be used for other
314 wastes containing long lived radionuclides since similar long-term protection
315 requirements can be formulated. An example of geological disposal is the
316 emplacement of waste in excavated tunnels or shafts, followed by backfilling and
317 sealing of the entire facility.

318
319 (4) The goal of a geological disposal facility is to achieve the isolation and
320 containment of the waste and to protect humans and the environment for time scales
321 that are comparable with geological changes. At great distance from the surface,
322 such changes are particularly slow and, at the same time, radioactivity will decrease
323 with time. Additionally, if a site is chosen in an area with no known natural resources,
324 the potential for human intrusion will be limited. Finally, a properly chosen geological
325 formation would assure stable chemical conditions for the waste. Further, it would
326 attenuate and slow down any releases of radionuclides. In this context 'distance' can
327 imply horizontal or vertical distance as, for example the case of a disposal facility
328 sited deep within a mountain.

329
330 (5) The safety strategy implemented for geological disposal is that to concentrate and
331 retain the waste. No exposure is ever intended, although these may happen. The
332 disposal facility is thus to be seen as a functional facility whose controls are in-built
333 and whose safety, after facility closure, does not rely on the presence of man. The
334 safety function to be fulfilled by a geological disposal facility independent of man is to
335 isolate and contain the waste over as long a period of time as possible. This will allow
336 radioactive decay to take place and attenuate and delay the eventual release of any
337 contaminants to the accessible environment. Furthermore, it will reduce the risk of
338 inadvertent human intrusion. In the situation of a human intrusion the health

339 consequences for the intruder might be high. But this is an inescapable consequence
340 of the decision to concentrate waste in a disposal facility.

341
342 (6) Geological disposal of long-lived solid radioactive waste poses a number of
343 challenges related to radiological protection over extended periods of time, e.g. the
344 nature and role of optimization of protection during the various phases of the
345 development and implementation of the disposal facility and the applicability of dose
346 and risk calculated for the far future for decision aiding. The report explains how the
347 protection principles as laid out in ICRP Publication 103 can be applied under these
348 circumstances. It also considers elements that can assist in demonstration of
349 compliance with the protection principles and how the principles, in broad terms,
350 relate to other protective goals that would be considered in an environmental impact
351 assessment/statement.

352
353 (7) Radiological protection is only one set of the protection concepts that will be used
354 by safety analysts in documenting the protection capability of the disposal facility.
355 Other concepts may relate to the protection of resources in a sustainable way such
356 as for example groundwater as a drinking water resource. The chemical toxicity of
357 the waste or the waste containment system in a disposal facility for radioactive waste
358 may be a further issue of concern. Optimal protection would be achieved by the
359 application of an integrated framework of protection concepts in which the level of
360 protection of humans, the environment and the resources are comparable for
361 radiotoxic and chemotoxic substances.

362
363 (8) The Commission has previously published protection recommendations for the
364 disposal of long-lived radioactive waste (ICRP Publications 46, 77, 81) consistent
365 with its general recommendations for the application of its overall System of
366 Radiological Protection (ICRP Publication 60). More recently, the Commission has
367 published new general recommendations (ICRP Publication 103). This report
368 summarizes and explains how these recommendations specifically apply to a
369 geological disposal facility for long-lived solid radioactive waste.

370
371 (9) This report is written as a stand-alone presentation of the Commission's
372 Publication 103 system of radiological protection as it should be applied in the
373 context of geological disposal of long-lived radioactive waste. It covers all issues
374 related to radiological protection of humans and the environment against harm that
375 may result from the geological disposal of long-lived solid radioactive waste. Where
376 the Commission's recommendations are unchanged, or issues are addressed
377 sufficiently in publications by other international organisations, references are given
378 and no detailed discussion is provided.

379
380 (10) In the case of geological disposal, the occupational exposure of workers and the
381 exposure of the public are managed in accordance with the ICRP system of
382 protection. The main protection issue dealt with in this report concerns exposures
383 that may or may not occur in the far future. Any corresponding estimates of doses to
384 individuals and populations will have growing associated uncertainties as a function
385 of time due to incomplete knowledge of the future disposal system behaviour, of
386 geological and biospheric conditions, and of human habits and characteristics.
387 Furthermore, due to the long timescales, verification that protection is being achieved

388 cannot be expected in the same manner as for current discharges since knowledge
389 of the disposal facility may eventually be lost and oversight may be absent. Neither
390 can it be assumed that effective mitigation measures will necessarily be carried out,
391 should they be required in the far future. Nevertheless, the Commission's system of
392 protection can be applied to the disposal of long lived solid radioactive waste, with
393 due interpretation.

394

395 **1.1 References**

396

397 ICRP (1985) Protection Principles for the Disposal of Solid Radioactive Waste. ICRP
398 Publication 46, Annals of the ICRP 15 (4).

399 ICRP (1991) 1990 Recommendations of the International Commission on
400 Radiological Protection. ICRP Publication 60, Annals of the ICRP 21 (1–3).

401 ICRP (1997) Radiological Protection Policy for the Disposal of Radioactive Waste.
402 ICRP Publication 77, Annals of the ICRP 27 Supplement 1997.

403 ICRP (1998) protection recommendations as applied to the disposal of long-lived
404 solid radioactive waste. ICRP Publication 81, Annals of the ICRP 28 (4).

405 ICRP (2007). The 2007 Recommendations of the International Commission on
406 Radiological Protection. ICRP Publication 103, Annals of the ICRP 37 (2–4).

407

408 **2. Scope of this report**

409

410 (11) This report deals with the radiological protection of workers, members of the
411 public and the environment, following the disposal of long-lived solid radioactive
412 waste in geological disposal facilities. The recommendations given in this report
413 apply to disposal facilities where there is still an opportunity for their implementation
414 during the site selection, design, construction, and operational phases. They should
415 also be taken into account in the justification of decisions involving practices
416 generating waste.

417

418 (12) The report does not describe the disposal safety assessment in detail. It rather
419 provides a description of how protection criteria can be used in the safety analysis,
420 and establishes recommendations on protection issues related to the disposal of
421 long-lived solid radioactive waste. Exposures are estimated in order to place
422 adequate control on the source of exposure. The characteristics and habits of
423 exposed individuals and populations are taken into account.

424

425 (13) The report does not address near surface facilities because they differ from
426 geological facilities with respect to the isolation function and the waste for which they
427 are intended. Near surface facilities principally rely on the engineering containment
428 provided by the facility and on the presence of man. The long term stability of the
429 surrounding soil or rock and its attenuation properties are of secondary importance.
430 Also, they are by definition more easily accessible and hence a near surface facility
431 can only provide short term isolation of the waste. Near surface facilities are suitable
432 for low and intermediate level wastes containing predominantly shorter lived and less
433 concentrated levels of radionuclides. The differences in the functions of near surface
434 facilities and geological facilities, together with the different wastes they receive,
435 result in the application of specific regulatory regimes: one for near surface disposal
436 and one for geological disposal. Previous ICRP recommendations for the radiological



437 protection of workers, members of the public and the environment in the case of near
438 surface disposal facilities or other disposal options are still valid.
439
440

441 **3. Basic values and goals underlying protection for a geological disposal of**
442 **radioactive waste**

443
444 **3.1 Values underlying the ICRP principles for protecting future generations**

445
446 **3.1.1 Basic values for the protection of future generations**

447
448 (14) The initial composition of radionuclides contained into long lived radioactive
449 waste evolves over time, changing the nature of the hazard. At the same time, even
450 though the activity decreases with time, the halflife of some radionuclides, and the
451 rate of ingrowth of others, are such that some of these wastes may never be
452 considered as not being a hazard.

453
454 (15) Over the last decade, reflections on safety and societal issues associated with
455 this long-term dimension clearly point out the complexity of the situation: on one hand
456 it is not possible to envisage how the society will be organized in the far future while
457 on the other hand the current generation has to take care of the possible future in
458 order to design the waste management strategy. This is notably the core of the
459 ethical reflections regarding the precautionary principle and sustainable
460 development, in order to preserve the resources and the environment for the future
461 generations.

462
463 (16) The 1997 Joint Convention on the Safety of Spent Fuel Management and on the
464 Safety of Radioactive Waste Management details the long-term aspects of the safety
465 objectives for disposal by requiring to meet the principle that "...individuals, society
466 and the environment are protected from harmful effects of ionising, now and in the
467 future, in such a way that the needs and aspirations of the present generation are
468 met without compromising the ability of future generations to meet their needs and
469 aspirations" (IAEA 1997). In a broad sense this principle is consistent with one of the
470 recommendations of ICRP Publication 77: "the Commission recommendations rely
471 on the basic principle that individuals and populations in the future should be afforded
472 at least the same level of protection as the current generation." These
473 recommendations were further expanded and clarified in ICRP Publication 81
474 (paragraphs 41 and 42).

475
476 (17) In the same vein, the obligations of the present generation toward the future are
477 complex, involving, for instance, not only issues of safety and protection but also of
478 transfer of knowledge and resources. Due to the technical and scientific uncertainties
479 and to the evolution of society in the long-term, it is generally acknowledged that the
480 capacity of the present generation to guarantee delivery of its obligations diminishes
481 with distance in time.

482
483 **3.1.2 Basic ICRP principles dealing with future generations**

484
485 (18) The main strength of ICRP consists in its unified protection system applicable to
486 all types of exposure situations. In its 2007 Recommendations (ICRP Publication
487 103), the ICRP protection system continues to rely on its three fundamental
488 principles: justification, optimisation of protection and application of dose limits,
489 applied according to the exposure situation considered.

490

491 (19) The optimisation principle is of primary importance and its role has been
492 reinforced in the new ICRP Recommendations. For this purpose, ICRP recommends
493 that, in assessing the level of protection for humans, “the likelihood of incurring
494 exposures, the number of people exposed, and the magnitude of their individual
495 doses should all be kept as low as reasonably achievable, taking into account
496 economic and societal factors” (ICRP Publication 103, paragraph 203).

497

498 (20) For this assessment, two concepts are considered by ICRP: dose and risk.
499 Associated with dose and risk, the concept of health detriment, as introduced by
500 ICRP in its Publication 26, is also a key concept to consider for assessing the level of
501 protection. The application of this concept aims at providing an estimate of the total
502 harm to health to individuals and their descendants as a result of an exposure,
503 assuming a linear-non-threshold dose-effect relationship. For exposures that may
504 occur in the long-term, the relevance and meaning of dose and risk is of interest and
505 their interpretation over the different time periods has to be clarified. It should be
506 noted that the knowledge of the relationship between dose and effect may very well
507 change in the future, as has already been demonstrated by past reassessments of
508 nominal probability coefficients. Likewise, the ability to cure or mitigate induced
509 health effects may change in the future. It is not possible to make any prediction of
510 the direction of these changes. Thus, the efforts to avoid and/or reduce any effect on
511 human health and on the environment in the far future have to be entirely guided by
512 the current understanding of health and environmental effects.

513

514 (21) Notwithstanding the uncertainty described above, the ICRP dosimetric quantities
515 and the health detriment can be used for long-term assessment. In fact, the
516 assessment of the robustness of the protection system provided by solid waste
517 disposal in the long-term does not need a precise knowledge of the evolution of the
518 general health of the population in the far future. At the design stage, what is at stake
519 is not to evaluate what would be the level of health effects in a group of population in
520 the far future. The challenge is rather to estimate, in an optimisation process through
521 a comparison (using dose and risk indicators) of alternative options, the levels of
522 protection achieved by a given disposal facility system and to judge if the estimated
523 protection level of the chosen strategy is acceptable in the light of the level of
524 protection accepted today.

525

526 **3.2 Geological disposal: Objective and Implementation steps**

527

528 **3.2.1 Strategies for the management of long-lived solid radioactive waste**

529

530 (22) Because of the nature and longevity of hazards, the fundamental strategy
531 adopted for the management of long-lived radioactive waste in order to achieve the
532 safety objective is to concentrate and contain the wastes and to isolate them from the
533 environment as long as possible. The goal of a geological disposal facility is to
534 provide protection of humans and the environment from the hazards that the
535 radioactive waste and the waste containment system would pose over time. The
536 current generation has to take care of the possible future developments when
537 designing the waste management strategy. These possible developments imply
538 different timescales with different levels of presence of human institutions but also

539 uncertainty concerning the level of presence of humans themselves.

540

541 (23) It is internationally recognized that only materials that have been declared as
 542 having no further use for society (waste) are disposed of, so that there is no intention
 543 by the current generation to retrieve it, even if technical options to do that were
 544 available. Disposal is not to be confused with a storage situation. Currently, the
 545 reference option is to dispose of these wastes in engineered deposition facilities
 546 located in suitable geological formations [IAEA 1997, OECD-NEA 2008].

547

548 (24) A step-wise process, involving various stakeholders, is considered as a
 549 responsible approach to planning for the disposal development and implementation,
 550 including final closure. In that context the concepts of reversibility and retrievability
 551 into the disposal facility programmes are also considered. Reversibility implies a
 552 disposal programme that is implemented in stages, keeps options open at each
 553 stage, and provides the capacity to manage the disposal facility with flexibility over
 554 time. Retrievability is the possibility to reverse the step of waste emplacement during
 555 the entire operational phase, e.g. before final closure of the disposal facility.
 556 Retrievability does not imply the intention to retrieve nor is retrieval a contingency
 557 plan for the disposal facility. The key is to consider any choices that could facilitate
 558 retrieval if this was ever required but to continue to ensure that the integrity of the
 559 facility is not jeopardised by these choices. The decision to actually carry out any
 560 retrieval would be a separate decision taken in the future, according to the
 561 radiological principles that apply to a new planned activity.

562

563 (25) The “concentrate and contain” strategy makes it possible, in principle, for the
 564 waste to be re-accessed either voluntarily or involuntarily at some time in the future.
 565 Therefore, disposal systems ought to be designed to reduce the possibility of
 566 inadvertent or malevolent events. There are to some extent conflicting requirements
 567 involved and a balance has to be found in each case, taking into consideration the
 568 timescales, the nature of the waste, the nature of the host geological formation, and
 569 the evolving desires of society.

570

571 **3.2.2 Life phases of a disposal facility and the safety analysis process**

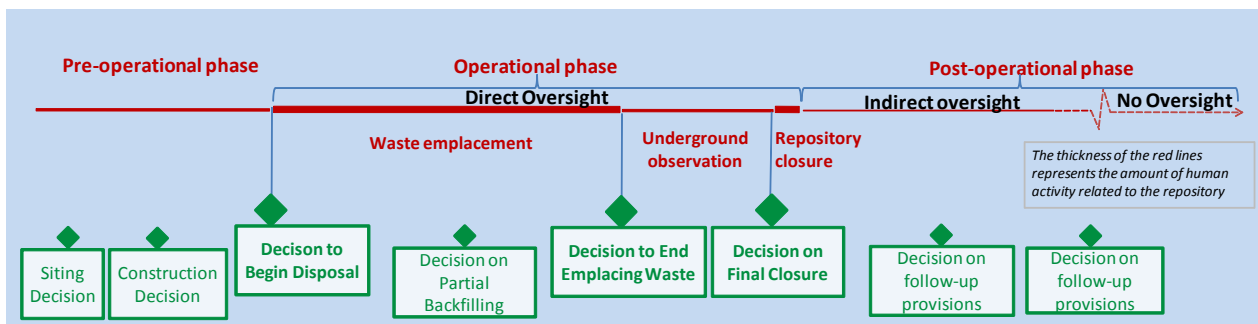
572

573 (26) With respect to the presence of man for managing the facility, the development
 574 of a geological disposal facility involves three main phases (Fig. 1) whose durations
 575 vary amongst national programmes depending on the design and on each country’s
 576 approach to decision making.

577

578 Fig. 1 Disposal facility life phases and relevant oversight periods

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(27) The **pre-operational phase**: During this phase, the disposal facility is designed, the site is selected and characterized, the man-made materials are tested and the engineering demonstrated, safety cases for operational and post-operational phases are developed, the licenses for building and operation are applied for and received, and construction begins. A baseline of environmental conditions is also performed.

(28) The **operational phase**: During this phase, the emplacement of waste is performed, followed by a period of observation prior to the closure. At one time during this phase, some galleries will be filled and sealed and will have thus reached their final configuration, while others will still be excavated.

This phase will be under **direct oversight** of the safety authorities in cooperation with other relevant stakeholders and it may be divided into three relevant time periods:

- **The emplacement period**: A licence is granted that authorizes the transfer and emplacement of waste packages to underground in pre-excavated galleries, rooms, and/or boreholes. The environmental conditions are continuously monitored and compared to the baseline data. Research and development continues. The regulator performs regular inspections of the underground operations. The long-term safety case is regularly updated and reviewed by the regulator. In this phase, new underground galleries may be built and partial backfilling and/or sealing of galleries and disposal facility areas may also take place.
- **The observation period**: After all waste packages are emplaced it might be decided to monitor (parts of) the disposal facility and to keep some accessibility to at least part of the waste while additional performance confirmation takes place.
- **The closure period**: A license to close is granted and access from the surface to the underground facility is terminated. Backfilling and sealing are performed according to design. Surface facilities may be dismantled. The archives of all relevant information are to be provided for long-term preservation.

(29) The **post-operational phase**: during this phase the presence of man is no longer required to directly manage the facility. This phase is the longest one, and is divided into two relevant time periods:

- The **period of indirect oversight**: After closure, safety is assured totally through the intrinsic, built-in provisions of the design of the disposal facility. Nevertheless, it is expected to continue monitoring of the baseline environmental conditions including some remote monitoring. Archives on technical data and configuration of waste packages and the disposal facility will be kept, as well as markers to remind coming generations of its existence. The relevant international safeguards controls continue to apply. Inadvertent human intrusion in the disposal facility can be ruled out.
- The **period of no oversight**: Although termination of indirect oversight is not foreseen, it will still have to be considered in the design and planning stage as there is no guarantee that it will be maintained as well as the memory of the

630 site in the distant future. Eventually, loss of oversight and memory may take
631 place, either progressively or following major unpredictable events such as
632 war or loss of records. Therefore, inadvertent human intrusion in the disposal
633 facility cannot be ruled out during this time period. The intrinsic hazard of the
634 waste will decrease with time but it may continue to pose a significant hazard
635 for a considerable time. The loss of oversight does not result in a change of
636 the protection capability of the disposal facility.

637
638 (30) As long as oversight is effective, it will be possible to evaluate the protection
639 capability of the disposal facility based on regular updates of the safety case. The
640 safety case provided by the developer of a disposal facility must address the
641 operational and the post-operational phase and, specifically the distant future, when
642 controls and interventions cannot be relied upon. The aim of the developed safety
643 case is to provide convincing evidence of the intrinsic protective capability of the
644 system. The safety case shows how the barriers in the disposal facility system work
645 together and how they fulfil their desired functions over time. It documents the
646 principles and strategies that were followed for developing the knowledge base. It
647 recognises the residual uncertainties in both the long-term processes and potential
648 future events that may affect the performance of the disposal facility and why these
649 have been considered as not to reduce protection unduly. Interactions with the
650 various stakeholders - e.g., the local public, outside experts brought in to conduct
651 independent reviews - are acknowledged elements to enhance the quality of the
652 decision-making process at the different phases of the disposal facility development
653 and implementation.

654 3.2.3 Relevant timeframes for radiological protection

655 (31) As stated before, the scope of this ICRP report is the description of how
656 protection criteria can be used in the safety assessment, and to establish
657 recommendations on protection issues related to the disposal of long-lived solid
658 radioactive waste. One of the crucial factors that influences the application of the
659 protection system over the different phases in the lifetime of a disposal facility is the
660 level of oversight that is present. The level of oversight will directly affect the
661 capability to reduce or avoid some exposures. Three main timeframes have to be
662 considered:

- 663 • **Time of direct oversight:** when the disposal facility is being implemented
664 and active oversight is taking place. This timeframe coincides with the pre-
665 operational and operational phases of the disposal facility;
- 666 • **Time of indirect oversight:** when the disposal facility is sealed and indirect
667 oversight is being exercised to provide additional assurance on behalf of the
668 society. This timeframe coincide with the post-operational phase of the
669 disposal facility.
- 670 • **Time of no oversight:** when oversight is no longer exercised because
671 memory is lost. This timeframe coincides with the post-closure period in the
672 distant future.

673
674 The transition between the different timeframes has also to be considered

675 (32). During the time of direct oversight both the operator and the regulator in
676 interaction with the concerned stakeholders will be able to actively manage the
677 protection of workers, the public and the environment through direct and indirect
678 actions. The transition from this timeframe into the timeframe of indirect oversight is
679 not abrupt. Thus parts of the disposal facility will be under direct oversight, and at the
680 same time others will be under indirect oversight.

681 (33) During the time of indirect oversight, there might be some presence of
682 people/staff/operator at the site. Knowledge is maintained, monitoring may continue
683 to occur and some corrective actions could be made if needed. However, in most
684 cases, options to address radiological protection will be indirect. As time progresses
685 the degree of oversight may change, corresponding, for example, to less frequent
686 inspections. The decisions to reduce the level of oversight would be based to some
687 extent on the degree of confidence in the behavior of the facility, and other societal
688 and economic factors. Decisions related to the organization and evolution of the
689 oversight should be discussed with the stakeholders concerned.

690 (34) It is to be expected that regulators and society will maintain forms of oversight
691 and memory as long as possible. However, there is no guarantee on there existence
692 in the distant future. At this point the facility implicitly leaves the regulatory regime.

693 (35) No matter in which way oversight ceases to exist, the disposal facility is still a
694 functioning facility and continues to be so. The potential to isolate and contain the
695 radioactive waste is an inherent feature of the radioactive waste disposal facility that
696 continues into the far future and responds to the considered evolution of the disposal
697 facility under natural processes and events. The multi-barrier, multi-function system
698 that is at the basis of the disposal facility design must have the potential to constrain
699 releases of radionuclides from the radioactive waste disposal facility.

700 (36) Another type of passive control that may continue after the direct oversight
701 ceases is provided by memory or records of the presence of a geological disposal
702 facility or other measures decided by the authorities in interaction with the different
703 stakeholders, however for a much shorter timescale. This reduces the probability of
704 direct inadvertent intrusion by people into the facility and it may assist in the
705 justification and planning for any advertent intrusion, if desired. At some point in the
706 distant future, the memory of the presence of the disposal facility may be lost and
707 there is no defense mechanism against direct inadvertent intrusion, apart from the
708 fact that the waste is out of sight and stored at great distance from the part of the
709 biosphere that people normally inhabit. The location of the geological disposal facility
710 and its technical design will constitute the remaining built-in "control" against
711 inadvertent intrusion.

712 (37) The cessation of direct oversight of the site will not occur before tens to
713 hundreds of years after the start of operations. It is not possible to specify the criteria
714 that will be used by the people making decisions at that time. The different decisions
715 to be made related to the evolution of the oversight should be discussed with the
716 stakeholders.

717 (38) As such, the assumption that cessation of indirect oversight will occur does not
718 correspond to a regulatory decision to release radioactive materials from regulatory
719 control.

720

721

722 **4. Application of the ICRP system of protection during different timeframes in**
723 **the life of a geological disposal facility**
724

725 (39) The major features of the 2007 ICRP Recommendations (ICRP Publication 103)
726 relevant to this report are:

- 727 • Maintaining the Commission’s three fundamental principles of radiological
728 protection, namely justification, optimisation, and the application of dose limits,
729 and clarifying how they apply to sources delivering exposure and to individuals
730 receiving exposure.
- 731 • Evolving from the previous process-based protection approach using practices
732 and interventions, by moving to a situation-based approach applying the
733 fundamental principles of justification and optimisation of protection to all
734 controllable exposure situations, which the 2007 ICRP Recommendations
735 characterise as planned, emergency, and existing exposure situations.
- 736 • Re-enforcing the principle of optimisation of protection, which should be
737 applied in a similar way to all exposure situations, with restrictions on
738 individual doses and risks, namely dose and risk constraints for planned
739 exposure situations and reference levels for emergency and existing exposure
740 situations.

741
742 **4.1 The application of the principles “justification”, “limitation” and**
743 **“optimisation”**
744

745 (40) The definitions of the three basic principles and basic considerations for their
746 application to waste disposal are described as follows.
747

- 748 • The Principle of Justification: *“Any decision that alters the exposure situation*
749 *should do more good than harm.”*

750 Waste management and disposal operations are an integral part of the
751 practice generating the waste. It is wrong to regard them as a free standing
752 practice that needs its own justification. The waste management and disposal
753 operations should therefore be included in the assessment of the justification
754 of the practice generating the waste (ICRP 77 §34). This assessment should
755 include considerations of different options for waste management and disposal
756 including the justification of these options. If the national waste disposal policy
757 has changed and the practice is continuing, it may be necessary to reassess
758 the justification of the practice. If the practice has ceased, the protection
759 strategy, rather than the practice, has to be considered for justification.
760

- 761 • The Principle of Optimisation of Protection: *“The likelihood of incurring*
762 *exposure, the number of people exposed, and the magnitude of their*
763 *individual doses should all be kept as low as reasonably achievable, taking*
764 *into account economic and societal factors.”*

765 As clearly stated in ICRP Publication 103, optimisation is of primary
766 importance and its role has been reinforced. This is also the key principle
767 guiding the application of the ICRP system of protection in the disposal of
768 long-lived solid radioactive waste, as discussed in this report (for details see
769 section 4.4).
770

- 771 • The Principle of Application of Dose Limits: *“The total dose to any individual*
772 *from regulated sources in planned exposure situations other than medical*
773 *exposure of patients should not exceed the appropriate limits specified by the*
774 *Commission.”*

775 The general statement of ICRP Publication 81 (paragraph 36) still applies:
776 “Although the Commission continues to recommend dose limits, it recognises
777 that ‘dose limits for public exposure are rarely limiting in practice’ (ICRP,
778 Publication 77, 1997b, paragraph 36). Furthermore, it considers that ‘...the
779 application of dose limits to waste disposal has intrinsic difficulties’ (ICRP,
780 Publication 77, 1997b, paragraph 19) and that control of public exposure
781 through a process of constrained optimisation will ‘obviate the direct use of the
782 public exposure dose limits in the control of radioactive waste disposal’ (ICRP,
783 Publication 77, 1997b, paragraph 48).”
784

785 **4.2 Dose and risk concepts**

786
787 (41) The main and primary use of the effective dose in radiological protection for both
788 workers and the general public is (ICRP Publication 103, paragraph 153):

- 789 • The prospective dose assessment for planning and optimisation of protection.
790 • The retrospective dose assessment for demonstrating compliance with dose
791 limits, or for comparing with dose constraints or reference levels.
792

793 In practical radiological protection applications, effective dose is used for the
794 demonstration of compliance with protection standards.
795

796 (42) A potential exposure is an exposure that is not expected to be delivered with
797 certainty but that may result from an accident at a source or an event or sequence of
798 events of a probabilistic nature, including equipment failures and operating errors.
799 The risk associated with such an event is a function of the probability of an
800 unintended event causing a dose, and the probability of detriment due to that dose.
801 Risk constraints correspond to dose constraints but refer to potential exposures. For
802 potential exposures of workers, the Commission continues to recommend a generic
803 risk constraint of 2×10^{-4} per year which is similar to the probability of fatal cancer
804 associated with an average occupational annual dose of 5 mSv (ICRP Publication
805 76). For potential exposures of the public, the Commission continues to recommend
806 a risk constraint of 1×10^{-5} per year.

807 **4.3 Exposure situations associated with geological disposal**

808
809 (43) The ICRP system of protection described in its Publication 103 distinguishes
810 three types of radiological situations: planned, existing and emergency situations
811 (ICRP Publication 103, paragraph 176).

- 812 • **“Planned exposure situations** are everyday situations involving the
813 operation of deliberately introduced sources including decommissioning,
814 disposal of radioactive waste including the post-closure phase and
815 rehabilitation of the previously occupied land. Planned exposure situations
816 may give rise both to exposures that are reasonably anticipated to occur
817 (normal exposures) and to higher exposures that are anticipated to occur with

818 a lower likelihood (potential exposures). These may arise following deviations
819 from normal operating procedures, but are considered at the planning stage.”

- 820 • **“Emergency exposure situations** are situations that may occur during the
821 operation of a planned situation, or from a malicious act, or from any other
822 unexpected situation, and require urgent action in order to avoid or reduce
823 undesirable consequences.”
- 824 • **“Existing exposure situations** are exposure situations that already exist
825 when a decision on control has to be taken, including prolonged exposure
826 situations after emergencies.”

827

828 **4.3.1 Exposure situations for waste emplacement activities**

829

830 (44) In terms of the basic types of exposure situations, waste emplacement activities
831 are subject to the same principles of dose limitations and the requirement to optimise
832 below constraints as those in any nuclear facility. Both worker and public exposures
833 are expected from the transportation, handling and disposal activities and thus, are
834 planned exposures including potential exposures from deviations from the normal
835 operations. The possibility also exists for incidents due to low probability/high
836 consequence initiating events, which could lead to an emergency situation.
837 Operations would be expected to be optimized consistent with the Commission’s
838 Recommendations in ICRP Publication 103. The annual dose limits for worker of e.g.
839 20 mSv in a year is applied with the obligation of optimising protection below dose
840 constraints to be specified by operators. The recommended dose constraint for the
841 public is 0.3 mSv in a year. At the end of the period of direct oversight worker
842 exposures are to be considered in two limited areas of exposure: (1) worker
843 exposure for any indirect monitoring of the facility and its surroundings during the
844 period of indirect oversight, and (2) exposure due to residual radioactivity after
845 decommissioning of the surface facilities.

846 **4.3.2 Exposure situations for the emplaced waste**

847

848 (45) For the emplaced waste, a typical disposal facility safety assessment would
849 suggest that significant releases are unlikely during the emplacement period and the
850 period of time during which a competently sited, operated and sealed disposal facility
851 is being actively observed and monitored. Therefore, any exposures would be
852 categorised as part of the potential exposure subset of planned exposure. Given the
853 potentially vast time periods involved in the period of no oversight, the possibility of
854 an eventual release of some radioactive substances is inherent in the concept of
855 geological disposal even if the system operates as intended (i.e., without deviations
856 from procedures in operations, construction or accidents). These very long term
857 potential releases of radioactive substances and subsequent exposures are assumed
858 to result from a variety of scenarios. While they may be foreseen and perhaps
859 assigned a probability they are still intrinsically uncertain. Evaluations of these
860 exposures serve the purpose of comparing alternative facility design options and
861 reaching a regulatory judgment regarding the capability of the system to isolate and
862 contain the waste. Such evaluations are not considered to be predictions, nor are
863 they intended to be used for the protection of specific individuals or populations.
864 Such exposures may in fact be projected to occur at such distant times that
865 traditional concepts such as dose and risk have to be used with caution.

866

867 (46) Any such releases would be expected to take place well beyond the operational
868 period of the facility so that the immediate causes of any release would be beyond
869 the control of the operator; this suggests that these are uncertain and hence treated
870 as potential exposures. The timing and magnitude of such releases is not predictable
871 except in the broadest sense. Even more, the presence of exposed populations at
872 the point of release as well as their capability to implement protective and/or
873 corrective actions in the far future cannot be assumed certain, should such releases
874 occur.

875 (47) The process of evaluating the potential exposure from emplaced waste includes
876 the understanding of the potential ways by which the radionuclides could be released
877 from the engineered facility, including the transport through the geosphere to the
878 biosphere and the resultant release into an appropriate environmental compartment
879 that could give rise to exposures to humans, flora or fauna. Depending on the level of
880 knowledge, probabilities may be estimated for these release scenarios. However, at
881 the long timescales considered in geological disposal, evolution of the biosphere and,
882 possibly, the geosphere and the engineered system will increase the uncertainty of
883 these probabilities. Hence the scientific basis for dose and risk assessments at very
884 long times into the future may become questionable and the results of such
885 assessments would then need to be interpreted in a qualitative way.

886 (48) The expected evolution of a geological disposal facility in the distant future
887 should not require active involvement to mitigate the consequences as this is counter
888 to the principle of avoiding placing an undue burden on future generations.
889 Therefore, the Commission continues to support its recommendations in ICRP
890 Publication 103 that either a dose constraint of 0.3 mSv in a year or an annual risk
891 constraint of 1×10^{-5} be used for potential exposures from the emplaced waste. As
892 noted in ICRP Publication 103, it may be useful to disaggregate the probability and
893 potential consequence to reach risk-informed decisions.

894 (49) In the distant future, in case oversight provisions are no longer operational and
895 the memory of the presence of the disposal facility is lost, it is possible that people
896 will 'rediscover' the disposal facility. This may be without compromising its integrity
897 (eg. remote sensing), by observing very small discharges into the biosphere, or it
898 may be by directly breaching the containment, albeit inadvertently, and causing
899 contamination of the environment. Situations of this kind would be treated as an
900 existing exposure situation and be handled as appropriate to the protection
901 guidelines at the time. However, these guidelines are inherently unknowable and
902 thus, while noted, are not relied on for protection decisions today.

903 **4.3.3 Natural disruptive events**

904 (50) The disposal facility and its surrounding environment could be impacted or
905 altered by natural disruptive events, e.g., earthquakes, during the periods of indirect
906 oversight or no oversight. Different scenarios can be envisaged in the future
907 according to the current knowledge. For these events, it may be possible to estimate
908 or bound the probability of occurrence, and the risk of potential consequences should
909 be taken into account in reaching risk-informed waste management decisions.

910 (51) Natural disruptive events with very low probability compared to the design-basis
911 may occur and may induce significant disturbances on the disposal system or the
912 migration of the radioactive substances. Examples of these types of events include
913 major landform change due to tectonic events, etc. Assessing their probabilities of
914 occurrence may neither be relevant nor feasible. The Commission recommends that
915 the regulatory authority develop a strategy for addressing such events with the
916 involvement of relevant stakeholders. Possible approaches include establishing a
917 probability value for which events with lesser probabilities are excluded from
918 consideration in the risk-assessment process, optimizing site selection to minimize
919 the probability of such events, or assessing specific events through stylized
920 assessments.

921 (52) Previously the Commission considered all natural events, disruptive or not,
922 within the same framework (Publication 81). Now, the Commission recommends
923 separate consideration of natural disruptive events which are included in the design-
924 basis evolution from those which are not. For the first ones, the Commission
925 recommends application of the dose or risk constraints for planned exposure
926 situation. For the severe natural disruptive events not taken into account in the
927 design-basis evolution, the Commission now recommends application of the
928 reference levels for emergency or existing exposure situations, depending on the
929 severity of the consequences. If the events were to occur, while there is still (direct or
930 indirect) oversight of the disposal facility, the authorities should be in a position to
931 implement adequate protection measures to deal with this situation as emergency or
932 existing exposure situation. If such a disruptive event occurs when oversight of the
933 disposal system has disappeared, there is no certainty about the possibility that an
934 organisation could be aware of the disturbance and therefore, it is not possible to
935 consider with certainty the implementation of protective measures. If the authorities
936 eventually became aware of the disturbance they would treat the situation as an
937 emergency exposure situation or an existing exposure situation depending on the
938 severity of the disturbance.

939 (53) For emergency exposure situations, the Commission recommends selection of a
940 reference level in the range of 20 mSv to 100 mSv for the first year and development
941 of protection strategies to reduce exposures to as low as reasonably achievable
942 below the reference level taking into account economic and societal factors
943 (Publication 109).

944 (54) According to Publication 103, long-lasting exposures resulting from natural
945 disruptive events (with or without an emergency phase) should be referred to as an
946 existing exposure situation and the recommended reference levels to be selected for
947 optimizing protection strategies ranges between 1 to 20 mSv per year. In agreement
948 with the Commission's recommendations in Publication 111, a reference level should
949 be selected in the lower part of the band, e.g., in the range of a few mSv per year.

950 **4.3.4 Inadvertent human intrusion**

951 (55) In general, waste is disposed in a geological disposal facility if it needs to be
952 isolated from possible human intrusion (IAEA, 2009). It is necessary to distinguish
953 between deliberate and inadvertent human intrusion into the facility. The first one is
954 not discussed further in this report as it is considered out of the scope of

955 responsibility of the current generation to protect a deliberate intruder, i.e. a person
956 who is aware of the nature of the facility. The design and siting of the facility will have
957 to include features to reduce the possibility of inadvertent human intrusion.

958 (56) A release resulting from inadvertent human intrusion, such as drilling into the
959 facility, could migrate through the geosphere and biosphere resulting in exposures
960 that are indirectly related or incidental to the intrusion event. It is also possible that
961 inadvertent human intrusion could bring waste material to the surface and hence lead
962 to direct exposure of the intruder and nearby populations. This introduces the
963 possibility of elevated exposures and significant doses which is an inescapable
964 consequence of the decision to isolate and contain waste rather than diluting or
965 dispersing it.

966 (57) Protection from exposures associated with human intrusion is best
967 accomplished by efforts to reduce the assumed possibility of such events. These
968 may include siting a disposal facility at great distance from the surface, avoiding
969 assumed valuable resources, incorporating robust design features which make
970 intrusion more difficult, or employing direct oversight (such as restricting access or
971 monitoring for releases) and indirect passive oversight (such as archived record and
972 site markers). While the actual probability of human intrusion at a specific site is
973 largely unknowable as it is based on future human actions, it is assumed that the
974 probability of intrusion during the direct and indirect oversight periods is effectively
975 zero.

976 (58) For longer time periods, in case oversight has disappeared, the occurrence of
977 human intrusion cannot be totally ruled out. Therefore, the consequences of one or
978 more plausible stylised intrusion scenarios should be considered by the decision-
979 maker to evaluate the resilience of the disposal facility to potential inadvertent
980 intrusion. Any estimates of the magnitude of intrusion risks are by necessity
981 dependent on assumptions that are made about future human behavior. Since no
982 scientific basis exists for predicting the nature or probability of future human actions,
983 the Commission continues to consider not appropriate to include the probabilities of
984 such events in a quantitative performance assessment that is to be compared with
985 dose or risk constraints (Publication 81). If recognized at the time an intrusion occurs,
986 it would be treated as an emergency exposure situation or an existing exposure
987 situation depending on the severity of the related disturbance.

988 (59) The Commission wishes to emphasise that the dose criteria specified in
989 Publication 81 for human intrusion only apply to near surface disposal. In case of
990 geological disposal, intrusion means that many of the barriers which were considered
991 in the optimization of protection for the disposal facility have been by-passed. Since a
992 future society may be unaware of the radiation risk associated with such events, any
993 protective actions required should be considered during the development of the
994 disposal system. Therefore the dose or risk constraints recommended by the
995 Commission for the application of the optimization of protection in geological disposal
996 do not apply to inadvertent human intrusion.

997 **4.3.5 Summary of relevant exposure situation according oversight**

998
999 (60) The application of the three exposure situations and of dose limits, dose



1000 constraints and reference levels as defined in ICRP Publication 103 during these
1001 timeframes is indicated in Table 1.
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1003

1004

RADIOLOGICAL EXPOSURE SITUATIONS AS FUNCTION OF DISPOSAL FACILITY EVOLUTION AND PRESENCE AND TYPE OF OVERSIGHT			
Disposal facility Status	Type of Oversight		
	Direct Oversight	Indirect Oversight	No oversight
Design-basis ¹ evolution	Planned Exposure Situation ²	Planned Exposure Situation ²	Planned Exposure Situation ^{2,3}
Non-design basis evolution involving significant exposures to people and the environment	Emergency Exposure Situation at the time of exposure, followed by an Existing Exposure Situation ⁴	Emergency Exposure Situation at the time of exposure, followed by an Existing Exposure Situation ⁴	Emergency and/or Existing Exposure Situation
Inadvertent Human Intrusion	not relevant	not relevant	Emergency and/or Existing Exposure Situation

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¹ The design basis is the envelope of both expected and less likely (potential) events that are used in planning the facility.
² At design: 20 mSv/a dose limit to worker and dose constraint to be specified by operators; 1 mSv/a dose limit and 0.3 mSv/a dose constraint for the public; in the case of less likely events within the design basis a risk constraint of $1 \cdot 10^{-5}$ per year for the public is suggested.
³ No worker dose is foreseen during the period of no oversight
⁴ For an emergency exposure situation a reference level between 20 and 100 mSv per year is recommended; for an existing exposure situation a reference level should be selected in the lower part of the band between 1 and 20 mSv per year, eg., in the range of a few mSv per year.

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4.4 Optimisation and Best Available Techniques

(61) The principle of optimisation is defined by the Commission (ICRP Publications 101 and 103) as the source-related process to keep the likelihood of incurring exposures (where these are not certain to be received), the number of people exposed, and the magnitude of individual doses as low as reasonably achievable, taking economic and societal factors into account. The general recommendations for the optimisation process are described in ICRP Publication 101, part 2.

(62) The ICRP principle of optimisation of radiological protection when applied to the development and implementation of a geological disposal facility has to be understood in the broadest sense of an iterative, systematic and transparent evaluation of options for enhancing the protective capabilities of the system and for reducing impacts (radiological and others).

(63) Optimisation of protection has to deal with the main aim of disposal systems, i.e. to protect humans and the environment, now and in the future, by isolating the waste from man, the environment and the biosphere and by containing the radioactive and

1033 other toxic substances in the waste to the largest extent possible. Optimisation of
1034 protection has to deal with the protection of workers and the public during the time of
1035 operation, as well as with the protection of future generations including possible
1036 periods with no oversight, and safety has to be ensured by a passively functioning
1037 disposal system.

1038

1039 (64) The stepwise decisional process for geological disposal facility development and
1040 implementation constitutes the framework for the optimisation process. As a central
1041 component, optimisation has to cover all elements of the disposal system in an
1042 integrative approach, i.e. site (incl. host formation), facility design, the application of
1043 Best Available Techniques (BAT), waste package design, waste characteristics as
1044 well as all relevant time periods.

1045

1046 (65) Optimisation of protection is a multi-facet endeavour, involving the disposal
1047 facility developer, safety and environmental protection authorities, local communities
1048 and other stakeholders and multiple decisions have to be taken. Therefore, it is not
1049 possible to define a priori the path for a sound optimisation process for a geological
1050 disposal facility, or the acceptance or success criteria for the end result of an
1051 optimisation process.

1052

1053 (66) Socio-economical factors (including e.g. policy decisions and societal
1054 acceptance issues) can constraint the optimisation process to various extents, e.g.
1055 by limiting the available options (e.g. siting) and/or by defining additional conditions
1056 (e.g. retrievability). It is important that these constraints are identified in a manner
1057 transparent to all involved stakeholders and that their safety implications are
1058 generally and broadly understood. These factors must not force the optimisation
1059 process to accept options that are questionable from a protection point of view.

1060

1061 (67) Although optimisation is a continuous effort, milestones will have to be defined in
1062 the stepwise process, where all involved stakeholders can judge the result of the
1063 optimisation process and indicate ways to improve various elements of the system.

1064

1065 (68) The process of optimisation will be considerably different for the pre-operational,
1066 operational and post-operational phases. During the operational phase, the general
1067 recommendations for any large nuclear facility apply. Experience gained during the
1068 operational phase can be factored into immediate or near term improvements,
1069 reducing the exposure to both workers and the public from the emplacement work.

1070

1071 (69) Nearly all aspects of optimisation for the post-operational phase must occur prior
1072 to waste emplacement, largely in the siting and design phase, with the plans to close
1073 the facility being part of the design phase. Some further optimisation of the protection
1074 that will be provided during the post-operational phase is still possible during the
1075 operational phase, for example as new materials or techniques may become
1076 available. Experience gained during the closure of parts of the facility, e.g. sealing of
1077 disposal rooms, can lead to improvements of the plans of the disposal facility closure.

1078

1079 (70) During the post-operational phase, there is no active operation of the disposal
1080 facility. The waste is emplaced and the protection of humans and the environment is
1081 mainly based on the passive isolation and containment capabilities of the disposal

1082 system. Hence decisions on optimisation in the post-operational phase can only
1083 relate to the time and method of oversight of the closed disposal system. During this
1084 phase optimisation of protection can best be achieved by maintaining oversight.
1085

1086 (71) Geological disposal facilities are sited, designed and implemented to provide for
1087 robust long-time isolation and containment, resulting in potential impacts on humans
1088 and the environment only in the very far future. Consequently, as explained earlier,
1089 the assessment of post-closure radiological impacts through the estimation of
1090 effective dose or risk to a reference person, given the increasing uncertainties with
1091 time and the cautious assumptions to be made, can only provide an indication or
1092 illustration of the robustness of the system, rather than predictions of future
1093 radiological consequences. As previously discussed, there comes a time in the
1094 distant future beyond which any such calculated dose or risk values must be
1095 considered for the sake of comparison of options rather than as absolute values.
1096

1097 (72) The elements guiding or directing the optimisation process should be those that
1098 directly or indirectly determine the quality of the components of the facility as built,
1099 operated and closed, where quality refers to the capacity of the components to fulfil
1100 the safety functions of isolation and containment in a robust manner. The
1101 assessment and judgment of the quality of system components essentially includes
1102 elements of BAT as well as the concepts of good practice and sound engineering
1103 and managerial principles. These elements complement and support radiological
1104 optimisation when potential impacts in the far future have to be dealt with.
1105

1106 (73) The judgment of the quality of the system design developed or implemented has
1107 to be made, and critically reviewed when needed, in a well-structured and
1108 transparent process, with the involvement of all relevant stakeholders. At the heart of
1109 this process is the interaction, transparent for all other stakeholders, between the
1110 developer and the safety authorities.
1111

1112 (74) When dealing with safety in the more distant future, optimisation can be
1113 complemented and supported by applying the concept of BAT on the various levels
1114 of the disposal system, through:
1115

- 1116 - the methodologies for identifying and selecting (a) host rock(s), zones and
1117 sites, and the methodological and scientific program of host rock and site
1118 characterization in order to assess its containment and isolation capacities
1119 now and in the distant future;
- 1120 - the development of the system design, including the choices of materials and
1121 technologies, and the way they will contribute, individually and together, to the
1122 main aim of isolation and containment, taking due account of the
1123 characteristics of the host rock;
- 1124 - the integration of waste, site and design characteristics within one disposal
1125 system and the iterative assessment of the isolation and containment
1126 capacities of the system as a whole;
- 1127 - the use of sound managerial and engineering methods and practices during
1128 system construction, operation and closure, within an integrated management
1129 system.
1130

1131 (75) Optimisation on the basis of radiological criteria (effective dose and risk) is an
1132 important part of the optimisation of the design and implementation process of the
1133 disposal facility at specific “windows” and for specific aspects of the disposal facility,
1134 e.g. when operational safety is assessed during the design development steps and
1135 during preparation and implementation of operational procedures and activities.
1136

1137 (76) The way the various elements of a disposal system can be optimized in an
1138 integrative manner during system development varies to a large extent. First of all
1139 stepwise optimisation decisions have to be taken mostly in a chronological order: e.g.
1140 the decisions on the choice of a host rock and on one or a limited number of sites are
1141 often prior to decisions on a detailed design. For the selection of a host rock and a
1142 site, a balance has to be struck between technical criteria related to the safety of a
1143 disposal system (long-term stability, barrier for radionuclide migration, absence or
1144 presence of natural resources in the vicinity, ...) and the requirement of local or
1145 supra-local societal acceptance. Favourable host rocks and sites can in a first step
1146 be identified on the basis of broadly defined “required qualities”, taking due account
1147 of the isolation and containment function(s) of the natural barriers and the natural
1148 environment in the disposal system.
1149

1150 (77) If several suitable host rocks or sites can be identified and evaluated the
1151 decision in favour of one specific host rock or site will always be a multi-factor
1152 decision, based on both qualitative and quantitative judgments. Radiological criteria
1153 (e.g. calculated effective dose) are often of limited value for this multi-factor decision,
1154 due to (1) the increasing uncertainties for longer assessment timescales, and (2) the
1155 observation that often calculated radiological impacts are so low that they do not
1156 constitute a discriminating factor for the choice of a host rock or site.
1157

1158 (78) The assessment of the robustness of the disposal facility can contribute to
1159 system optimisation, because it provides insight, quantitative or qualitative, in the
1160 performance of the disposal facility and its components, in the relative contributions
1161 of the various components to the overall system. So, the value of such an
1162 assessment for the optimisation process is mainly through the insights it provides on
1163 the relative contributions of the various components to the overall system objective of
1164 isolation and containment, and how these contributions can be affected by disturbing
1165 events and processes or by remaining uncertainties. The indicative nature of
1166 calculated effective dose and risk in the very far future reduces their usefulness for
1167 the optimisation process.
1168

1169 **5. „Endpoint considerations“**

1170 **5.1 The Representative Person**

1171 (79) As general guidance, the Commission considers that its recommendations on
1172 the estimation of exposures in Publication 101, part 1, apply. The Commission
1173 therefore continues to recommend that for planned exposure situations exposures
1174 should in general be assessed on the basis of the annual dose to the representative
1175 person.
1176
1177

1178 (80) During the operational phase, management of exposures to workers and the
1179

1180 public would be the same as for any other large nuclear facility. During the post-
1181 operational phase, due to the long time-scales under consideration, the habits and
1182 characteristics of the representative person, as well as those of the environment in
1183 which it is located, can only be based on a number of assumptions. In that case, any
1184 such representative person has to be hypothetical and stylized. The habits and
1185 characteristics assumed for the individual in a distant future should be chosen on the
1186 basis of reasonably conservative and plausible assumptions, considering site or
1187 region specific information as well as biological and physiological determinants of
1188 human life. Moreover, in many cases, different scenarios, each associated with
1189 different representative persons, may be considered for the long term and have
1190 different probabilities of occurrence, although establishing discreet probabilities may
1191 be problematic. Thus, the scenario leading to the highest dose may not be linked to
1192 the highest risk. It is therefore important for the decision-maker to have a clear
1193 presentation of the different scenarios and their associated probabilities of
1194 occurrence or at least with an appreciation of their corresponding probabilities.

1195
1196 (81) As stated in ICRP Publication 101, part 1, for the purpose of protection of the
1197 public, the representative person corresponds to an individual receiving a dose that is
1198 representative of the more highly exposed individuals in the population. Therefore, it
1199 should be assumed that the hypothetical representative person is located at the time
1200 and place of the maximum concentration of radionuclides in the biosphere. This is an
1201 assumption since the environment may have evolved such that humans are no
1202 longer inhabiting these areas in the far future.

1203
1204 (82) A representative person cannot be defined independently of the assumed
1205 biosphere. Major changes may occur in the biosphere in the long-term due to the
1206 action of natural forces in a similar manner to those occurring in the past. Human
1207 actions may also affect the biosphere, but one can only speculate about human
1208 behaviour in the long-term. In the definition of the scenarios, consideration of
1209 biosphere changes should be limited to those due to natural forces. A representative
1210 person and biosphere should be defined using either a site specific approach based
1211 on site or region specific information or a stylized approach based on more general
1212 habits and conditions; the use of stylized approaches will become more important for
1213 longer time-scales.

1214
1215 (83) In the long term, if radionuclides are present in the environment, exposures of
1216 the representative person are expected to occur during a whole lifetime. The
1217 Commission recommends in its Publication 101, part 1, to use three age categories
1218 for estimating annual dose to the representative person, for comparison with annual
1219 dose or risk criteria. (Note that the annual dose from the intake of a radionuclide
1220 already includes a component relating to the fact that the radionuclide will deliver a
1221 dose in successive years, the length of time being determined by the biological half
1222 life of the radionuclide in the body). These categories are 0-5 years (infant), 6-15
1223 years (child), and 16-70 years (adult). Decisions can also be made by considering
1224 doses or risks on a lifetime exposure instead on a per annum scale. For the
1225 comparison of doses to individuals of current and future generations, however, it may
1226 be necessary to calculate doses for different age groups for future exposures from
1227 the radioactive waste site or vice versa to calculate doses for a representative person
1228 of the current generation on the basis of lifetime exposure.

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5.2 Protection of the environment

(84) Illustration that the environment is protected against harmful effects of releases from facilities is an increasing requirement in national legislation and in relation to many human activities including the management of long-lived waste. ICRP has responded to this need as well as to a number of other requirements of ethical nature (as laid out in its Publication 91) by directly and specifically addressing environmental protection in ICRP Publication 103 and by offering a methodology to address this issue, as outlined in ICRP Publication 108.

(85) The ICRP approach considers the health of the environment (not the presence of contamination or other factors that may affect the environment as a resource), with the aim of “preventing or reducing the frequency of deleterious effects on fauna and flora to a level where they would have a negligible impact on the maintenance of biological diversity, the conservation of species, or the health status of natural habitats, communities and ecosystems” (ICRP Publication 103 para 30). The full evaluation of environmental impact would normally be assessed through the Environmental Impact Assessment process and in the Environmental Impact Statement, where effects will be considered within a broader context including such factors as inter alia, visual impact, chemotoxic impact, noise, land use and amenities.

(86) The default target for protection and protective actions could be the set of Reference Animals and Plants that have been described by ICRP and for which the relevant data sets have been derived (Publication 108). The use of Reference Animals and Plants offers on one hand a challenge for waste management which is at least similar to the challenges of demonstrating compliance with dose/risk standards; but, on the other hand, also offers an additional line of argument and reasoning in building a safety case, using endpoints that are different from, but complementary to, protection of human health. Consideration of environmental protection, where appropriate, would thus broaden the basis for risk-informed decision making and addressed issues that may have differing levels of importance for different stakeholders.

(87) Over the long time frames that are considered in waste disposal, the biosphere is likely to change, and even change substantially. Such changes entail biosphere evolution with time that is either natural, or enhanced or perturbed through human action. Contributing factors may be, e.g., climate change including glaciations cycles, and land uplift or depression. Understanding different biospheres today and assessing impacts in such biospheres based on an approach involving Reference Animals and Plants, may guide our understanding of future biosphere changes also for the purpose of environmental protection.

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1343 **Annex 1: The ICRP system of protection, focusing on aspects relevant to the**
1344 **geological disposal of long-lived solid radioactive waste**
1345

1346 The purpose of this annex is to summarize the key recommendations of ICRP
1347 relevant to waste disposal.
1348

1349 In its Publication 103, the ICRP Recommendations evolve from the previous process-
1350 based protection approach using practices and interventions by moving to an
1351 approach based on the exposure situation. They recognise planned, emergency, and
1352 existing exposure situations, and apply the fundamental principles of justification and
1353 optimisation of protection to all of these situations. They maintain the Commission's
1354 current individual dose limits for effective dose and equivalent dose from all regulated
1355 sources in planned exposure situations. They reinforce the principle of optimisation of
1356 protection, which should be applicable in a similar way to all exposure situations,
1357 subject to the following restrictions on individual doses and risks; dose and risk
1358 constraints for planned exposure situations, and reference levels for emergency and
1359 existing exposure situations. The Recommendations also include an approach for
1360 developing a framework to demonstrate radiological protection of the environment.
1361

1362 **I. Principles of Protection**
1363

1364 The three fundamental principles of protection are
1365

- 1366 • **Justification:** Any decision that alters the exposure situation should
1367 do more good than harm. This means that, by introducing a new source, by
1368 reducing existing exposure, or by reducing the risk of potential exposure, one
1369 should achieve sufficient individual or societal benefit to offset the detriment it
1370 causes.
1371

1372 Waste management and disposal operations are an integral part of the
1373 practice generating the waste. It is wrong to regard them as a free standing
1374 practice that needs its own justification. The waste management and disposal
1375 operations should therefore be included in the assessment of the justification
1376 of the practice generating the waste (ICRP 77 §34). This assessment should
1377 include considerations of different options for waste management and disposal
1378 including the justification of these options. If the national waste disposal policy
1379 has changed and the practice is continuing, it may be necessary to reassess
1380 the justification of the practice. If the practice has ceased, the protection
1381 strategy, rather than the practice, has to be considered for justification.
1382

- 1383 • **Optimisation of protection:** the likelihood of incurring exposures, the
1384 number of people exposed, and the magnitude of their individual doses should
1385 all be kept as low as reasonably achievable, taking into account economic and
1386 societal factors. This means that the level of protection should be the best
1387 under the prevailing circumstances, maximising the margin of benefit over
1388 harm. In order to avoid severely inequitable outcomes of this optimisation
1389 procedure, there should be restrictions on the doses or risks to individuals
1390 from a particular source.
1391

- 1391 • **Application of dose limits:** The total dose to any individual from

1392 regulated sources in planned exposure situations other than medical exposure
1393 of patients should not exceed the appropriate limits recommended by the
1394 Commission. Regulatory dose limits are determined by the regulatory
1395 authority, taking account of international recommendations, and apply to
1396 workers and to members of the public in planned exposure situations.
1397

1398 **The role of optimisation**

1399
1400 When optimising protection strategies, it is necessary to consider all aspects and
1401 protective measures to reduce residual dose, questioning whether ‘the best has been
1402 done in the prevailing circumstances, and if all that is reasonable has been done to
1403 reduce doses’ (ICRP Publication 103, Para. 217). This approach focuses efforts on
1404 optimising protection in order that individual exposures, from all pathways, resulting
1405 from the operation of a waste disposal facility (i.e. residual doses) are judged to be
1406 acceptable in the context of the circumstances being planned for and the expected
1407 resources required/allocated for protection. This approach implies the simultaneous
1408 optimisation of all protective measures that are included in the protection strategy,
1409 implemented if necessary in a stepwise fashion to address prevailing circumstances
1410 appropriately.
1411

1412 All aspects of optimisation cannot be codified; rather, there should be a commitment
1413 by all parties to the optimisation process. Where optimisation becomes a matter for
1414 the regulatory authority, the focus should *not* be on specific outcomes for a particular
1415 situation, but rather on processes, procedures, and judgements. An open dialogue
1416 should be established between the authority and the operating management, and the
1417 success of the optimisation process will depend strongly on the quality of this
1418 dialogue.
1419

1420 Societal values usually influence the final decision on the level of radiological
1421 protection. Therefore, while this report should be seen as providing decision-aiding
1422 recommendations mainly based on scientific considerations on radiological
1423 protection, the Commission’s advice will be expected to serve as an input to a final
1424 (usually wider) decision-making process, which may include other societal concerns
1425 and ethical aspects, as well as considerations of transparency (ICRP Publication
1426 101). This decision-making process may often include the participation of relevant
1427 stakeholders rather than radiological protection specialists alone.
1428

1429 **II. Types of exposures and of exposure situations**

1430
1431 The Commission distinguishes between three categories of exposure: occupational,
1432 public, and medical exposures of patients.
1433

1434 The Commission intends its Recommendations to be applied to all sources and to
1435 individuals exposed to in the following three types of exposure situations which
1436 address all conceivable circumstances (ICRP Publication 103, para.176).

- 1437 • **Planned exposure situations** are situations involving the deliberate
1438 introduction and operation of sources; including decommissioning, disposal
1439 of radioactive waste and rehabilitation of the previously occupied land.
1440 Planned exposure situations may give rise both to exposures that are

1441 anticipated to occur (normal exposures) and to exposures that are not
1442 anticipated to occur (potential exposures).

- 1443 • **Emergency exposure situations** are situations that may occur during the
1444 operation of a planned situation, or from a malicious act, or from any other
1445 unexpected situation, and require urgent action in order to avoid or reduce
1446 undesirable consequences.
- 1447 • **Existing exposure situations** are exposure situations that already exist
1448 when a decision on control has to be taken, including prolonged exposure
1449 situations after emergencies.

1450
1451 It follows that what the Commission has previously called ‘practices’ could be the
1452 origin of planned, emergency, and existing exposure situations. The principles of
1453 protection for planned situations also apply to occupational exposure in connection
1454 with existing and emergency exposure situations.

1455 1456 **III. Dose concepts (effective dose, collective dose)**

1457
1458 The main and primary uses of **effective dose** in radiological protection for both
1459 occupational workers and the general public are (ICRP Publication 103, para. 153):

- 1460 • prospective dose assessment for planning and optimisation of protection; and
- 1461 • retrospective dose assessment for demonstrating compliance with dose limits,
1462 or for comparing with dose constraints or reference levels.

1463 In practical radiological protection applications, effective dose is used for managing
1464 the risks of stochastic effects in workers and the public.

1465
1466 The overall exposure, which is projected to occur as a result of the emergency
1467 exposure situation, should no protective actions be employed, is called the *projected*
1468 *dose*. The dose that would result when a protection strategy is implemented is called
1469 the *residual dose*. In addition, each protective measure will avert a certain amount of
1470 exposure. This is referred to as *averted dose*.

1471
1472 ICRP Publication 103, para. 159: For the purpose of optimisation of radiological
1473 protection, predominantly in the context of occupational exposure, the Commission
1474 has introduced **collective dose** quantities (ICRP Publication 26). These quantities
1475 take account of the exposure of all individuals in a group over a given time period or
1476 during a given operation executed by this group in designated areas. Collective
1477 effective dose is not intended as a tool for epidemiological studies, and it is
1478 inappropriate to use it in risk projections.

1479 1480 **IV. Dose limits, constraints and reference levels**

1481
1482 (B 174) In practice, limits, constraints, reference levels, and action levels are defined
1483 in terms of dose quantities in order to restrict the risks from exposure for both
1484 occupational workers and the public. Since neither quantity can be directly
1485 measured, they are assessed using other measurable quantities, models and
1486 computations. Depending on the situation considered (occupational or public
1487 exposure), different procedures are applied.

1488
1489 **Dose limit**

1490 The value of the effective dose or the equivalent dose to individuals from planned
1491 exposure situations that shall not be exceeded. Numerical values are given in Tab. 8
1492 (ICRP Publication 103).

1493

1494 **Dose constraint**

1495 A prospective and source-related restriction on the individual dose from a source,
1496 which provides a basic level of protection for the most highly exposed individuals
1497 from a source, and serves as an upper bound on the dose in optimisation of
1498 protection for that source. For occupational exposures, the dose constraint is a value
1499 of individual dose used to limit the range of options considered in the process of
1500 optimisation. For public exposure, the dose constraint is an upper bound on the
1501 annual doses that members of the public should receive from the planned operation
1502 of any controlled source. Numerical values are given in Tab. 8 (ICRP Publication
1503 103).

1504

1505 **Reference level**

1506 In emergency or existing exposure situations, the reference level represents the level
1507 of dose or risk, above which it is judged to be inappropriate to plan to allow
1508 exposures to occur, and below which optimisation of protection should be
1509 implemented. The chosen value for a reference level will depend upon the prevailing
1510 circumstances of the exposure under consideration. Numerical values are given in
1511 Tab. 8 (ICRP Publication 103).

1512

1513 **Derived consideration reference level**

1514 For the purpose of environmental protection, ICRP has in Publication 108 identified
1515 Derived Consideration Reference Levels (DCRLs). These are ‘bands’ of
1516 environmental dose (expressed as absorbed dose) rates, spanning one order of
1517 magnitude, for the different Reference Animals and Plants, that “can be considered a
1518 band of dose rates within which there is likely to be some chance of deleterious
1519 effects occurring to individuals of that type of Reference Animal or Plant...that, when
1520 considered with other relevant information, can be used as a point of reference to
1521 optimise the level of effort expended on environmental protection (Publication 108,
1522 para. 195).

1523

1524 **Potential exposure** is an exposure that is not expected to be delivered with certainty
1525 but that may result from an accident at a source or an event or sequence of events of
1526 a probabilistic nature, including equipment failures and operating errors.

1527

1528 **Risk constraint**

1529 A prospective and source-related restriction on the individual risk (in the sense of
1530 probability of detriment due to a potential exposure) from a source, which provides a
1531 basic level of protection for the individuals most at risk from a source and serves as
1532 an upper bound on the individual risk in optimisation of protection for that source.
1533 This risk is a function of the probability of an unintended event causing a dose, and
1534 the probability of detriment due to that dose. Risk constraints correspond to dose
1535 constraints but refer to potential exposures.

1536

1537 ICRP Publication 103, para. 268: Risk constraints, like dose constraints, are source-
1538 related and in principle should equate to a similar health risk to that implied by the

1539 corresponding dose constraints for the same source. However, there can be large
1540 uncertainties in estimations of the probability of an unsafe situation and the resulting
1541 dose. Thus, it will often be sufficient to use a generic value for a risk constraint. In the
1542 case of workers, this could be based on generalisations about normal occupational
1543 exposures, rather than on a more specific study of the particular operation. For
1544 potential exposures of **workers**, the Commission continues to recommend a generic
1545 risk constraint of **2 10⁻⁴ per year** which is similar to the probability of fatal cancer
1546 associated with an average occupational annual dose of 5 mSv (ICRP, Publication
1547 76). For potential exposures of the **public**, the Commission continues to recommend
1548 a risk constraint of **1 10⁻⁵ per year**.

1549 1550 **V. Protection of the environment.**

1551
1552 The Commission acknowledges that, in contrast to human radiological protection, the
1553 objectives of environmental protection are both complex and difficult to articulate.
1554 The Commission does however subscribe to the global needs and efforts required to
1555 maintain biological diversity, to ensure the conservation of species, and to protect the
1556 health and status of natural habitats, communities, and ecosystems. It also
1557 recognises that these objectives may be met in different ways, that ionising may be
1558 only a minor consideration – depending on the environmental exposure situation –
1559 and that a sense of proportion is necessary in trying to achieve them (ICRP
1560 Publication 103, para. 361).

1561
1562 The Commission therefore believes that the development of a clearer framework is
1563 required in order to assess the relationships between exposure and dose, and
1564 between dose and effect, and the consequences of such effects, for non-human
1565 species, on a common scientific basis. This issue was first discussed in ICRP
1566 Publication 91, and it was concluded that it was necessary to draw upon the lessons
1567 learned from the development of the systematic framework for the protection of
1568 human beings. This framework is based on an enormous range of knowledge that
1569 the Commission attempts to convert into pragmatic advice that will be of value in
1570 managing different exposure situations, bearing in mind the wide range of errors,
1571 uncertainties, and knowledge gaps of the various databases (ICRP Publication 103,
1572 para. 364).

1573
1574 The Commission does not therefore propose to set any form of ‘dose limits’ with
1575 respect to environmental protection. However, by setting out data for some
1576 Reference Animals and Plants, in a transparently derived way, and upon which
1577 further action may be considered, the Commission offers practical advice as laid out
1578 in Publication 108. The Commission will continue to develop this framework to
1579 gather and interpret data in order to provide more comprehensive advice in the
1580 future, particularly with regard to those aspects or features of different environments
1581 that are likely to be of concern under different exposure situations (ICRP Publication
1582 103, para. 370)

1583 1584 **VI. Stakeholder involvement**

1585
1586 Since the mid 90s, the involvement of stakeholders in decision making related to
1587 protection issues has been recognised as a key process notably for favouring the

1588 understanding of the protection measures, improving the protection, adapting the
1589 measures to the local context and ensuring the sustainability of the protection. ICRP
1590 Publication 82 (1999) is the first ICRP Publication mentioning explicitly stakeholder
1591 involvement: “Many situations of prolonged exposure are integrated into the human
1592 habitat and the Commission anticipates that the decision-making process will include
1593 the participation of relevant stakeholders, rather than radiological protection
1594 specialists alone.” (para. 4).

1595
1596 Furthermore, in ICRP Publication 91 (2003) stakeholder involvement is introduced as
1597 part of the “principles” for protecting the environment: “The principle of informed
1598 consent, which emphasises the need for communication and public involvement,
1599 starting at the planning stage and well before decisions are taken from which there is
1600 no return. Such transparency of decision making should enable analysis and
1601 understanding of all stakeholder’s arguments... » (Current environmental
1602 management principles, para. 47).

1603
1604 In ICRP Publication 101 Part 1 (2006), dealing with Assessing Dose of the
1605 Representative Person for the Purpose of Protection of the Public, there is a first
1606 elicitation of the advantages of engaging stakeholders: “In the case of defining
1607 characteristics of the representative persons, stakeholder involvement can play an
1608 important role... In particular, stakeholders can be helpful in determining the
1609 reasonableness, sustainability, and homogeneity of habit data. Collaboration with
1610 stakeholders can significantly improve the quality, understanding and acceptability of
1611 characteristics of the representative person, and also strengthen support for the
1612 process and the results.” (Value of stakeholder input in characterising the
1613 representative person, § 102).

1614
1615 It is then reinforced in ICRP Publication 101 Part 2 (2006) as well as in ICRP
1616 Publication 103 (2008) for the Optimisation of Radiological Protection: “The
1617 involvement of stakeholders is a proven means to achieve incorporation of values
1618 into the decision-making process, improvement of the substantive quality of
1619 decisions, resolution of conflicts among competing interests, building of shared
1620 understanding with both workers and the public, and building trust in institutions.
1621 Furthermore, involving all concerned parties reinforces the safety culture and
1622 introduce the necessary flexibility in the management of the radiological risk that is
1623 needed to achieve more effective and sustainable decisions.” (The optimisation
1624 process, ICRP Publication 101 Part 2, para. 39).

1625
1626 More recently, stakeholder engagement processes were considered as key
1627 components of the development of strategies in case of preparedness of emergency
1628 situations and management of existing situations. (ICRP Publication 109 related to
1629 the Application of the Commission’s Recommendations for the Protection of People
1630 in Emergency Exposure Situations and ICRP Publication 111 related to the
1631 Application of the Commission’s Recommendations to the Protection of People Living
1632 in Long Term Contaminated Areas After a Nuclear Accident or a Radiological
1633 Emergency).

1634
1635 These considerations fully apply to radioactive waste management. The Commission
1636 recognises that the nature and extent of stakeholder involvement may vary between

1637 countries, but suggests that engagement with stakeholders is an important
1638 component to the justification and optimisation of protection strategies in waste
1639 disposal projects. During planning, it is essential that the plan is discussed, to the
1640 extent practicable, with relevant stakeholders, including other authorities and the
1641 public. Otherwise, it will be difficult to implement the plan effectively during operation.
1642 The overall protection strategy and its constituent individual protective measures
1643 should have been worked through with all those potentially exposed or affected.

1644
1645 In addition, because of the long time scale at stake, it is also necessary to consider
1646 the role of stakeholders to deal with intergenerational transmission of knowledge and
1647 memory of installations and protection strategies.
1648

1649 **Annex 2 ICRP use of “potential exposure“**

1650

1651 ICRP has frequently used the term „potential exposure“ in its publications:

1652

1653 *“.....The 1955 Conference on the Peaceful Uses of Atomic Energy had aroused*
1654 *great interest in the development of atomic power plants throughout the world. In*
1655 *time this would greatly increase the number of persons occupationally exposed*
1656 *and would also bring about actual or **potential exposure** of other persons and*
1657 *the population as a whole.” (ICRP Publications 1, 3, 4).*

1658

1659 Further uses of the term „potential exposure“ can be found in ICRP
1660 recommendations related to various fields of radiological protection (Publ. 10, 36, 37,
1661 40, 42, 43, 54, 57).

1662

1663 The first comprehensive discussion of the nature and application of the term
1664 „potential exposure“ is given in ICRP Publ. 60 and 64 (Protection from potential
1665 exposure):

1666

1667 *“(2) exposure which might result from the introduction of a practice is also divided*
1668 *into two broad categories: normal exposure and **potential exposure**. Normal*
1669 *exposure is that exposure which can reasonably be expected to occur, i.e., the*
1670 *exposure is predicted to occur with a probability of one or near one, independent*
1671 *of the time when the exposure occurs. It includes both exposure from operations*
1672 *conducted as planned as well as unintended high probability, low consequence*
1673 *events. These events are nearly certain to occur during operations but result in*
1674 *doses that are within prescribed limits. **Potential exposure** is exposure that,*
1675 *while not certain to occur, can be anticipated as a result of introducing or*
1676 *modifying a practice and to which a probability of occurrence can be assigned.*
1677 *Such exposure involves consideration of risk which falls outside the general*
1678 *boundaries considered for normal exposure. The occurrence of potential events*
1679 *and the chances that such events will result in a dose to an individual or group of*
1680 *individuals, when combined with the probability of effects from the expected*
1681 *resulting dose, can be presented as an a priori probability of harm. The initial*
1682 *consideration of potential exposures, therefore, should form part of the system of*
1683 *protection applied to practices, but it should be recognised that the exposures, if*
1684 *they occur, may lead to intervention (ICRP, 1991).”*

1685

1686 *(4) Potential exposure situations may arise from the introduction of most, if not all,*
1687 *practices and involve a large variety of potential consequences. There are*
1688 *also potential exposure situations, such as those associated with radioactive*
1689 *waste disposal, which can arise in the far distant future where consequences*
1690 *become much more difficult to predict. Although safety for this wide spectrum of*
1691 *situations should be governed by coherent and consistent principles, the level of*
1692 *effort required to implement the principles and the formulation of acceptance*
1693 *criteria will differ substantially depending on the complexity of the practice,*
1694 *sophistication of the engineering safety systems and the possible consequences.*

1695

1696 *(5) In practical application, a system of protection against potential exposure must*
1697 *apply fundamental safety principles developed for complex technical systems.....*
The report is intended to show how the fundamental safety principles can be
applied to all potential exposure situations..... Although the methods of
application of those principles may be less complex for a less complex source of ,
a conscientious application of the safety principles to the design and operation of

1698 sources appears appropriate to reduce the risk of accidental exposure in many
 1699 industrial and medical practices.
 1700 (11) In order to maintain a strict coherence in the treatment of actual and potential
 1701 exposures, it is necessary to extend the concept of detriment to include the
 1702 probability of occurrence of the situation giving rise to the detriment.... emphasis
 1703 has to be placed on one part of detriment - the probability of an attributable death.
 1704 However, nominal probability coefficients for stochastic effects that include non-
 1705 fatal cancer and severe hereditary effects can be used in considering detriment to
 1706 individuals from potential exposure. It must also be recognised that the
 1707 uncertainties in estimating the probability of occurrence will usually be much
 1708 greater than the uncertainties in estimating the probability of the consequences,
 1709 should the dose occur.
 1710 (33) The system of radiological protection recommended by the Commission for
 1711 proposed and continuing practices is based on the following general principles.
 1712 (b) In relation to any particular source within a practice, the magnitude of
 1713 individual doses, the number of people exposed and the likelihood of incurring
 1714 exposures where these are not certain to be received should all be kept as low as
 1715 reasonably achievable, economic and social factors being taken into account.
 1716 This procedure should be constrained by restrictions on the doses to individuals
 1717 (dose constraints), **or the risks to individuals in the case of potential**
 1718 **exposures (risk constraints)**, so as to limit the inequity likely to result from the
 1719 inherent economic and social judgments. (The optimisation of protection)
 1720 (61) Limits are used in safety to control the risk to individuals from all stipulated
 1721 sources of exposure. However, in order to establish requirements to constrain
 1722 exposure to individuals from a particular source, the Commission has
 1723 recommended the use of constraints in the process of optimisation, which are
 1724 source related and should be established in a manner such that the sum of the
 1725 risks from all relevant sources does not exceed the individual limit. **For the**
 1726 **treatment of potential exposure, the Commission recommends that limits of**
 1727 **risk be of the same order of magnitude as the health risk implied by the**
 1728 **dose limits for normal exposures. However, the dose limits themselves are**
 1729 **not applicable to potential exposure situations.**
 1730

Table 1. Range of probabilities in a year from which constraint may be selected

Sequence of events leading to doses treated as part of normal exposures	10^{-1} to 10^{-2}
Sequence of events leading to stochastic effects only but above dose limits	10^{-2} to 10^{-5}
Sequence of events leading to doses where some radiation effects are deterministic	10^{-5} to 10^{-6}
Sequence of events leading to doses where death is likely to result	$< 10^{-6}$

1731
 1732
 1733 The guidance provided in Publication 64 has been used and further developed in
 1734 ICRP Publications 73, 77, 81, 82, 92, 94 and 101.

1735
 1736 **Publication 103** confirms the basic principles by the following statements:
 1737 *Para. 176: Planned exposure situations are situations involving the deliberate*
 1738 *introduction and operation of sources. Planned exposure situations may give rise*

1739 both to exposures that are anticipated to occur (normal exposures) and to
1740 exposures that are not anticipated to occur (**potential exposures**).

1741 Para. 205: The Commission recommends that, when activities involving an
1742 increased or decreased level of exposure, **or a risk of potential exposure**, are
1743 being considered, the expected change in detriment should be explicitly included
1744 in the decision-making process.

1745 Para 214: Optimisation is always aimed at achieving the best level of protection
1746 under the prevailing circumstances through an ongoing, iterative process that
1747 involves: evaluation of the exposure situation, **including any potential**
1748 **exposures**...

1749 Para 229: In Table 4 the different types of dose restrictions used in the
1750 Commission's system of protection (limits, constraints, reference levels) are
1751 shown in relation to type of exposure situation and category of exposure. In
1752 planned exposure situations, there are also **risk constraints in order to take**
1753 **account of potential exposures**.

1754 Para 254: All categories of exposure can occur in planned exposure situations,
1755 i.e., occupational exposure, public exposure, and medical exposure of patients.....
1756 The design and development of planned situations should have proper regard **for**
1757 **potential exposures** that may result from deviations from normal operating
1758 conditions. Due attention should be paid to the assessment of **potential**
1759 **exposures** and to the related issue of the safety and security of sources.
1760 Chapter 6.1.3 provides further details.

1761 Para 265 states: "Events in which the potential exposures could occur far in the
1762 future, and the doses be delivered over long time periods, e.g., in the case of
1763 solid waste disposal in deep repositories: Considerable uncertainties surround
1764 exposures taking place in the far future. Thus dose estimates should not be
1765 regarded as measures of health detriment beyond times of around several
1766 hundreds of years into the future. Rather, they represent indicators of the
1767 protection afforded by the disposal system. The Commission has given specific
1768 guidance for the disposal of long-lived solid radioactive waste in Publication 81
1769 (ICRP, 1998b). This guidance remains valid."

1770 Para 267: The principles of constructing and analysing scenarios are well known
1771 and are often used in engineering. Their application was discussed in Publication
1772 76 (ICRP, 1997b). Decisions on the acceptability of potential exposures should
1773 take account of both the probability of occurrence of the exposure and its
1774 magnitude. In some circumstances, decisions can be made by separate
1775 consideration of these two factors. In other circumstances, it is useful to consider
1776 the individual probability of -related death, rather than the effective dose (ICRP,
1777 1997b). For this purpose, the probability is defined as the product of the
1778 probability of incurring the dose in a year and the lifetime probability of -related
1779 death from the dose conditional on the dose being incurred. The resulting
1780 probability can then be compared with a risk constraint. If the probability is lower
1781 than the risk constraint, it may be tolerated. Both of these approaches are
1782 discussed in the Commission's Recommendations for the disposal of long-lived
1783 solid radioactive waste in Publication 81 (ICRP, 1998b).

1784 Para 268: Risk constraints, like dose constraints, are source-related and in
1785 principle should equate to a similar health risk to that implied by the
1786 corresponding dose constraints for the same source. However, there can be large
1787 uncertainties in estimations of the probability of an unsafe situation and the

1788 *resulting dose. Thus, it will often be sufficient to use a generic value for a risk*
1789 *constraint. In the case of workers, this could be based on generalisations about*
1790 *normal occupational exposures, rather than on a more specific study of the*
1791 *particular operation. Where the Commission's system of dose limitation has been*
1792 *applied and protection is optimised, annual occupational effective doses to an*
1793 *average individual may be as high as about 5 mSv in certain selected types of*
1794 *operation (UNSCEAR, 2000). For potential exposures of **workers**, the*
1795 *Commission therefore continues to recommend a generic **risk constraint of $2 \cdot 10^{-4}$***
1796 *per year which is similar to the probability of fatal cancer associated with an*
1797 *average occupational annual dose of 5 mSv (ICRP, 1997b). For potential*
1798 *exposures of the **public**, the Commission continues to recommend a **risk***
1799 ***constraint of $1 \cdot 10^{-5}$ per year.***

1800
1801 Both dose and risk constraints should be applied in planned exposure situations.
1802 For the specific situation of waste disposal dose constraints can be used for
1803 comparison of options for normal releases, referred as “desing-basis evolution” of
1804 the depository facility. Events with lower probabilities than the desing-basis
1805 evolution should be treated as potential exposures and would require the
1806 application of relevant risk constraints. Risk constraints will be applied either in an
1807 aggregated or a disaggregated way.

1808
1809
1810

1811 **Annex 3 Technical and management principles and requirements**

1812

1813 Ref.: ICRP 101 section 6.6.4, §315, 316 ff

1814

1815 The general implementation of the Commission's recommendations on the disposal
1816 of radioactive waste requires that organizational and managerial structures and
1817 processes are put into place, and that technical principles are applied. Organizational
1818 structures and processes can largely differ from country to country, but should be
1819 based on the principles laid down by the IAEA in its Fundamental Safety Principles.

1820

1821 The Commission recommends that management principles and requirements should
1822 be applied to the disposal system development and implementation process to
1823 enhance the confidence that the protection of humans and the environment will be
1824 ensured for as long as needed.

1825

1826 Management systems play an important role "to improve the safety performance of
1827 the organization through the planning, control and supervision of safety related
1828 activities in normal, transient and emergency situations" and "to foster and support
1829 strong safety culture through the development and reinforcement of good attitudes
1830 and behaviour in individuals and teams so as to allow them to carry out their tasks
1831 safely" (IAEA GS-R-3).

1832

1833 The general requirements for establishing, implementing, assessing and continually
1834 improving a management system have been formulated by IAEA, and specific
1835 recommendations for the management system for the disposal of radioactive waste
1836 in IAEA Safety Standards publication GS-G-3.4.

1837

1838 A management system designed to fulfill the international IAEA requirements
1839 integrates safety, health, environmental, security, quality and economic elements,
1840 with safety being the fundamental principle upon which the management system is
1841 based. "The main aim of the management system shall be to achieve and enhance
1842 safety by:

1843

- 1844 - *bringing together in a coherent manner all the requirements for managing the*
1845 *organization;*
- 1846 - *describing the planned and systematic actions necessary to provide adequate*
1847 *confidence that all these requirements are satisfied;*
- 1848 - *ensuring that health, environmental, security, quality and economical*
1849 *requirements are not considered separately from safety requirements, to help*
1850 *preclude their possible negative impact on safety." (IAEA GSG-3.4)*

1851

1852 Maintaining and further developing knowledge, competences and skills for the
1853 disposal of radioactive waste, as an essential element to ensure high levels of safety,
1854 should be based on a combination of scientific research and technological
1855 development, insights gained from successive safety cases, learning through
1856 operational experience and technical cooperation between all actors. Independent
1857 reviews, transparency and accessibility of information, and openness to stakeholder
1858 participation are also important contributors for ensuring high levels of safety.

1859

1860 A key technical principle for developing disposal systems and assessing their safety
1861 is the concept of defence in depth which provides for successive passive safety
1862 measures, enhancing the confidence that the disposal system is robust and has an
1863 adequate margin of safety. The defence in depth concept as applied to disposal
1864 systems imposes that safety is provided by means of the various components of the
1865 system contributing to fulfilling the main safety functions in different ways over
1866 different timescales. The performance of the various components contributing to
1867 fulfilling the main safety functions has to be achieved by diverse physical and
1868 chemical processes, such that the overall performance of the system will not be
1869 unduly dependent on a single component or function. The main safety objective of
1870 the siting (a.o. selecting the natural barrier system and its environment) and
1871 designing (a.o. developing the man-made barrier system, taking due account of the
1872 site characteristics) of a disposal system is to ensure that post-closure safety will be
1873 provided by means of multiple safety functions and that even if a component or
1874 safety feature does not perform fully as expected, a sufficient margin of safety will
1875 remain.