

TECHNICAL AND ECONOMICAL ISSUES IN RADIOACTIVE WASTE CONDITIONING

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ABSTRACT

The waste acceptance requirements define the envelope or framework for all radioactive waste intended for disposal in a repository. Such requirements are of utmost importance as guidance in radioactive waste management decisions, i. e. in particular in waste conditioning techniques. According to them the waste generators and conditioners have to select appropriate conditioning techniques and/or to adjust existing methods to these requirements.

Thus, a repository being available, it is to be anticipated that the most economical solution of waste treatment and conditioning will lately be addressed and applied in practice. This may result in the decision that rather simple comparatively low-priced and well-proven conditioning techniques will be applied, i. e. conditioning techniques not aiming at waste form volume reduction and the use of self-shielded waste containers/packages. The costs of particular waste conditioning techniques must be evaluated and be compared with the respective number of waste packages produced as well as with the related shipment and disposal costs. As a result, optimized procedures for waste conditioning are finally to be expected.

INTRODUCTION

Waste acceptance requirements are relevant to the safety of a repository in its operational and post-closure phase. In addition, both the guidance to waste conditioning given by them [1] and the costs for disposal, e. g. per m³ waste package volume, basically determine the proper choice of radioactive waste conditioning concepts and strategies taking in particular economical aspects into consideration.

GERMAN RADIOACTIVE WASTE DISPOSAL POLICY

Since the early sixties, i. e. from its very beginning, the German radioactive waste disposal policy has been based on the decision that all types of radioactive waste are to be disposed of in deep geological formations. Thus, vitrified fission product solution originating from reprocessing and spent fuel elements as well as alpha bearing waste, spent sealed radiation sources and miscellaneous waste from small waste generators are affected by this decision and must be emplaced in a repository. As liquid and gaseous wastes are excluded from disposal in such a mine, only solid or solidified waste is accepted.

This approach has been taken up and confirmed in the coalition agreement between the Social Democrats and the Greens issued on October 20, 1998, representing the respective basis for the radioactive management and disposal policy of the Federal Government. Thus, all types of radio-

active waste will only be disposed of in a repository constructed and operated in deep geological formations.

SITE-SPECIFIC SAFETY ASSESMENTS

With respect to the planning work for a geological repository the basic aspects to be taken into account comprise, among other things, the following criteria being considered to be most important [2]:

- (a) The required safety of a repository constructed in a geological formation must be demonstrated by a site-specific safety assessment, including the respective geological situation, the technical concept of the repository including its scheduled mode of operation and the waste packages intended to be disposed of.
- (b) During the post-closure phase, the radionuclides which might reach the biosphere via the water path as a result of transport processes not completely excludable must not lead to individual dose rates exceeding the limiting values specified in section 45 of the Ordinance on Radiological Protection (0.3 mSv/a concept).

Thus, in order to demonstrate the safety of a repository in the operational and post-closure phase, site-specific safety assessments have to be carried out covering the following aspects:

- (a) Exposure of the operating staff and of the vicinity of the repository to direct and scattered radiation as well as to radiation due to radioactive substances released from the waste packages, and discharged via the exhaust air and waste water path (normal operation).
- (b) Exposure of the operating staff and of the vicinity of the repository to radiation due to radioactive substances released as a result of mechanical and/or thermal loads on the waste packages in the operational phase (assumed incidents).
- (c) Decay heat of the radionuclides contained in the waste packages (thermal influence upon the host rock).
- (d) Nuclear criticality safety in the operational and post-closure phase (criticality safety).
- (e) Exposure to radiation in the surroundings of the repository due to radioactive substances released via the water path in the post-closure phase (radiological long-term effects).

This work has to be based on detailed site-specific geological and hydrogeological data, a sufficiently detailed concept of the repository including the planned mode of operation, and data concerning the types, quantities and properties of the waste packages intended for disposal in the respective facility. The results of such investigations provide information on the acceptability of waste packages. In particular, they serve as a basis to prepare waste acceptance requirements and thus become an essential part of these requirements.

RADIOACTIVE WASTE CONDITIONING

Waste Origins and Arisings

In Germany, 19 nuclear power plants with a gross generating capacity of about 22 GW are presently in operation. 13 of them are PWRs, six are BWRs. Basic and applied investigations are performed in several nuclear research establishments, uranium enrichment and fuel element fabrica-

tion facilities are operated, and nuclear facilities are decommissioned and dismantled. Finally, there are many smaller waste generators, e. g. universities, industrial companies, hospitals, medical centres, the German Federal Armed Forces, as well as pharmaceutical and biomedical companies.

As to the waste arisings, BfS carries out an annual inquiry into the amounts of unconditioned and conditioned waste in Germany. According to the 1997 inquiry [3], the amounts of untreated/ unconditioned LLW/ILW and HLW were about 28,500 m³ and 500 m³, respectively. The existing amounts of conditioned LLW/ILW and HLW (without spent fuel) totalled to about 62,000 m³ and 1,400 m³, respectively, on December 31, 1997. Besides, a forecast (as of december 1998) into expected future waste arisings until 2080 resulted in about 328,000 m³ for conditioned LLW/ILW and about 48,000 m³ HLW including spent fuel in thick-walled casks.

Conditioning techniques

Conditioning of radioactive waste includes processing and/or packing of the waste, eventually after pre-treatment or sorting. Various strategies and techniques are applied. The selection of a conditioning process is dependent upon factors like the requirements for interim storage and disposal, acceptance of the process, and number/total volume of the resulting waste packages. Therefore, it is not surprising that different conditioning techniques for the same types of waste may be applied.

Primary waste must be collected and pre-treated in such a manner that it is suitable for the selected conditioning process. Principal pre-treatment methods are decontamination, crushing, compression, evaporation/distillation/rectification, decantation/dewatering/filtration and incineration/pyrolysis.

Incineration is especially attractive for all types of combustible waste. Solid or liquid waste and also alpha-bearing waste may be incinerated. The large volume reduction and, in particular, the inorganic and inert character of the intermediate product (e. g. ashes or slags) are reasons to recommend the incineration process from a repository-related point of view. Nevertheless, the off-gas treatment and the secondary waste must be taken into account.

The cementation of radioactive waste is the most well-known immobilisation process being widely applied. It is used for the solidification of liquids, the embedding of solids as well as the grouting of voids in scrap, rubble of filters. Various cementation techniques are used and the equipment may be mobile or stationary. If necessary, special cement formulae and/or suitable additives are to be used. Reactions with the cement, e. g. gas generation due to amphoteric metals in the ashes must be taken into account. Possible chemical reactions between the radioactive waste, the immobilisation material and the packaging must be limited to permissible levels.

The high-force compaction with 1500 Mg to 2000 Mg compactors is a new development to minimise waste amounts. Solid materials are compacted to a stable pellet. This technique is applied, for example, to metallic material, paper, plastic, rubble and even ashes from the incineration of organic radioactive waste. Due to possible gas generation occurring in compacted waste, a

segregation before compaction is reasonable, i.e. to separate metallic and wet organic materials. Alternatively the compacted pellets may be dried.

The drying of liquid radioactive waste is another new development for waste minimisation. The liquids are fed into a packaging which is heated. The evaporation is supported by application of a slight vacuum. The resulting dry residue consists of the constituents dissolved or dispersed in the liquid. The resulting product contains a higher activity concentration than, for example, the cemented waste form and therefore needs a superior shielding which is often made of cast iron.

The melting of activated and/or contaminated metallic material is of special interest for the de-commissioning and dismantling as well as the repair and maintenance of nuclear facilities. Depending on the radioactivity level in the melt it is of special interest to re-use the metals by casting waste containers/packagegings for radioactive waste. If the radionuclide content is too high the melt might be poured into a packaging as radioactive waste. The resulting slag has also to be conditioned and disposed of.

Radioactive waste has to be packed for handling, transport and storage. The necessary quality of a packaging is dependent on the type of waste and its radionuclide inventory. Sheet steel, reinforced concrete and cast iron are common as packaging material. Cylindrical and box-shaped packagegings of different size and weights are being used. A standardisation of the packagegings has been successfully achieved in order to harmonise the equipment as well as the repository-related handling and emplacement techniques

DERIVATION AND STRUCTURE OF WASTE ACCEPTANCE REQUIREMENTS

Derivation of Requirements

For the preparation of waste acceptance requirements two different procedures are basically available. On the one hand, it is possible to derive specific requirements on individually characterized or specified wastes, e.g. for radioactive waste originating from the operation of nuclear power plants. On the other hand, it is possible to define such requirements not addressing individual waste streams but to establish a framework all types of radioactive waste to be disposed of must comply with.

In Germany, the latter possibility was pursued. The waste acceptance requirements which were prepared for the Morsleben repository [4] and the Konrad repository project [5], define the safety-related envelope or framework for radioactive waste intended for disposal in the respective repository. In particular, they are based on the results of site-specific safety assessments. These requirements cover a broad range of different waste packages and are not prepared for individual types of waste packages, i.e. they do not include specific requirements on individually characterized or specified wastes. Both of them were prepared in such a way that a flexible system of requirements could be established, which is not only tailored to the radioactive waste presently generated but which also allows improvements and future developments in waste conditioning techniques. Such a flexible system includes several alternatives and different options for the waste packages all of which ensuring the required level of safety for the repository in the operational and post-closure phase. The waste generators and conditioners thus need not meet "general" requirements but have the possibility of applying and fulfilling only those requirements which are

specifically applicable to the radioactive waste packages produced by them and intended for disposal. Naturally, such a flexible system of requirements is considerably extended and has become more complicated. The advantages offered to the waste generators and conditioners preponderate, however, over this apparent disadvantage.

The Konrad Waste Acceptance Requirements

The results of the Konrad site-specific safety assessment have been converted into both the design of the surface and underground facilities as well as in a system of preliminary waste acceptance requirements. This system is formulated in such a way that it first describes the general disposal-related aspects and the general requirements to be fulfilled by the waste packages and then develops into more specific requirements on the waste forms, the waste containers/packagings, the activity limitations on individual radionuclides, the documentation and the delivery of waste packages. A survey as the structure of the Konrad waste acceptance requirements is given in following:

- (a) General basic requirements on radioactive waste to be disposed of
- (b) General requirements on waste packages
 - Local dose rate
 - Surface contamination
 - Depressurized delivery
- (c) Requirements on waste forms
 - Basic requirements
 - without immobilization material
 - with immobilization material
 - Waste form groups
 - Exhausting of activity limiting values
 - Filling of waste packages
- (d) Requirements on waste containers/packagings
 - Basic requirements
 - Waste container classes
 - Incident resistant packagings
 - Inner containers
- (e) Limitations of activity
 - Permissible activities for individual radionuclides per waste package
 - normal operation
 - assumed incidents
 - thermal influence upon the host rock
 - nuclear criticality safety
 - Total activities
 - Declaration of radionuclides
- (f) Delivery of waste packages
 - Compliance with transport regulations
 - Permits

- Labeling of waste packages
- Requirements on shipping units.

The results of the Konrad incident analysis are of particular importance to waste conditioning. Attention shall be focussed on the six waste form groups and the two waste container classes derived from this analysis. They include safety-related requirements on the quality of the waste product and of the waste container/packaging.

In general, the requirements rise from waste form group 1 to 6, i.e. more and more specific requirements must be fulfilled in addition to basic requirements (waste form group 1). As the activity concentration in a waste package and the increased quality of the waste form or the waste container are connected, the permissible activity in a waste package can be increased from waste form group 1 to waste form group 6. This demonstrates the very close connection between waste form, packaging and radionuclide inventory and their interdependence and interaction with respect to the requirements to be met.

The waste forms can be assigned to that group for which the specific requirements are fulfilled. No generally valid rule can be defined for a distinctive assignment of a waste form to a waste form group. Careful consideration must be given by the waste generator or conditioner to the identification of the waste form and packaging properties and the determination of the radionuclide inventory of each waste package. That is why the Konrad waste acceptance requirements have been the starting point for those decisions being necessary to allow an appropriate radioactive waste pretreatment and conditioning for disposal. Thus, in particular, these requirements have provided guidance to the waste generators and conditioners [1].

According to the barrier quality of the packaging, a basic distinction is made between two waste container classes. In parallel to the waste forms, a packaging can be assigned to one of the two classes if the specific requirements are fulfilled. The respective activity limiting values for waste packages with class I containers are dependent on the waste form. This is not the case for waste class II containers which are of such a quality that the barrier function of the waste form does not contribute significantly to the total quality of a waste package. According to this, the Konrad waste acceptance requirements have again been an essential prerequisite as to the proper selection of a waste container and/or a packaging.

The Morsleben Waste Acceptance Requirements

The structure of the Morsleben waste acceptance requirements is similar to that of the Konrad requirements. Nevertheless, there are two decisive differences:

- (a) The operation of the Morsleben repository is regulated by the license issued on April 22, 1986, and by further documents pertinent to it. As the license is still effective, these documents represent the legally binding framework which must be adhered to. Thus, the Morsleben waste acceptance requirements prepared by BfS [4] include both boundary conditions prescribed in the license and additional regulations, in particular self-restrictions, results of supplementary safety assessments which keep to this framework and instructions by the self-

surveillance of the Morsleben repository. According to this, at first sight, the Morsleben requirements appear to be rather complicated.

- (b) The Morsleben waste acceptance requirements clearly distinguish between requirements on solid radioactive waste and on sealed radiation sources. Such a difference is not explicitly made within the Konrad requirements; they are formulated in a more general sense.

A survey on the structure of the Morsleben waste acceptance requirements is given in the following:

- (a) Introductory remarks
- (b) Classification of radioactive wastes
- (c) General basic requirements on radioactive waste to be disposed of
- (d) Requirements on radioactive waste of type A1 (solid waste)
 - Basic requirements on waste form
 - Activity limitations
 - Requirements on packagings
 - Packagings
 - Requirements on waste packages
 - Requirements on sealed radiation sources to be converted into type A 1 waste
- (e) Requirements on radioactive waste of type A 3 (sealed radiation sources)
 - Assignment of spent sealed radiation sources to waste types
 - Basic requirements on sealed radiation sources
 - Packagings
 - Activity limitations
 - Surface contamination
 - Labeling of waste packages
- (f) Declaration of radionuclides
- (g) Delivery of waste packages.

The Morsleben waste acceptance requirements which form part of the operational license and its additional documents are based on a classification of radioactive waste to be disposed of, so-called radiation protection groups and the respective emplacement techniques. They clearly distinguish between requirements on solid radioactive waste (type A1 waste) and on sealed radiation sources (type A3 waste). Liquid radioactive waste (type A2 waste) is no longer accepted. BfS stopped the in-situ solidification of that waste as a self-imposed restriction [6]. Some special waste (type A4 waste) may be disposed of in the Morsleben repository provided that it is converted into type A1 waste. The classification due to the radiation protection groups S1 to S5 accounts for the dose rate at the unshielded surface of solid wastes, and for the activity of spent sealed radiation sources.

The requirements on both type A1 and A3 waste specify, among other things, quality characteristics of the waste form, waste containers/packagings and limitations of permissible individual radionuclide activity concentrations. As to the activities per waste package, it should be pointed

out that, due to the license issued in 1986, the activity concentration of alpha emitters is limited to $4 \cdot 10^8$ Bq/m³. With regard to beta/gamma emitters, radiation protection groups S1 to S5 were established representing bandwidths of permissible activity concentrations from below $4 \cdot 10^9$ Bq/m³ up to $4 \cdot 10^{13}$ Bq/m³. Radioactive waste assigned to S1 and S2 is stacked whereas waste assigned to S3, S4 or S5 has to be dumped. In addition to this, supplementary safety assessments were performed for the normal operation of the repository, assumed incidents, nuclear criticality safety and long-term radiological effects, thus concretizing the operational license of 1986 by introducing radionuclide-specific activity limitations. The most restrictive limitations on permissible activity concentrations must be met.

WASTE ACCEPTANCE REQUIREMENTS AND RADIOACTIVE WASTE CONDITIONING

Basic Considerations

In Germany, the emplacement of radioactive waste in the Asse salt mine ceased at the end of 1978. Since that time, waste conditioning has predominantly been determined by the lack of a repository, the type of interim storage facilities and the available interim storage capacity. Thus, the necessity to use self-shielded waste containers and to minimize the volume of conditioned radioactive waste emerged and, consequently, the development of new and advanced conditioning techniques has been stimulated. As a result, in particular high-force compaction of miscellaneous waste, incineration of combustible waste and drying of liquid waste as well as the use of self-shielded waste containers have extensively and successfully been applied. In parallel to that development, the Konrad waste acceptance requirements were prepared. Even in their preliminary form these requirements have been of great importance as guidance in waste conditioning decisions since their first issue in 1987 [7]. Finally, the operation of the Morsleben repository from January 13, 1994, through September 28, 1998, offered potential new developments or modifications in the application of existing conditioning techniques at that period of time.

Having this development in mind, the interaction between waste acceptance requirements and decisions on radioactive waste conditioning shall be focussed on taking the Morsleben requirements as an example.

Consequences Resulting from the 1994 to 1998 Operation of the Morsleben Repository

From a conditioner's point of view, the range of validity of the Morsleben waste acceptance requirements as well as the disposal costs per m³ waste package volume were of utmost importance offering a sound basis to decide upon waste treatment and conditioning. Thus, the waste generators and conditioners re-evaluated and optimized/rationalized present radioactive waste conditioning.

As the Morsleben requirements constituted the basis for detailed specifications of those wastes to be disposed of, it was meaningful to analyze these requirements very carefully and to adapt conditioning strategies and techniques, respectively. In this connection, it should be taken into account that the validity of these requirements covered the operational life time of the Morsleben repository, thus providing in particular security regarding decisions on waste conditioning.

In addition to technical aspects, due to the Morsleben costs for disposal fixed at 12,500 DM (approx. 6,900 \$) per m³, i. e. 2,500 DM (approx. 1,400 \$) per 200 litre drum, it was henceforth pos-

sible to select appropriate conditioning procedures also taking into account economic aspects [8]. For example, regarding combustible waste, it could be meaningful to use high-force compaction instead of incineration. Decantation and/or immobilization of liquid waste seems to be preferable compared to drying. As to miscellaneous waste (i. e., metal scrap, protective clothing, insulation material, worn-out equipment, paper, polyvinylchloride, rubble or contaminated soil), processing via high-force compaction should be opposed to less expensive treatment using a baling press and resulting disposal costs be compared with. The use of cylindrical shielded transport containers, i. e. so-called drum containers and primary containers [4], allows the emplacement of radioactive waste forms packaged into not-shielded waste containers, e. g. 200 litre drums.

Economical Considerations

In practice, the operation of the Morsleben facility and the experiences gathered so far gave rise to changes and alternative procedures in radioactive waste conditioning. According to the repository's availability, immediate waste package delivery after conditioning and successfully passing of quality assurance/quality control measures was allowed for. Thus, both the necessity for conditioning techniques aiming at waste form volume reduction and the consideration of costs for waste package interim storage strongly decreased, thereby contributing to savings. This shall be discussed in a more detail referring to typical wastes and conditioning techniques from the areas of nuclear power plant operation and radioisotope application in research, medicine or industry.

Modern conditioning techniques like drying of resins or the incineration of combustible waste including the high-force compaction of ashes and slags cause total costs in the order of magnitude of up to 80,000 DM (approx. 44,000 \$) per m^3 and up to 700,000 DM (approx. 385,000 \$) per m^3 waste package volume, respectively [9]. The interim storage of waste packages may be estimated to amount annually to about 1,500 DM (approx. 825 \$) per m^3 waste package volume. Consequently, the application of modern conditioning techniques turns out to be rather expensive.

In contrary to such techniques, the Morsleben waste acceptance requirements offered, among other things, the simple packaging/filling of radioactive waste into containers, the high-force compaction of miscellaneous waste or the immobilization of radioactive waste by embedding in cement or grouting. For example, the high-force compaction of primary waste originating from the operation of nuclear power plants totals to about 33,000 DM (approx. 18,150 \$) per m^3 waste package volume [9]. Total costs for waste immobilization using cement may be estimated to be in the same order of magnitude. Thus, the application of such comparatively low-priced conditioning techniques contribute to an overall expenditure decrease. Depending upon the type of waste, such savings may even turn out to be more beneficial if only the packaging/filling of radioactive waste into containers without any further treatment is applied.

The majority of short-lived low and intermediate-level radioactive waste in Germany was disposed of in the Morsleben repository. Since the resumption of waste emplacement operations, a total radioactive waste volume of 22,320 m^3 was disposed of. Of this, the major part of 21,284 m^3 (95.4%) was stacked whereas the minor part of 1036 m^3 (4.6%) was dumped (1994 to 1998 operation). In addition to the emplacement of short-lived low and intermediate-level radioactive waste, in particular the operators of nuclear power plants started activities to re-condition waste with comparatively higher specific activity concentrations by transferring it into a form being

suitable for disposal in the Morsleben repository, i. e. waste packages being characterized by comparatively lower specific activity concentrations. On average, respective costs for , e.g., the re-conditioning of resins in thick-walled cylindrical cast-iron containers could be estimated to be in the order of magnitude of up to 76,000 DM (approx. 41,800 \$) per m³ waste package volume [9]. Waste processing and disposal costs could thus be optimized and the most economical solution be applied [10].

As far as radioactive waste originating from radioisotope application in research, medicine or industry is concerned, immobilization using cement and high-force compaction are usually applied. The cementation of spent sealed radiation sources as well as concentrates and liquids originating from decontamination activities totals to about 22,000 DM (approx. 12,100 \$) per m³ waste package volume [9]. The high-force compaction of miscellaneous waste, e.g. subsequent to an appropriate pretreatment (shredder process), amounts to about 15,150 DM (approx. 8,300 \$) per m³ waste package volume. It should be mentioned that detailed acceptance criteria with regard to processing and packaging as well as price-lists for the conditioning of such waste are available [11-14].

As a result, it can be concluded that the waste conditioners offer a broad spectrum of different pretreatment, treatment, processing and packaging techniques. Thus, the waste generators are enabled to decide upon the most appropriate and economic conditioning method according to the specific properties of the waste concerned and the acceptance criteria or requirements to be applied for an interim storage facility and/or a repository. Respective conditioning costs may vary in the order of magnitude of 15,150 DM (approx. 8,300 \$) to 700,000 DM (approx. 385,000 \$) per m³ waste package volume. It should be pointed out that these costs in general comprise shipment of primary waste to the conditioning facility, waste container costs, waste conditioning costs (processing and packaging), preparation of respective documentation and shipment to an interim storage facility or repository. In addition, due to recent experiences, the waste package quality assurance (i.e., the demonstration of the fulfilment of waste acceptance requirements) amounts to about 1,300 DM (approx. 700 \$) per m³ waste package volume [9].

CONCLUSIONS

Technical and economical issues resulting from the Morsleben repository's operation has helped to increase the awareness for thoughtful practices in the proper selection of waste conditioning strategies and techniques. The validity of waste acceptance requirements offering security as well as fixed disposal costs are the most decisive prerequisites for decisions to be taken in waste conditioning. Thus, a repository being available, it is to be anticipated that the most economical solution will lately be addressed and applied in practice. Having existing waste conditioning techniques in mind, this may result in the decision that rather simple, comparatively low-priced and well-proven conditioning techniques as packaging of waste in drums, decantation/dewatering or cementation and grouting of waste may increasingly be applied as compared to conditioning techniques aiming at volume reduction and the use of self-shielded packagings. Nevertheless, such developments depend on the respective waste acceptance requirements and require careful technical analyses and detailed economical considerations. The costs of particular waste conditioning techniques must be evaluated and be compared with the respective numbers of waste packages produced as well as with the related shipment and disposal costs. Further aspects, e. g. radiation

exposure, should additionally be taken into account. As a result, optimized procedures for waste conditioning are to be expected whereby the required safety of a repository in its operational and post-closure phase will always be ensured.

REFERENCES

- [1] P. Brennecke/E. Warnecke, in: Proc. Waste Management '93, Vol. 1, 411-415, WM Symposia Inc., Tucson (1993).
- [2] Sicherheitskriterien für die Endlagerung radioaktiver Abfälle in einem Bergwerk, Bundesanzeiger **35** 2 (1998) 45-46.
- [3] A. Hollmann, BfS- Report ET-IB-101, Salzgitter, October 1998
- [4] K. Kugel/W. Noack/B.-R. Martens/H. Giller/P. Brennecke, BfS Report ET-IB-85, Salzgitter, August 1996.
- [5] P. Brennecke, BfS Report ET-IB-79, Salzgitter, December 1995.
- [6] W. Noack/K. Kugel/P. Brennecke, in: Proc. ICEM '95, Vol. 2, 1285-1288, ASME, New York (1995).
- [7] P. Brennecke/E. Warnecke, Report PTB - SE-17, Braunschweig, January 1987.
- [8] P. Brennecke, in: Proc. Waste Management '97, Paper 38-2, WM Symposia Inc., Tucson (1997).
- [9] D. Ehrlich, in: Proc. Seminar Neue Entwicklungen im Strahlenschutz, TÜV Akademie GmbH, München (1998).
- [10] S. Theis, in: Report BfS-13/97, 74-96, Salzgitter, January 1997.
- [11] Forschungszentrum Karlsruhe GmbH - Hauptabteilung Dekontaminationsbetriebe, Bedingungen für die Annahme radioaktiver Stoffe, Karlsruhe, January 1997.
- [12] Forschungszentrum Karlsruhe GmbH, Preisliste 1998 für Dienstleistungen der Hauptabteilung Dekontaminationsbetriebe, Karlsruhe, December 1997.
- [13] AEA Technology QSA GmbH, Bedingungen für Abholung und Übernahme radioaktiver Stoffe, Braunschweig, October 1998.
- [14] AEA Technolgy QSA GmbH, Umwelt-Technik Preisliste 1995, Braunschweig, April 1995.