Investigating environmental and technical problems in the remediation bunds
Kármentők tervezésénél felmerülő környezeti és műszaki problémák hatásvizsgálata

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Introduction

Our daily lives are unimaginable without the use of chemicals. In order to make chemical products available at the retail level, industrial companies that produce and use chemicals in large quantities need to operate. On average, there are between 20 and 40 serious accidents involving dangerous substances in the EU every year. Inadequate design, construction and plant operation further increase the likelihood of environmental contamination. Relevant international and national legislation and recommendations require the use of a containment system to contain the chemical spillage in the event of a chemical storage unit failure, avoiding significant environmental contamination. However, the sizing of the containment is limited to determining the containment capacity and there is no guidance in the legislation or recommendations on the ratio of floor area to wall height or on the operating requirements. This publication examines the main environmental and technical issues affecting chemical storage tank containment. As a result, a safety recommendation and methodology is formulated that can be easily implemented in daily practice.

Bevezetés

A mindennapjaink elképzelhetetlenek vegyi anyagok felhasználása nélkül. Ahhoz, hogy a kiskereskedelemben a vegyi termékek elérhetővé váljanak, vegyi anyagokat nagy mennyiségben gyártó és felhasználó ipari vállalkozásoknak kell működniük. Az EU-ban bekövetkezett veszélyes anyagokkal kapcsolatos súlyos balesetek száma átlagosan évente 20-40 eset közé tehető. A nem megfelelő tervezés, kivitelezés és üzemi működés a környezetszennyezés bekövetkezésének valószínűségét tovább növeli. A vonatkozó nemzetközi és hazai jogszabályok és ajánlások előírják a kármentő alkalmazását, melynek célja, hogy egy esetlegesen bekövetkező vegyi anyag tároló egység meghibásodásakor felfogja a szabadba kerülő vegyi anyagot, elkerülve a jelentős mértékű környezetszennyezés kialakulását. Azonban a kármentő méretezése kizárólag a befogadóképesség meghatározására terjed ki, az alapterület és a falmagasság arányára, valamint az üzemeltetési előírásokra a jogszabályok, ajánlások nem tartalmaznak útmutatást. Ezen publikáció a vegyi anyag tároló tartályok kármentőit érintő főbb környezeti és műszaki problémákat vizsgálja. Ennek

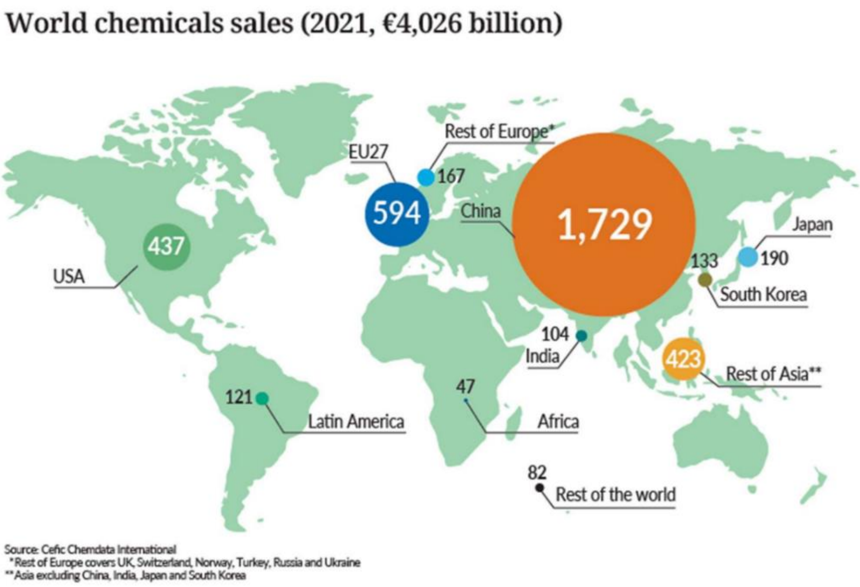
eredményeként olyan biztonsági javaslat, módszertan kerül megfogalmazásra, amely könnyen átültethető a napi gyakorlatba is.

Kulcsszavak: kármentő, méretezés, hatásvizsgálat, modellezés, hatásterület

Keywords: remediation bund, dimensioning, impact assessment, modelling, area of influence

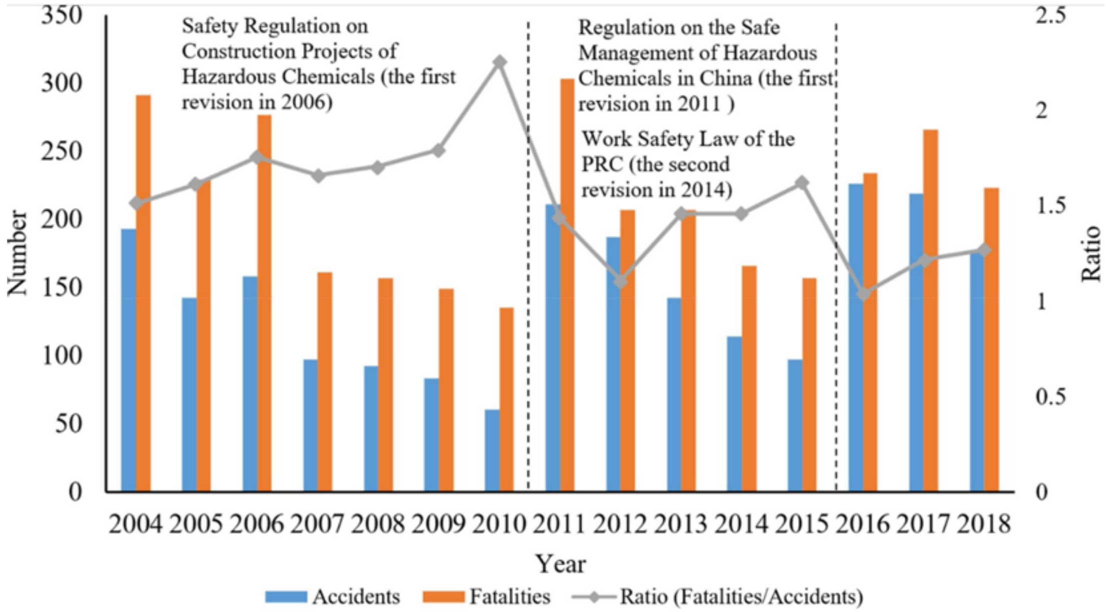
Analyses of the Statistics

Due to the rapid technological development, our everyday life is unimaginable without the use of chemicals, this is true for both producer and private use. However, for these chemical products to become commercially available, industrial enterprises producing and using chemicals in large quantities are necessary. Based on literature sources, the following order has been established regarding chemical production: China, EU, USA. (1. picture)



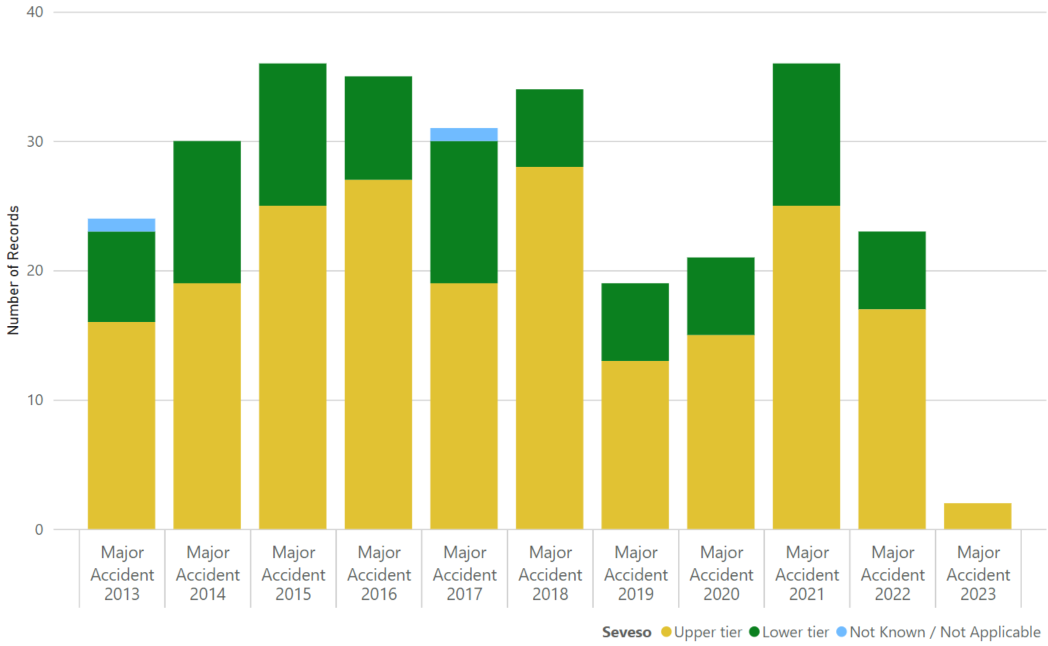
1. picture: World chemicals salest in 2021 [1, p. 3]

In China, the leader in chemical emissions, between 2016 and 2018, the number of chemical accidents exceeded 150 per year, which means an average of one chemical accident every two days. (2. picture)



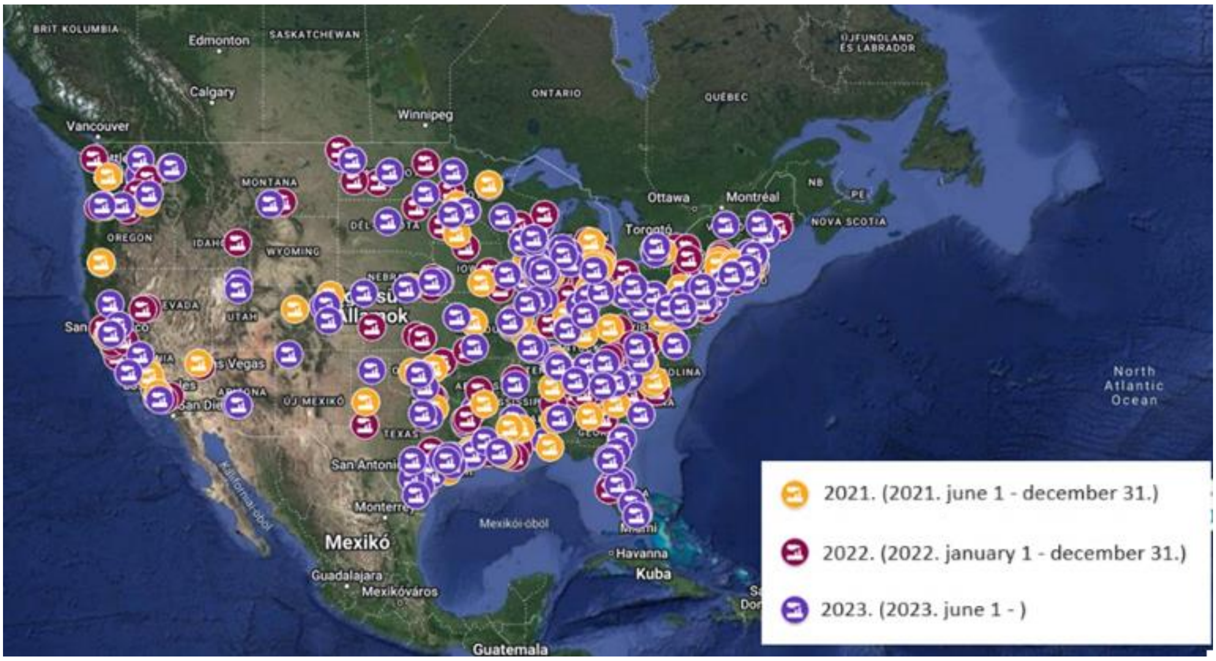
2. picture: Chemical accidents and fatalities evolution over time [2, p. 4]

On average, the number of major accidents involving dangerous substances in the EU is between 20 and 40 per year. (3. picture)



3. picture: Major accident in EU, 2013-2023 [3]

Similar statistics can be observed in the USA, according to which a chemical accident occurs on average every two days. [4] (4. picture)



4. picture: Accidents involving hazardous substances in the USA, 2021-2023 [5]

In practice, industrial companies producing and using chemicals in large quantities have to carry out an environmental impact assessment procedure prior to the construction procedure. The purpose of the procedure is to determine the environmental effects of the planned investment and to establish the conditions of environmental use. However, in many cases, the fulfilment of the environmental use conditions determined as a result of the environmental impact assessment procedure is implemented unevenly during construction, therefore the planned function is not fully realized, thus the risk of environmental pollution increases. [6, pp. 81-96] Inadequate operation further increases the likelihood of environmental pollution. [7, pp. 17-31]

The publication deals with the topic of the construction and operation of a reinforced concrete remediation bund within the framework of chemical storage. The purpose of the remediation bund is to trap the chemical released into the open air in the event of a failure of the chemical storage unit, thus avoiding the development of significant environmental pollution. Although sizing the remediation bund can be considered a seemingly simple operation, in this publication the authors highlight the complex nature of the activity. Based on modelling and illustrative images, a safety proposal and methodology is formulated that can be easily implemented into daily practice.

Relevant international and national regulations

The importance of international and national laws and regulations was mentioned several times in the introduction. Of these, the documents considered relevant for publication are briefly described below.

International regulations and guidelines

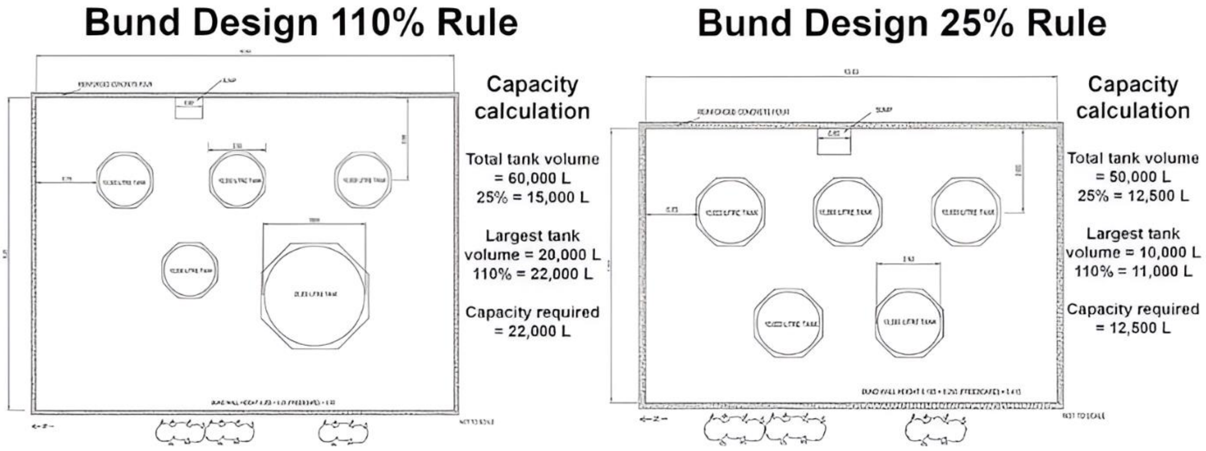
There is a large number of literature dealing with the sizing and design of remediation bund. The *Health and Safety Executive (HSE)*, the English authority responsible for occupational safety, recommendations on the subject:

- limit the number of tanks in one remediation bund room to a total capacity of 60 000 m^3;
- prohibits the storage of incompatible materials in the salvage;
- the remediation bund must be sized to accommodate 110% of the capacity of the largest tank, taking into account possible extinguishing water or foam;

– Due attention must be paid to the design of stormwater drainage in the remediation bund. [8]

There is no recommendation in the literature regarding the ratio of floor space to wall height. The advantage of low wall height (1-1.5 m) is easier fire fighting, but the disadvantage is that the hazardous material can spread outside the wall.

Based on industry standards, the 110% and 25% rules apply when designing a remediation bund. The 110% rule applies if only 1 storage unit is stored in the remediation bund. Thus, the calculation is simple: the remediation bund must capture at least 110% of the stored containment volume. In the case of several storage units, the remediation bund shall have the capacity to contain either 110 % of the maximum containment or 25 % of the total volume of the storage units. (5. picture)



5. picture: Determine the capacity of the remediation bund [9]

The VdS 2557. Planning and Installation of Facilities for Retention of Extinguishing Water. Guidelines for Loss Prevention by the German Insurers standard also deals with the sizing of the catchment area of remediation bund, which already takes into account the amount of contaminated fire extinguishing water that may be generated. According to German literature, contaminated extinguishing water can be calculated using the following formula:

$$V = \frac{\{(A_{act} \times SWL \times BAF \times BBF) + M\}}{BSF}, \text{ where}$$

V [m^3]:	the volume of the remediation bund
A_{act} [m^2]:	Actual fire pit area
SWL [m^3/m^3]:	specific water power. It can be assumed that a specified SWL water outlet with the specified extinguishing time will be used in the fire pit.
BBF:	fire load factor (dimensionless).
BAF:	factor of the area of the fire pit (dimensionless).
M [m^3]:	the amount of fluid that used for manufacture, operation and storage
BSF:	fire protection factor (dimensionless) The BSF factor is defined in the fire protection standard for the fire pit. [10]

In general, the Swiss guide is simpler to apply compared to the previous German guide (*VdS 2557*). Based on the literature, the theoretical comprehension volume depends:

– from the fire protection concept,
– the method of storage,

– flammability of stored substances, preparations and articles,
– and the size of the fire area. [11]

National laws and standards

EU legislation on the management of activities involving dangerous substances and major-accident hazards has been transposed into the Hungarian legal environment. The provisions of Seveso III Directive are contained in *Act CXXVIII of 2011 on Disaster Management and the amendment of certain acts related to it (Act Cat.)*, and its implementing decree is contained in *Government Decree No 234/2011 (XI.10.) on the implementation of Act CXXVIII of 2011 on disaster management and amending certain acts* related to it. The Disaster Management Act basically aims to increase the security and sense of security of the population. Furthermore, it is an important goal to increase the efficiency of protection against natural and civilisational disasters and to increase the effectiveness of disaster management organization and measures.[12] Government Decree 234/2011 (XI.10.) lays down the tasks and competences of protection against disasters in addition to the interpretative provisions concerning the area, furthermore, it defines the rules of disaster management classification of settlements and protection requirements. [13] *Decision No 219/2011. (X. 20.) Government Decree on Protection against Major Accidents involving Hazardous Substances* contains the principles and rules of identification, evaluation and the elements of the safety system. [14] Decision *No 1/2016. (I. 5.) NGM Regulation on the technical safety requirements and official supervision of storage tanks and storage facilities of hazardous liquids or melts*. Paragraph 19(1) of that decree requires storage tanks and storage facilities to be designed, constructed, installed, commissioned, operated and regularly maintained in such a way as to meet both technical safety requirements and legal requirements. In addition, Annex 1 to this Regulation incorporates the technical safety code for storage tanks for hazardous liquids and melts. [15] Official supervision is of paramount importance both from the point of view of disaster management and technical safety. Government Decree 216/2019 (IX.5.) on the technical safety authority supervision of storage tanks and storage facilities of hazardous liquids or melts contains, in addition to interpretative provisions, general rules regarding establishment, commissioning, repair, modification, inspection and termination.[16] *Government Decree 246/2014 (IX.29.) is a decree on the rules of the establishment and operation of certain waste management facilities* Section 6 stipulates that if hazardous waste is stored in the waste yard, the covering of the collection area must be made of a material (liquid-tight, if necessary chemical-resistant surface protection or a substrate with a remedation bund) that is resistant to chemical reactions in case of possible contact with hazardous waste.[17]

Decision No 1/2016. (I. 5.) NGM decree stipulates that the designer, the contractor, the operator of the storage tank and the person entitled to have a storage facility must make a declaration on the achievement and maintenance of the significant technical safety level during the official procedure. For this reason, the specifications and recommendations of standards relevant to the field should apply. The MSZ-05-94.0024:1979 standard defines the main dimensions of an above-ground, stationary, cylindrical tank for the storage of flammable liquids [18], while MSZ-05-95.0450:1982 lays down the general technical requirements of storage tanks (e.g. structural materials, design, strength dimensioning). [19] In the MSZ 15633:1992 series of standards, fire protection requirements for storage and service facilities and equipment of combustible liquids and melts have been defined. [20] The fitting, safety and environmental regulations of above-ground, stationary, cylindrical steel tanks for storing combustible liquids and melts are contained in the MSZ 9910-2:1993 standard. According to this standard, the capacity of the receiver must be dimensioned so that stored material cannot escape from the receiver compartment in the event of danger. It also contains a requirement for the placement of several containers in one containment area. In this case, the nominal capacity of the tank group shall not exceed

– 10 000 m^3 for crude oil and crude production,
– 20 000 m^3 for flammability grade 1 to 2,
– 30 000 m^3 for flammable substances up to an open space flash point of 100 °C,

– 120,000 m^3 above 100°C flash point in open space. [21]

The standard also provides guidance on the volume of the receiver chamber that can be filled with liquid, which can be done as the followings:

- for one tank its 100 % of the nominal capacity of the tank,
- 50 % of the nominal total capacity of the tanks in the containment compartment in the case of several containers or, if any tank is larger, its nominal capacity,
- in the case of crude oil and crude production, 75 % of the nominal total capacity of the tanks in the containment area. [21]

According to MSZ 9910-2:1993, the building regulations for receivers are the followings:

- The receiver shall be of non-combustible material, of sufficient strength and tightness so as not to allow liquid to pass through in the event of fire.
- Reception areas shall be constructed by sinking into the ground, by ramparts around them or by stable walls. In the case of adjacent reception areas, they may have common walls.
- When determining the dimensions of the receiver area, care must be taken to ensure that in the event of breakage/puncture of the container, the liquid spilled in the jet always enters the receiver compartment.
- Extinguishing and rainwater collected in the containment area may be diverted by means of a pipe fitted with a double shut-off device or collected by means of a shaft in the containment area. [21]

Statements on international and national standards

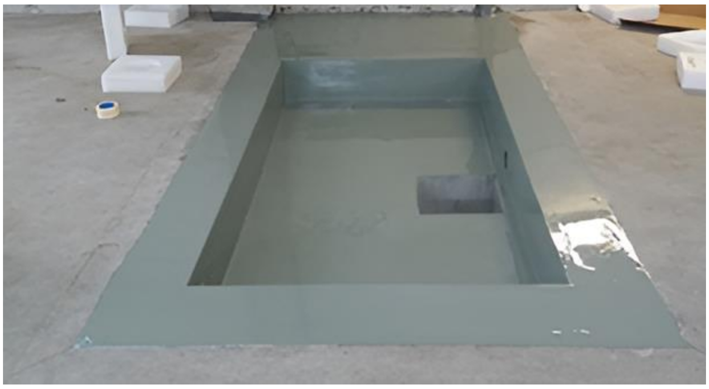
Relevant international and national legislation and recommendations require the use of remediation bund. The sizing of the remediation bund only covers the determination of capacity, neither legislation nor recommendations provide guidance on the ratio of floor area to wall height and operating regulations.

Remediation bund sizing

In this section, practical examples and computer modelling are used to explain the role of remediation bund and the importance of correct design/dimensioning.

Sizing issues

In practice, liquid chemicals are typically stored in package or single-walled containers in a remediation bund. If the rescuer performs its function properly, it can absorb the entire amount of chemicals released into the air as a result of an incident. In practice, recessed damage salvages (6. picture) and above-ground ones (7. picture) are typically used.

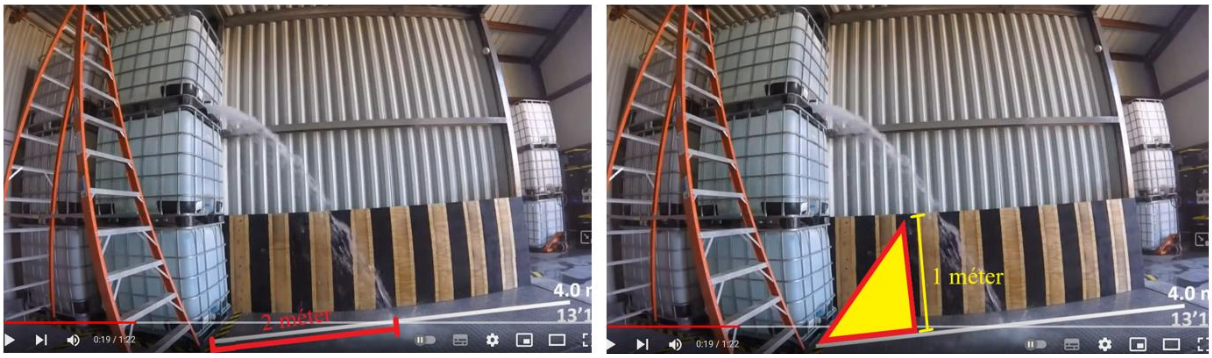


6. picture: Remediation bund buried in the ground [22]

7. picture: Remediation bund above the ground [23]

If the remediation bund is undersized, it cannot perform its function. It is also clear from international and domestic regulations and standards that the capacity of the remediation bund must be planned. As a rule of thumb, if a chemical "container" (tank, IBC, etc.) is located in the remediation bund, the useful volume of the remediation bund is at least 110% of the volume of the "container". At the same time, when sizing the remediation bund, taking into account the capacity is a necessary but not sufficient condition of the design, so the height of the remediation bund must also be planned. If the height of the remedation bund wall is incorrect, the outflow liquid will be transferred outside the remedation bund, which is clearly confirmed by the video made by the Safespill System. If storage takes place in three superimposed IBC tanks and the tap of the uppermost IBC is damaged, the experiment shows that the outflow liquid reaches the ground at a distance of about 2 meters, and the area of impact of the spill is about 4 meters.

In the event that the height of the remedation bund 's sidewall is 1 meter and the IBC group is placed at a distance of 1 meter from the remedation bund's wall, the remedation bund will not be able to fulfilits function. (8. picture)



8. picture: IBC damage at the tap, own editing by [24]

So, when the tap of the highest IBC tank is damaged, the chemical reaches ground level outside the side wall of the remedation bund.

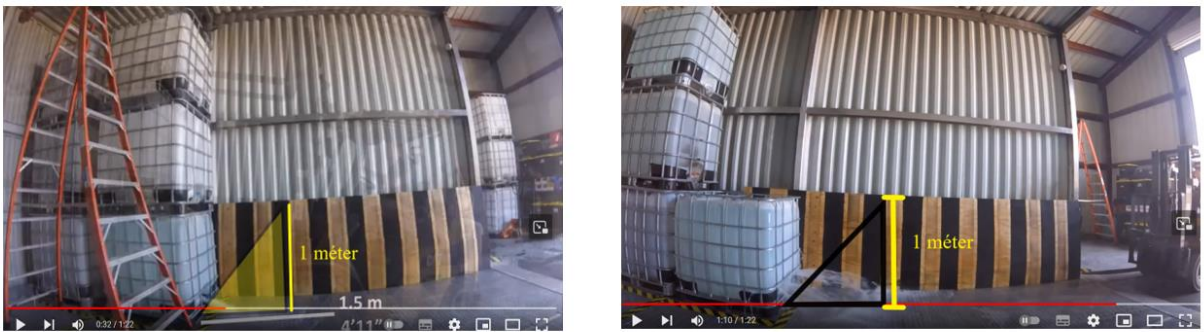
If the IBC is violated with a forklift, the size and shape of the puncture will also be different, during which the image of the outflow will also change. (9. picture)

9. picture: Damage to IBC due to forklift fork, own editing by [24]

In the event that the second IBC is damaged at the tap (10. picture, left), the 1 meter high sidewall is already able to absorb the outflowing liquid. This can achieve that instead of the 3-meter impact area, a so-called limited puddle surface is created in the area of the remedation bund. If a forklift pierces the IBC (10. picture, right), the 1-metre-high remedation bund can only partially perform its function, so the liquid can be discharged outside the remedation bund.

10. picture: IBC damage at the tap and due to forklift fork, own editing by [24]

If the lower IBC is damaged – regardless of the cause of the injury (damage at the tap – or by forklift), the remedation bund with a 1 meter high sidewall can fully fulfill its function, so a so-called limited puddle surface can be formed corresponding to the area of the remedation bund. (11. picture)



11. picture: IBC damage for one storage level, own editing by [24]

Determining the impact area using software modelling

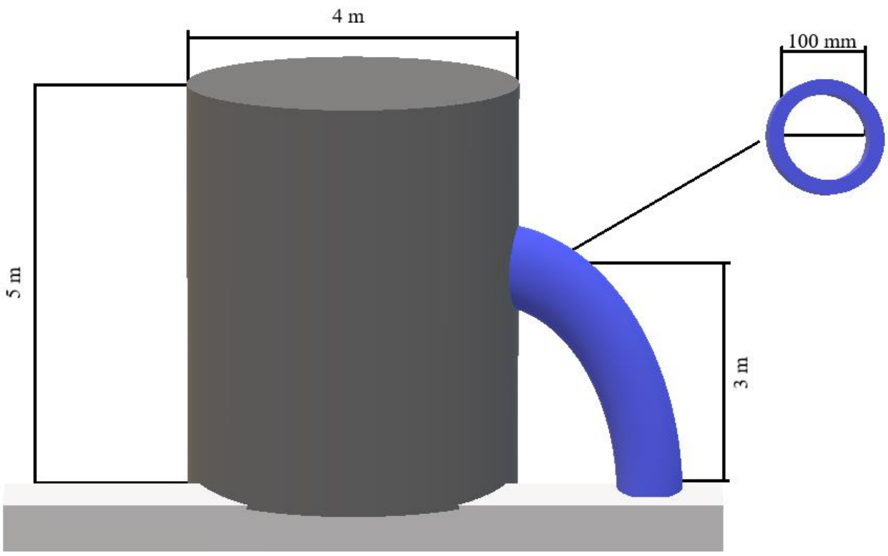
DNV Phast consequence analysis software was used for modelling. This software is a program for modeling emissions, spread, fires, explosions and toxic effects, the main features of which are as follows:

- Developed and certified by DNV experts for 40 years.
- 40+ scenario types.
- Models that change over time, including the effects.
- Weather consideration (wind speed, atmosphere, surface roughness).
- 2000+ materials.
- Map import option.
- Use of GIS coordinate systems.
- Results: dispersion results (concentration functions), thermal radiation, steam fire, explosive excess pressure and pulse, toxic substance dose, probability of death as a function of distance. Results can be displayed in reports, 2D and 3D graphs, and tabular formats.

Basic datas

The aim of modelling is to examine the relationship between remedation bund sizing and possible consequences under the same environmental and technical conditions. A flammable liquid was selected as a reference material, so the area of action can be analyzed in a complex way. This means that the area of impact will not only be the surface of the resulting puddle, but also the area limited by the thermal radiation caused by the possible fire. Acetone, an organic solvent used in large quantities in everyday life, was selected as a flammable liquid, which is a colorless, sweetish smell and liquid under normal environmental conditions. It has a melting point of about -95°C, a boiling point of about 56°C and a flash point of -17°C. The vapour pressure at 20 °C is 240 hPa. Extremely flammable (H225), severe eye irritation (H319), drowsiness or dizziness (H336).

Due to the fact that meteorological data and surface roughness are indifferent for modelling purposes, wind speeds of 1.5 m/s, Pasquali stability index "F" and an average ambient temperature of 10°C were entered. During the modelling, it was assumed that a hole with a diameter of 100 mm would form on a fully filled tank with a useful volume of 60 m^3 at a height of 3 meters, and the direction of outflow would be horizontal. The event is illustrated in picture 12.



12. picture: Modeled sequence of events, own editing

According to international recommendations, the rescuer should be at least 110% of the usable volume (V = 60 m^3), in this case it is 66 m^3. Based on Picture 12, it can be seen that a volume of liquid corresponding to the storage space above the puncture will be released into the open air, which amount can be calculated by the formula:

$$V = r^2 \times \pi \times h, \text{ where}$$

V: volume (m^3)

r: radius of the tank (m)

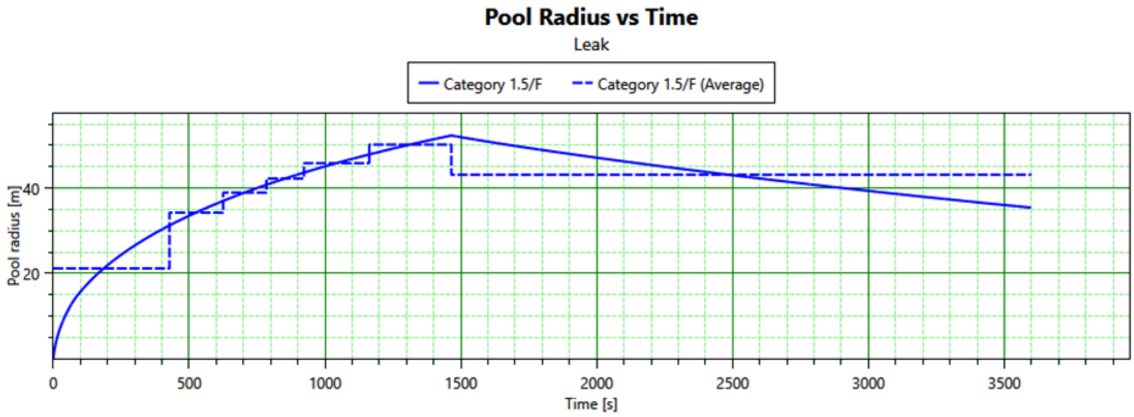
h: height of fluid above the puncture (m)

The shape of the puncture has been ignored, as it would result in minimal deviation in this case. Using the above formula, the volume of liquid released into the open air is 25.12 m^3.
During the study, the following series of events were modeled:

1. Event sequence: no remedation bund, puddles with unlimited surface area.
2. Event sequence: the tank is in a remedation bund which has an area of 33 m^2, and a height of 2 meters.
3. Event sequence: the tank is in a remedation bund which has an area of 66 m^2, and a height of 1 meters.

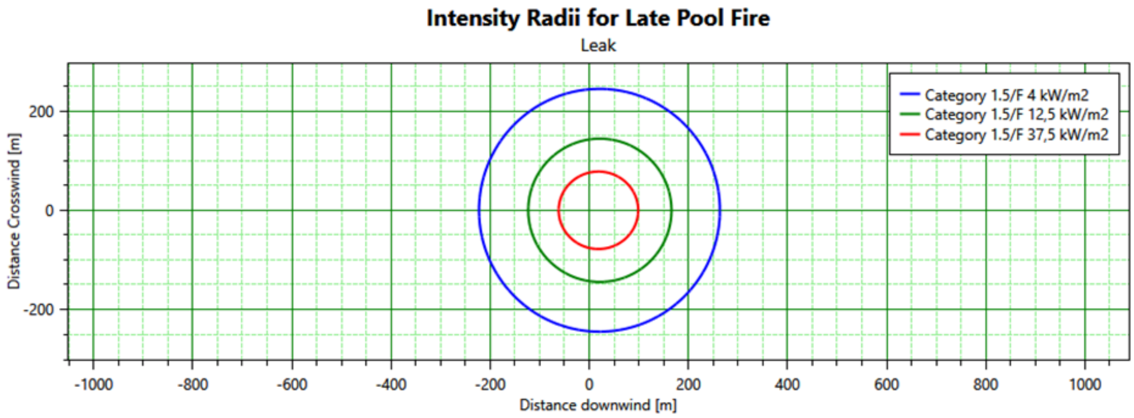
Modelling results

<u>1. Event sequence:</u>
The change in the radius of the puddle formed during the event as a function of time is shown in 13. picture. It can be concluded that during the event a puddle with a radius of up to 50 meters can form.



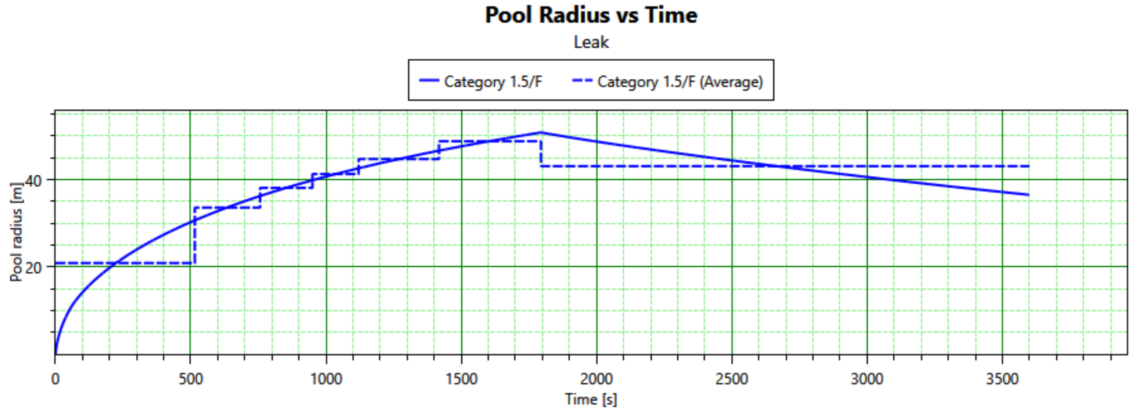
13. picture: Variation of pool radius as a function of time, without remediation bund, own editing by DNV Phast modelling

If an ignition source is present in the area, puddle fire may occur, characterized by thermal radiation. If the amount of thermal radiation exceeds 37.5 kW/m^2, steel structures will be damaged and buildings will collapse. If the human body is exposed to more than 12.5 kW/m^2 of thermal radiation, it is fatal, and if it is higher than 4 kW/m^2, second-degree burns develop [25, p. 53]. In the case of the series of events under consideration, the development of second-degree burns must be expected within an area whit a radius of approximately 250 meters. (14. picture)



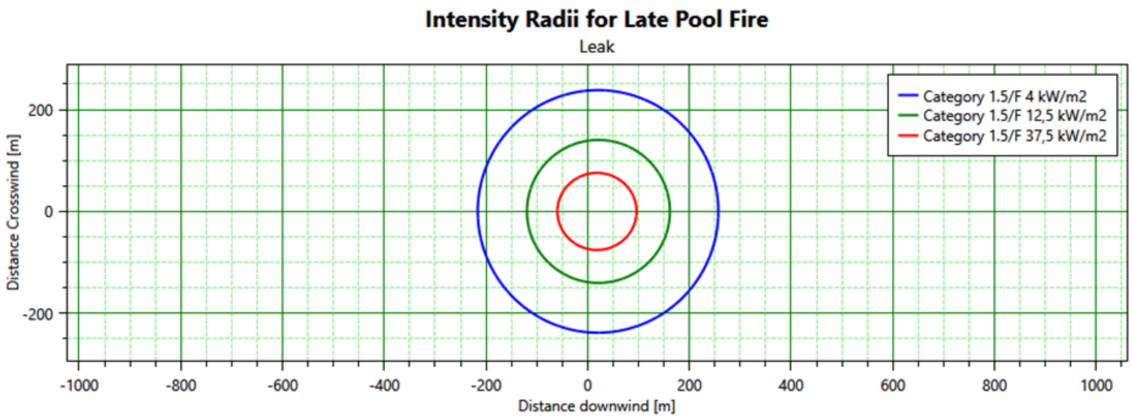
14. picture: Intensity radii for late pool fire, without remediation bund, own editing by DNV Phast modelling

2. Event sequence:
The change in the radius of the puddle as a function of time is shown in 15. picture, which shows that during the event – similarly to Event 1 – a puddle with a radius of up to 50 meters can form. This means that the fluid flow extends beyond the sidewall of the remedation bund, so that the remedation bund cannot fulfil its function.



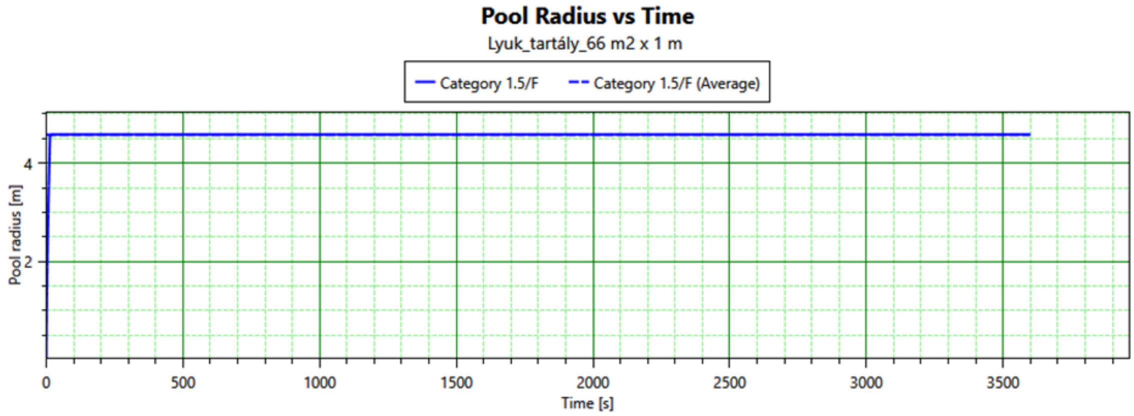
15. picture: Variation of pool radius as a function of time, with 33 m^2 x 2 m remediation bund, own editing by DNV Phast modelling

The consequences in 16. picture, despite the presence of a remedation bund around the tank with sufficient capacity, are similar to those shown in event 1. Event 2 is likely to result in second-degree burns within an area with a radius of approximately 250 m.



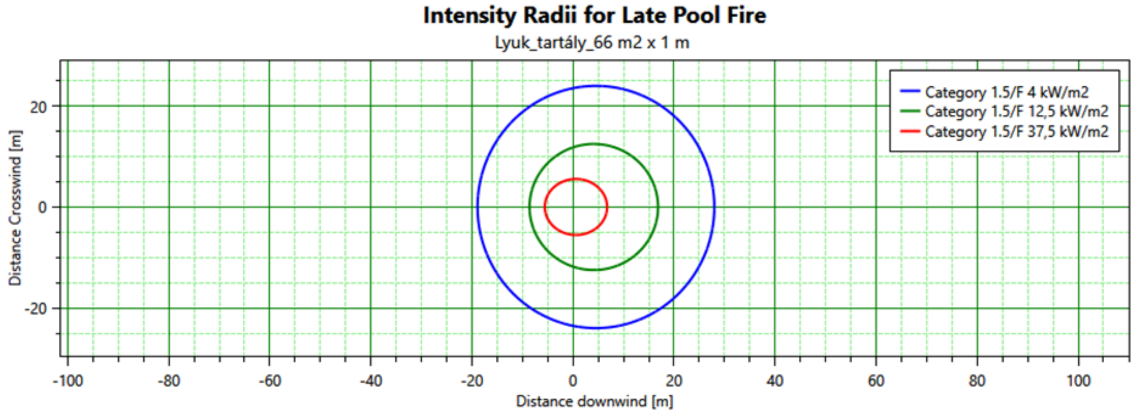
16. picture: Intensity radii for late pool fire, with 33 m^2 x 2 m remediation bund, own editing by DNV Phast modelling

3. Event sequence:
Based on 17. picture, it can be concluded that the remedation bund fully fulfills its function (a puddle with a radius of ~4.6 meters eq. is formed). Due to the fact that the puddle surface is limited by the remedation bund, it is smaller than in events 1 and 2. Thus, in the event of a fire, the area of impact will also be smaller.



17. picture: Variation of pool radius as a function of time, with 66 m^2 x 1 m remediation bund, own editing by DNV Phast modelling

In the case of Event 3, 18. picture illustrates the size of the impact area associated with second-degree burns, which in this case affects an area with a radius of approximately 30 meters.



18. picture: Intensity radii for late pool fire, with 66 m^2 x 1 m remediation bund, own editing by DNV Phast modelling

<u>Summary and evaluation of modelling results:</u>
The results of the modelling are summarized in 1. table, which clearly reflects that in the case of event series 2, the volume of the remedation bund is right but the lenght and hight of the wall are not dimensioned correctly.

Eseménysor szám	1.	2.	3.
volume of the remedation bund (m^3)	-	66 m^3	66 m^3
area of the remedation bund (m^2)	-	33 m^2	66 m^2
hight of the remedation bund (m)	-	2 m	1 m
puddle radius (m)	~ 50 m	~ 50 m	~ 50 m
Radius of the area of impact of second-degree burns (m)	~ 250 m	~ 250 m	~ 30 m
Radius of the area of impact of a fatal burn (m)	~ 100 m	~ 100 m	~ 18 m
Irreversible damage to building structure, radius of the impact area (m)	~ 150 m	~ 150 m	~ 6 m

1. table: Summary of modelling results, own editing

Based on modelling, for events 1 and 2, the 150 meter eqv. thermal radiation may develop within the radius of influence, which causes irreversible damage to the building structure. This means that the construction of other installations within this area of influence should be prohibited. 250 eqv. the effect causing second-degree burns may occur within radius, so protective measures must be taken within this area.
It can also be seen that if a properly sized remedation bund is used, the size of the impact areas can be minimized: the construction barrier must be taken within an impact area with a radius of 6 meters, and personal protection measures must be taken within an impact area with a radius of ~ 30 meters.

Practical experience

In practice, there are a number of tanks – open source images are presented below – where the appropriateness of the remedation bund sizing is questionable. 19. picture shows the design of diesel tanks, where the capacity of the remedation bund is presumably adequate, they are suitable for catching small drips or flows. However, in an exceptional event, they are unlikely to be able to perform their function.

19. picture: Examples of diesel tank design [26]

Conclusion

In general, it can be stated that Hungarian legislation and standards do not examine the topic in its complexity. More detailed regulations on remedation bund are contained in the standard, which is still in force but is more than 20 years old. However, technology is constantly evolving, and revision of the standard(s) is essential for this aspect as well. Based on the legislation, standards and modelling presented in the publication, it is recommended to address the following during the review:

- changes in externalities, such as increases in significant rainfall
- to determine the capacity of the remedation bund,
- planning the dimensions of the remedation bund – floor area, height,
- the issue of catching contaminated extinguishing water.

In the case of stationary atmospheric tanks, the tank approval documentation shall also include a remedatin bund permit plan. The designer must prove by calculations and modelling that the floor area, the height of the remedation bund and the placement of the tank are designed in such a way that the remedation bund can fulfil its function under all circumstances. For the storage of package units – IBCs, barrels, etc. – in the salvage, the operator must develop an internal procedure in which the following must be recorded:

- how many packages can be stored in the remedation bund,
- at what height – how many rows – can packages be stored,
- how far packages can be stored from the edge of the remedation bund,
- In the case of an IBC, in which direction the tap should face.

It is recommended to mark the possibility of placing packages in the remedation bund by painting, and in addition to the remedation bund, it is recommended to mark the most important rules of storage with the help of a warning/reminder board.

Regarding further research directions, it is worth reviewing the standard industrial safety literature, from which we can gain important practical experience [25, 27-28]. The prevention of environmental disasters is related to the effectiveness of mitigation measures, therefore it is necessary to review industrial safety publications on the topic [25, 29].

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