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Extended summary on possible storage options for liquid and solidified mercury and the corresponding acceptance criteria and facility related requirements

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Beratungsgesellschaft für integrierte Problemlösungen

1 Legal background and methodology

Legal background

Regulation (EC) N° 1102/2008 lays down that metallic mercury resulting from specific sources (e.g. chlor-alkali-plants) has to be considered as waste from 15 March 2011. In combination with the export ban of metallic mercury from 15 March 2011 a safe storage for considerable amounts of surplus mercury has to be ensured within the Community to prevent the metallic mercury from re-entering the market.

By way of derogation from Article 5 (3) (a) of the landfill directive¹ the Hg-Regulation allows the permanent or temporary storage of metallic mercury - that is considered as waste – at certain storage facilities. The possible storage facilities have to fulfil the requirements set out in Directive 1999/31/EC (landfill directive) and Decision 2003/33/EC (WAC decision). But as the existing provisions are established for the storage of solid waste it has to be investigated if these provisions are sufficient to ensure a safe storage of metallic mercury with its specific properties (e.g. liquid status, high vapour pressure).

Against this background one major objective of this study was to elaborate waste acceptance criteria for liquid mercury as well as facility related requirements which storage facilities have to fulfil – apart from the already existing requirements laid down in the landfill directive and WAC decision.

Apart from the storage of liquid mercury also the possibility of a pre-treatment of the liquid mercury prior to the storage has been investigated within this study (as foreseen in Article 8 (2) of the Hg-Regulation). A pre-treatment in this study means the stabilisation or solidification of the liquid mercury to a solid form (e.g. mercury sulphide). An extensive overview on possible pre-treatment technologies for elemental mercury is presented in the study including an assessment of the technology against technical, environmental and economic criteria. The assessment also provides an overview on the maturity and availability of the technologies (see also extended summary on pre-treatment technologies for metallic mercury).

Although Regulation (EC) N° 1102/2008 only applies for metallic mercury acceptance criteria and facility related requirements have been elaborated within this study for stabilised metallic mercury which should apply in addition to the existing legal requirements.

¹ Council directive 1999/31/EC of 26 April 1999 on the landfill of waste (OJ L14, 20.1.2009, p.10)

Methodology

Against the described background and objectives the methodological approach of the project is visualized in the following figure:

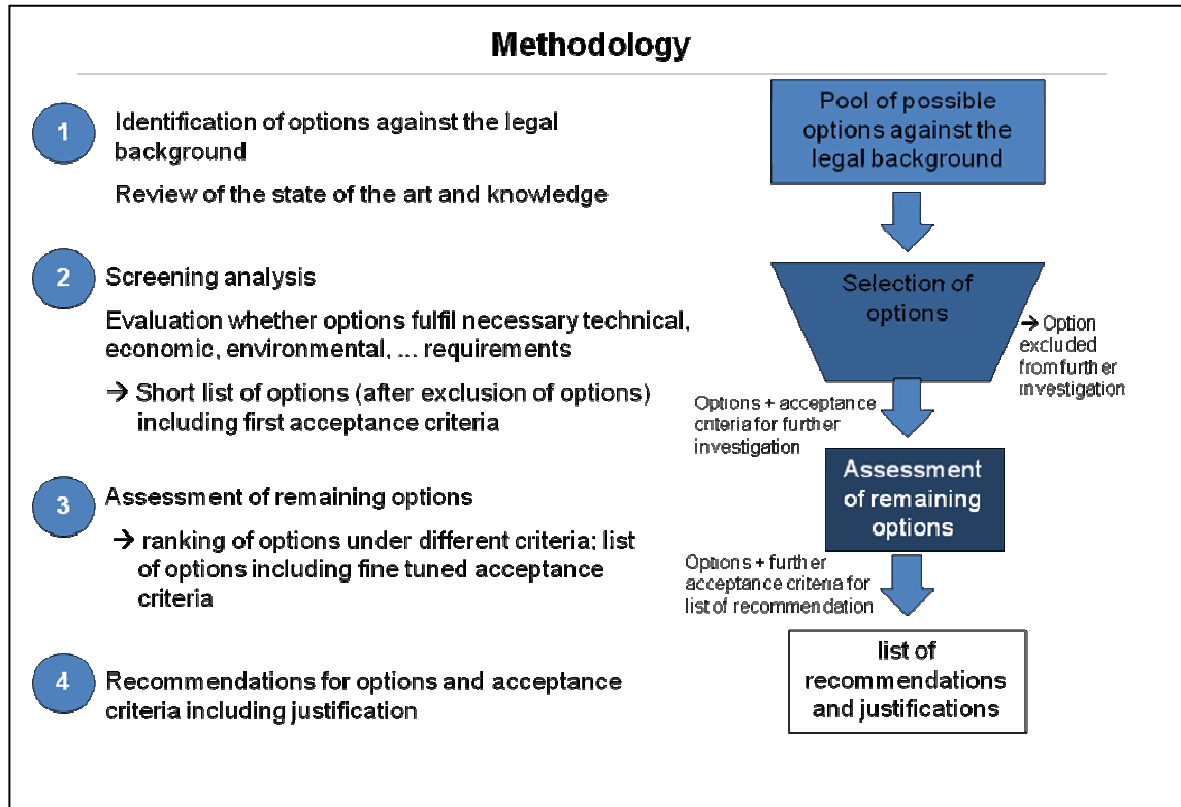


Figure 1-1: Overview on the methodological approach

In a first step legally compliant storage options have been identified for the storage of metallic mercury as well as for the possible storage of stabilized mercury. For this purpose a detailed review (literature and patents research, expert interviews, site visits, conferences) of the existing pre-treatment technologies, disposal facilities for temporary and permanent storage and of different types of containment has been carried out. With regard to disposal facilities, apart from existing hazardous waste landfills (above ground and underground), also experience from radioactive waste disposal is included in the review. An overview on the current status of knowledge explains the hazardous properties and characteristics of metallic mercury with a special focus on its behavior in the environment. An overview on existing legal requirements, policies and best practice related to the disposal of mercury waste in Europe as well as on an international level is provided.

The objective of this initial work was to get a current and updated status on the scientific and technical knowledge related to the storage or disposal of mercury.

Based on the outcome of the review process a screening analysis has been carried out. One target of the screening analysis was to exclude options from further investigation if there was no reasonable possibility to realize them in compliance with minimum technical, environmental and economic criteria. A second target of the screening analysis was to identify basic acceptance criteria and facility

related requirements that need to be linked to the options (or to combinations of options) to fulfill the minimum criteria. It was investigated whether these minimum requirements would be fulfilled by applying already implemented legal provisions (e.g. in the WAC Decision) or whether additional requirements for the facilities or criteria for the acceptance of the waste would be necessary. Within the screening analysis also the feasibility of options related to their implementation under the given time constraints (the export ban enters into force on 15 March 2011) and required resources for realization are investigated.

Options which have been assessed as not fulfilling the minimum requirements set out in Regulation (EC) N° 1102/2008 have not been further investigated.

The screening analysis was followed by an assessment of remaining options or combinations of options on their strengths and weaknesses. Within this assessment environmental and economic targets have been used to basically evaluate the options. After the basic evaluation potential combinations of options and fine tuning of correlated acceptance criteria took place and the evaluation was repeated for a final overview on the appropriateness of options which then found their way to the list of recommendations.

2 Overview on options

Against the legal background the following options have been identified for the storage of liquid or pre-treated mercury:

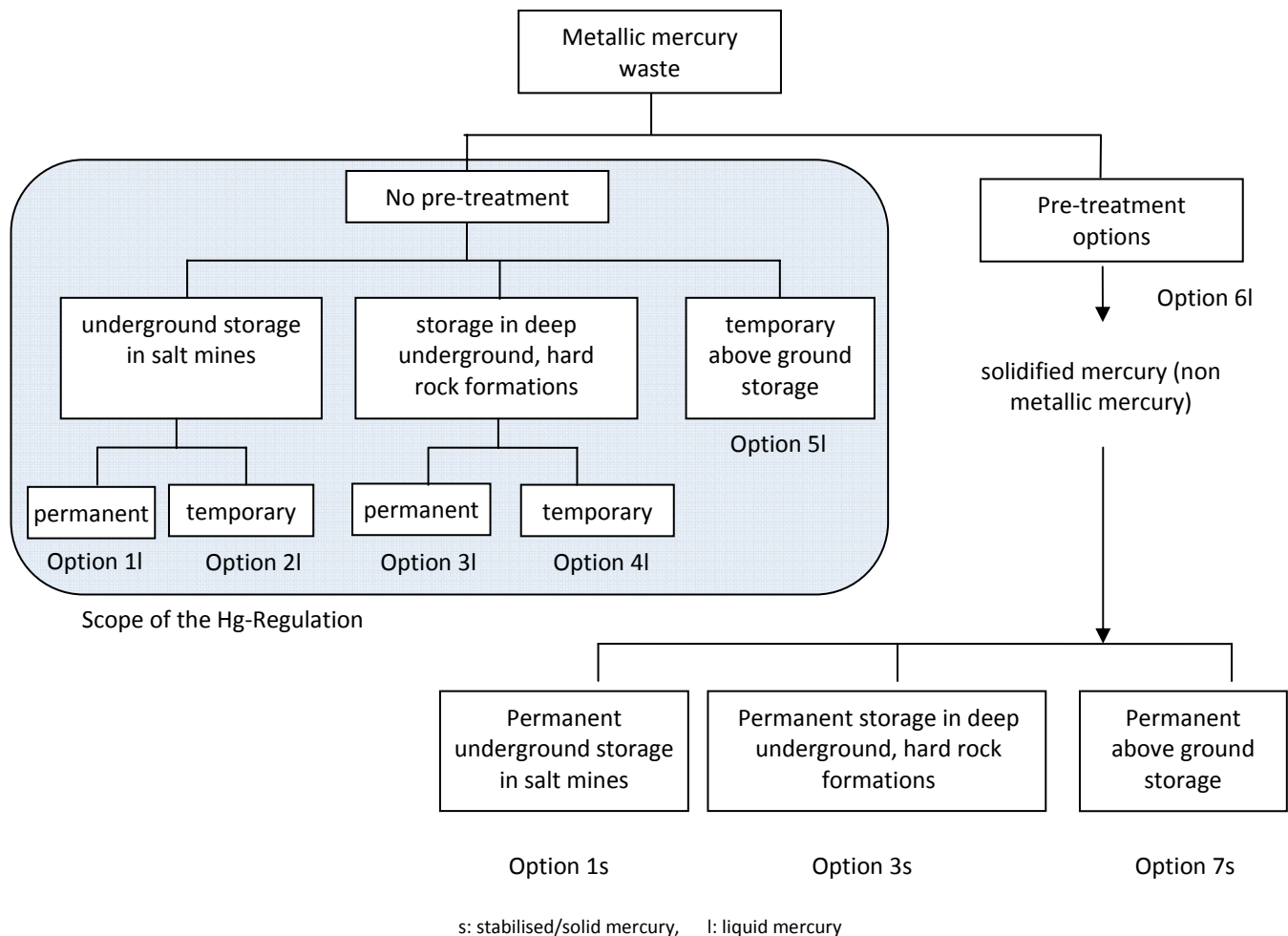


Figure 2-1: Overview on options

In contrary to the other options, option 6 has already been divided into sub options as different treatment technologies related to different environmental performance, costs and in particular maturity of the technologies have to be evaluated. After the pre-treatment of mercury a suitable permanent storage option has to be identified for the stabilised mercury. Another temporary storage after the pre-treatment does not provide the requested type of a solution, therefore after pre-treatment only permanent storage options are considered further.

In case permanent options are not available at present, e.g. due to lack of research activities or immature pre-treatment technologies, the possibility of a temporary storage before a permanent storage to bridge the gap has also been taken into consideration. The various options can also be

combined (e.g. temporary storage + pre-treatment + permanent storage) and in this way form a broad basis for all potential solutions related to the problem of the disposal of liquid mercury.

3 Outcome of the screening analysis

Based on the screening analysis the following storage options have been assessed as potentially suitable for the storage of **metallic mercury** – under the condition that specific waste acceptance criteria and facility related requirements are fulfilled:

- Permanent storage of metallic mercury in salt mines
- Temporary storage of metallic mercury in salt mines
- Temporary storage of metallic mercury in above ground facilities

Specific waste acceptance criteria for **metallic mercury** and facility related requirements have been elaborated correspondingly.

The temporary or permanent storage of **metallic mercury** in underground hard rock facilities has been assessed as not appropriate.

The evaluation of the pre-treatment technology concluded that technologies are available or will be available in future for a stabilization of metallic mercury waste in a way that it can be stored on landfills (underground and above-ground). Consequently waste acceptance criteria as well as facility related requirements have been elaborated for **stabilized mercury** which should be taken into consideration in addition to the already existing legal requirements for the storage of waste.

4 Waste acceptance criteria and facility related requirements

Important:

Only sites with a valid permit for the disposal of (hazardous) waste have been investigated. The provisions set out in the landfill directive as well as in the WAC decision are valid for the disposal of metallic or stabilized mercury (with few exceptions). The following acceptance criteria and facility related requirements have to be fulfilled additionally to the provisions set out in the above mentioned legal documents.

4.1 Proposed acceptance criteria for metallic mercury and additional facility related requirements

Storage option	Salt mine with valid permit as underground storage facility for hazardous waste (D _{HAZ})		Above ground storage site with valid permit for the storage of hazardous waste, category C
	Permanent storage	Temporary storage	Temporary storage
Waste acceptance criteria for metallic mercury Hg	<ul style="list-style-type: none"> - Purity of the mercury: > 99.9 % per weight - Max. metallic contaminates (like iron, nickel, copper): < 20 mg/kg each - Presence of sodium < 1 mg/kg - No residual radioactivity (e.g. from tracers used in the chlor-alkali industry) - No impurities capable of corroding carbon or stainless steel (e.g. nitric acid solution, chloride salts solutions, or water) 		
Containment	<ul style="list-style-type: none"> - Container material: Stainless steel (AISI 304, 316L) or carbon steel (ASTM A36 minimum) - Container has to be gas and liquid tight - Outer side of the container must be resistant against the storage conditions - Containers should be certified for the storage of mercury - Welds should be avoided as far as possible 		

Storage option	Salt mine with valid permit as underground storage facility for hazardous waste (D _{HAZ})		Above ground storage site with valid permit for the storage of hazardous waste, category C
	Permanent storage	Temporary storage	Temporary storage
Waste acceptance procedure	<ul style="list-style-type: none"> - Only acceptance of metallic mercury which fulfils the minimum acceptance criteria as set out above (verification required either by sampling or a certificate issued by a certified person) - Visual inspection of the container, no acceptance of damaged, leaking or corroded containers - Only acceptance of containers with adequate labelling (at least according to the transport requirements) - Only acceptance of containers with a certificate which confirms the appropriateness for the storage of liquid mercury <p>The certificate – might also be a plate permanently fixed on the container - should include as a minimum, the identification number of the container, container material, producer of the container, date of production and a confirmation that only mercury has been stored/transported in the container (exclusion of storage of products which might react with mercury or the container material).</p> <p>In the case of sealed containers, the filling and the sealing of the containers should be supervised by a certified person, which confirms that only mercury of the required specification is contained in the sealed containers. The certificate, which has to be issued by the certified person, should include at least:</p> <ul style="list-style-type: none"> - Name and address of the company (waste owner) - Place and date of packaging - The purity of the mercury (min. >99.9%) and, if relevant, description of the impurities (analytical report has to be provided) - Quantity of the mercury - Any specific comments - Signature 		

Storage option	Salt mine with valid permit as underground storage facility for hazardous waste (D_{HAZ})		Above ground storage site with valid permit for the storage of hazardous waste, category C
	Permanent storage	Temporary storage	Temporary storage
Record keeping	<p>Documents referring to the metallic mercury (e.g. basic characterization, compliance testing) shall be kept at least until the closure of the disposal site.</p> <p>A plan of the storage area should be kept also after the closure of the storage site.</p>	<p>Documents referring to the metallic mercury (e.g. basic characterization, compliance testing) shall be kept at least 3 years after the termination of the storage.</p>	
Facility related requirements	<ul style="list-style-type: none"> - Effectiveness of the geological barrier in terms of migration time for mercury to the biosphere >1 million years (verification by a site-specific assessment including a long term safety verification) - Minimum thickness of the isolating salt rock: 100m (justified exemption possible) - Minimum depth of the storage area: 300m (justified exemption possible) - Minimum distance from access shafts and other waste storage areas: 100m - No storage together with other waste - Storage of the liquid mercury containers in collecting basins able to catch the whole amount of stored mercury 	<ul style="list-style-type: none"> - Cavity stability and secure access to the storage area >100 years - No storage together with other waste - Minimum distance to access shafts and other waste storage areas: 100 m - Storage of the liquid mercury containers in collecting basins able to catch the whole amount of stored mercury 	<ul style="list-style-type: none"> - Storage in constructed building with engineered barriers to protect the environment against mercury emissions - Storage of the liquid mercury containers in collecting basins able to catch the whole amount of the stored mercury - Hg-resistant sealants for the floor and installation of a slope towards a collection sump - Fire protection system - Ventilation system - No storage together with other waste - Area should be secured to prevent

Storage option	Salt mine with valid permit as underground storage facility for hazardous waste (D _{HAZ})		Above ground storage site with valid permit for the storage of hazardous waste, category C
	Permanent storage	Temporary storage	Temporary storage
			unauthorised removal of the mercury
monitoring, inspection and emergency requirements	<p>Installation of a permanent mercury vapour monitoring systems</p> <ul style="list-style-type: none"> - with a sensitivity of at least 0.02 mg mercury/m³ - visual and acoustic alert system - annual maintenance and control of the system - sensors have to be installed at ground level and head level <p>Regular visual inspection of the container and the storage site by a certified person</p> <ul style="list-style-type: none"> - max. interval: 12 months, or 		<p>Installation of a regular immission monitoring system of the surrounding of the storage facility.</p> <p>Installation of permanent mercury vapour monitoring systems</p> <ul style="list-style-type: none"> - with a sensitivity of at least 0.02mg mercury/m³

Storage option	Salt mine with valid permit as underground storage facility for hazardous waste (D _{HAZ})		Above ground storage site with valid permit for the storage of hazardous waste, category C
	Permanent storage	Temporary storage	Temporary storage
	<ul style="list-style-type: none"> - 1 month after detection of a leak <p>Availability of emergency plans and adequate protective equipment suitable for metallic mercury</p> <p>Information and training of workers on how to deal with liquid mercury</p>		<ul style="list-style-type: none"> - visual and acoustic alert system - annual maintenance and control of the system - sensors have to be installed at ground level and at head level <p>Regular visual inspection of the container and the storage site by a certified person</p> <ul style="list-style-type: none"> - min. interval: 12 months, or - 1 month after detection of a leak <p>Availability of emergency plans and adequate protective equipment suitable for metallic mercury</p> <p>Information and training of workers on how to deal with liquid mercury</p>

4.2 Proposed acceptance criteria for stabilized mercury and additional facility related requirements

Storage option	Salt mine with valid permit as underground storage facility for hazardous waste (D_{HAZ})	Hard rock formation with valid permit as underground storage facility for hazardous waste (D_{HAZ})	Above ground storage site (with valid permit)
Waste acceptance criteria for stabilised Hg	<ul style="list-style-type: none"> - A Vapour pressure (e.g. $< 0.003 \text{ mg/m}^3$) to guarantee a metallic mercury free, stabilised product - Leaching limit value of the stabilised product $< 2 \text{ mg/kg}$ dry mass (L/S = 10 l/kg; EN 1247/1-4) 		
Waste acceptance procedure	Standard waste acceptance procedure applies as defined in the landfill directive and the WAC decision.		
Facility related requirements	<ul style="list-style-type: none"> - Storage of stabilised mercury has to be taken into consideration in the site-specific assessment - Storage of stabilised mercury in salt rock formation has to take place in a separate area to avoid any reaction with other waste - Storage area has to be separated by adequate barriers 	<ul style="list-style-type: none"> - Site-specific assessment has to be carried out for the safe storage of stabilised mercury and a long term proof has to be provided which indicates at least the compliance with the currently existing environmental limit values - Storage of stabilised mercury in hard rock formations has to take place in a separate area to avoid any reaction with other chemicals. - The areas have to be separated by adequate barriers 	<ul style="list-style-type: none"> - Storage in separated cells, no storage together with other waste (especially biodegradable waste or waste with a high pH value, e.g. above $\text{pH} = 10$) - The cell shall be sufficiently self-contained - Appropriate measures shall be taken to limit the possible uses of the land after closure of the landfill in order to avoid human contact with the waste - After closure, a plan shall be kept of the location of the landfill/cell indicating that stabilised mercury waste has been deposited - No works shall be carried out on the landfill/cell that could lead to a release of the stabilised mercury (e.g. drilling of holes) - A final top cover shall be put on the landfill/cell

Storage option	Salt mine with valid permit as underground storage facility for hazardous waste (D _{HAZ})	Hard rock formation with valid permit as underground storage facility for hazardous waste (D _{HAZ})	Above ground storage site (with valid permit)
Monitoring and control	Standard monitoring and control procedures apply as defined in the landfill directive and the WAC decision.		In addition "Methylmercury" should be included as parameter in the leachate control.

5 Conclusions and recommendation

One major objective of Regulation EC (N°) 1102/2008 is to ensure a safe storage of surplus mercury which is considered as waste and to prevent it from re-entering the market. The goal of the study was to identify feasible storage options and – if necessary – to define draft acceptance criteria and minimum requirements for the implementation.

1. Possible options for a safe storage of surplus mercury are available

The following permanent storage options (without a prior temporary storage) have been assessed as possible options:

- Permanent storage of metallic mercury in salt mines
- Pre-treatment of metallic mercury with a subsequent permanent storage in salt mines
- Pre-treatment of metallic mercury with a subsequent permanent storage in deep underground hard rock formations
- Pre-treatment of metallic mercury with a subsequent permanent storage in above ground facilities

Due to the fact that still uncertainties exist on the availability of these options also temporary storage options have been screened and identified:

- Temporary storage of metallic mercury in salt mines
- Temporary storage of metallic mercury in above-ground facilities

These options are most probably available by March 2011. Slight uncertainties are caused by the fact that for the storage of liquid mercury at landfills (above ground and underground) currently no disposal site has a valid permit. Further uncertainties are based on the fact that sufficient capacities for pre-treatment are announced for March 2011 but do not yet exist.

2. Acceptance criteria and additional facility related requirements have been developed

For all options which have been assessed as possible options for a safe storage of liquid mercury acceptance criteria and additional facility related requirements are now available. These concern in particular:

- Minimum acceptance criteria and procedure for metallic mercury (e.g. purity > 99.9% per weight) and its containment (e.g. carbon steel container)
- Minimum acceptance criteria for stabilised mercury (e.g. leaching rate below 2 mg/kg dry mass)
- Additional facility related requirements for the permanent storage in salt rock (e.g. minimum depth of the storage area: 300 m)

3. Recommended options

Based on an economic and environmental assessment the following options are recommended:

1. Pre-treatment (Sulphur stabilisation) of metallic mercury and subsequent permanent storage in salt mines (highest level of environmental protection, acceptable costs)
2. Pre-treatment (Sulphur stabilisation) of metallic mercury and subsequent permanent storage in a hard rock underground formation (high level of environmental protection, acceptable costs)
3. Permanent Storage of metallic mercury in salt mines (high level of environmental protection, most cost effective option)

4. Recommended timeframe for a temporary storage

Due to the fact that currently no permanent solution is available – all potential permanent solutions still have a certain level of uncertainty related to their availability by March 2011 – temporary storage solutions are required to bridge the gap until final solutions are available. A period of 5 years is recommended as timeframe for the temporary storage.

A review of the Regulation (EC) N° 1102/2008 is foreseen not later than 15 March 2013. Within this review process the actual availability of permanent options should be checked and the requirement of future temporary storage discussed.