Supplement of Saf. Nucl. Waste Disposal, 1, 289–290, 2021
https://doi.org/10.5194/sand-1-289-2021-supplement

SaND
Safety of Nuclear Waste Disposal
Open Access

Supplement of

Long-term storage of information about nuclear waste. 100 000 years and beyond

Martin Kunze

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Information Carriers with Unlimited Longevity
Even Under Extreme Conditions

This keynote is about *how* knowledge can lead to informed decisions

But the „how“ is not only about the intellectual process, it is also about the physical limits of keeping information at all.
In order to make decisions , knowledge needs to be transmitted into the future : 100 years, 1000 years or 100.000 years

I will present a short analysis of conventional data carriers,
compare their durability and capacity and
introduce durable information carriers
and finally present a suggestion for a Nuclear Message for marking a deep geological repository.

NEA/IDKM/**EGAP**
Expert Group for Awareness Preservation

I am Martin Kunze, Chair NEA, Expert Group for Awareness Preservation .
Awareness in this case means awareness of the existance of a nuclear site

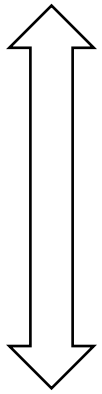
My background is ceramic and silicate technologies, I am founder of the Memory of Manind project, Expert for long term data storage, archives

Nuclear waste consists of dangerous though precious materials. The concept of sustainability and responsible usage of resources prompted the demand not to bury and isolate nuclear waste from the biosphere and forget it forever, but rather to leave the information about it in such a way that future generations can make their own informed decisions how to further proceed with the site.
And even if the transmission of information is interrupted, it should then be possible for a technically industrialized society to reconstruct this information.
The materials that we store in deep underground, especially in places where one would not geologically expect it, could represent valuable resources for future generations.

NEA/IDKM/EGAP
Expert Group for Awareness Preservation

The Expert Group works on Awareness preservation

NEA/IDKM/EGAP
Expert Group for Awareness Preservation

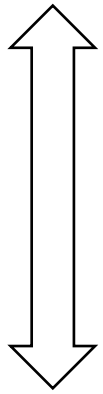


Information

Being aware of something requires information about this matter.

NEA/IDKM/EGAP

Expert Group for Awareness Preservation



Information Safekeeping

Awareness PRESERVATION deals with safekeeping Information

NEA/IDKM/EGAP

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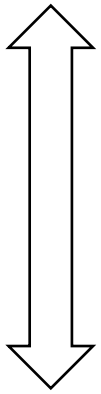
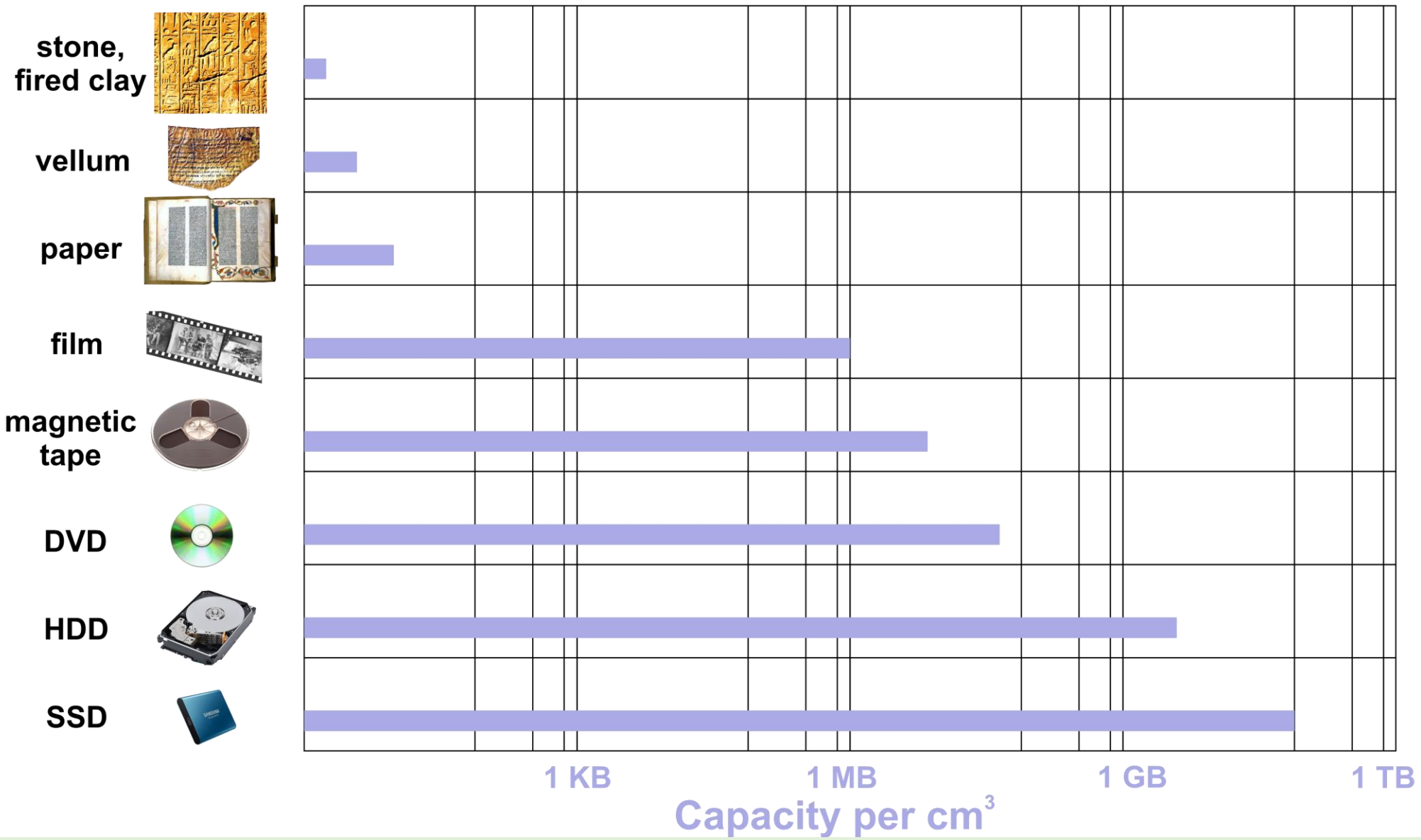


1.000.000 years

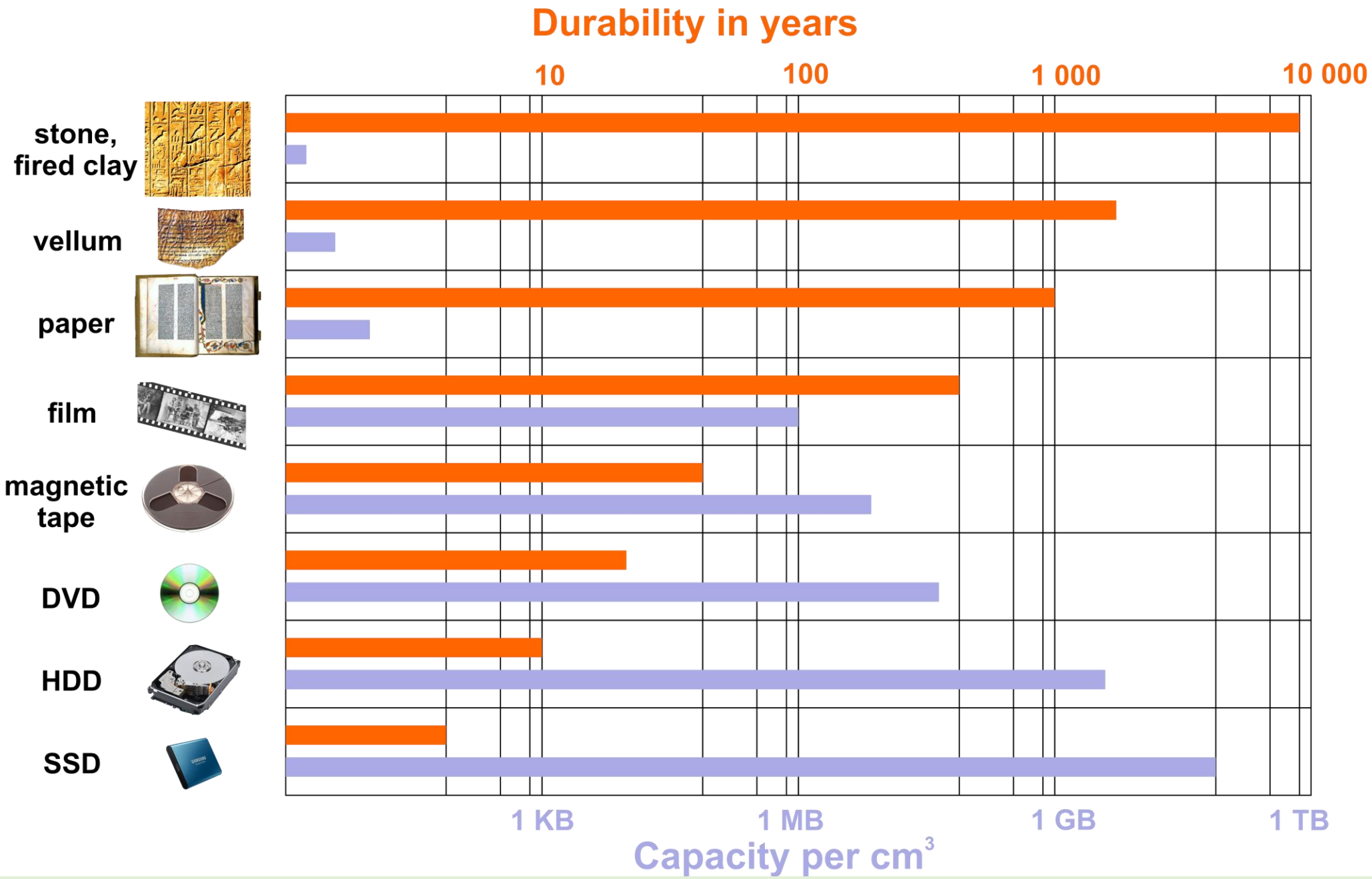
Long Term Information Safekeeping

The solutions to keep information in order to create awareness should cover a time period of information storage, unprecedented in human history.

Conventional information carriers are unsuitable for these purposes. Even the most durable have a shelf life that is orders of magnitude below the temporal safety requirements of nuclear waste repositories.

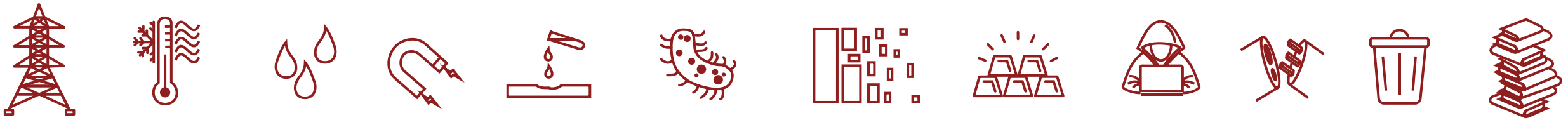


The capacity of data carriers increased over the millenia



whereas in the same way the durability increased, it seems to be inversly proportional.

Limits of Long Term Information Storage

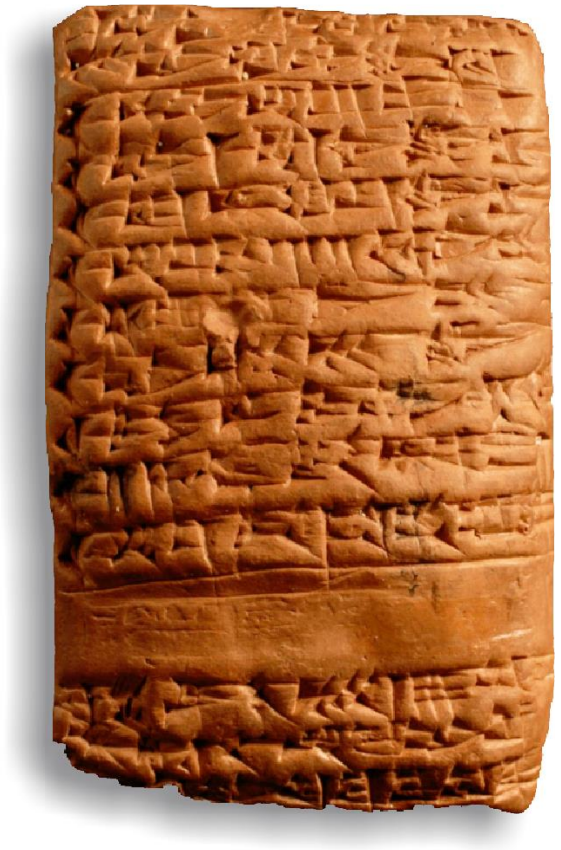


Today´s most widely used data carriers permanently consume energy – not eligible on the long run.
Temperature and humidity needs to be controlled, microfilm for example has a durability of 500 years at 5°C and 50% humidity. The durability significantly decreases when parameters change.
A magentic pulse e.g. from a solar storm, destroys data carriers.
Erosive gases destroy optical data carriers.
Microbes infest paper but also film and organic materials of optical data carriers.
Self degradation is not only a problem of color photos or microfilm, but also of SD memory cards. The reason why a flash memory can hold huge amounts of data in incredibe tiny space is also the reason for ist decay: quantum effects.
Precious materials, such as platinum or gold as non corroding data carrier is not the best idea. egyptian tombs were robbed, not because of the nice statues, but for the material they were made of.
cyber attacks can block data from access
incompatibility of systems, languages or formats , hard- and software create problems that lead to inaccessibility of data
Inadverted deletion, loss of access keys, or loss of data structure, lead to situations where data somewhere exists but cannot be retrieved.
And finally profusion: The larger the overall amount of existing data, the harder it gets to mark a dataset as significant.

Ceramic as Basis for Data Carriers

My background is ceramic and silicate technologies.
About 10 years ago I started to use a new printing technology , which was originally developed to print company logos on coffee cups with fine color glazes.
I misused this technology to print images and text onto bathroom tiles, which resulted in the most durable data carriers ever.

Proof of Concept



5000 years

That ceramic works as data carrier is impressively proven by babylonian cuneiform tablets.

The Origin of Ceramic Data Carriers
Memory of Mankind - MOM

These data carriers are the core of the Memory of Mankind (MOM) project, located within the oldes saltmine in Hallstatt, Austria.

The high quality ceramic tiles with the ceramic color print are used to store essential information of our time for 1 million years.

High Quality Tiles with Ceramic Color Print

Institutions such as universities or museums store PhD-theses, most important objects of the collection or present MOM tablets as awards for outstanding scientific research.

Additionally, individuals also contribute to MOM by describing their families or weddings or sending an entire story of life into the future.

Media Response

BBC

DIE ZEIT

POPULAR SCIENCE

arte

The Atlantic

GQ

Reader's Digest

The New York Times

31.12.2020, page 2

ALEX HALADA/AGENCE FRANCE-PRESSE — GETTY IMAGES

A salt mine in Hallstatt, Austria, that contains a time capsule featuring Times articles.

News That Can Last a Million Years

By LAUREN JACKSON

Inside an ancient salt mine, on the edge of a small Alpine lake in Austria, Martin Kunze is preparing for the end times.

He is not a doomsayer or a conspiracy theorist. A ceramist, Mr. Kunze simply inhabits a longer view of history, one in which humans are the dinosaurs, facing down a probable extinction. He knows we're poised to leave our foam cups, shattered Ikea bowls and slowly decomposing trash islands for a future species to decipher. Still, he's holding out hope that a few more meaningful items will manage to survive, too — including the work of The New York Times.

Mr. Kunze is an artist and researcher based in Hallstatt, Austria, who founded

In total, Mr. Kunze has added nearly 30 Times articles from this year to MOM, archived chronologically. He said he hopes to add a Times coronavirus retrospective once the pandemic is over. When asked why he has turned to The Times in this process, he said in an email, "for the same reason I am a subscriber: The good job Times journalists are doing in respect of research and background information."

The Times articles included in the archive go through a specially designed process to be transferred to ceramic tablets. First, a modified color laser printer uses ceramic toner (finely ground ceramic glaze) to print the articles on a paper that will then be coated, glazed, pressed, dried and fired onto the tablets at 850 degrees

MOM is covered worldwide in print and TV.

On December 31, on page 2 of The New York Times a retrospect editorial about 2020 and the corona crisis proudly reported, that several NYT articles are part of the MOM archive.

2019:

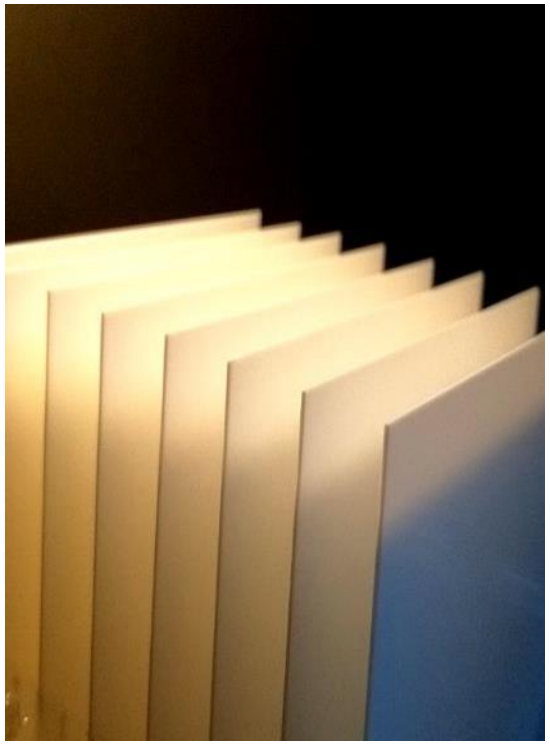
Research Programme for Ceramic Data Carriers:
Technical University Vienna,
Material Science and Photonics

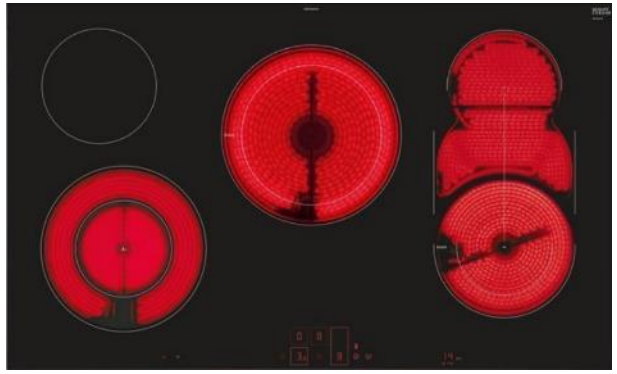
2019-2021 Grants of 1.000.000+ €

Using high tech ceramic as basis for long term data carriers triggered a research project which is financed with over 1 mio € grants by Austrian national research promotion entities.
The MOM project was split into:
MOM foundation , a non-profit association under Austrian Law and
Ceramic Data Solution, a research company.

The Know-How for **analogue data storage** is going to be used in the new company: **CeraMicro**

Substrate: High Performance Ceramic and Glass-Ceramic





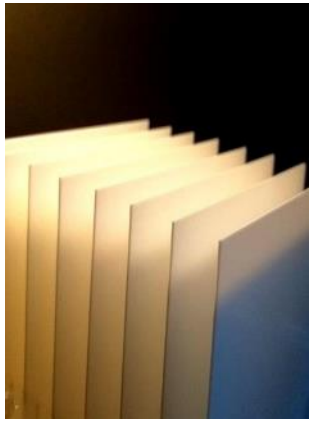
Aluminium Oxide Substrate used in medicine for artificial joints or in the motor- and jetindustry for valves, heat-, corrosion- and stress- resistant parts.

We also included the latest developments of advanced glass and glass-ceramic as promising material for long term data carriers into our research program.

Temperature-shock resistant glass-ceramic and thinglass foils are widely used.

Ceramic Data Layer

Al_2O_3 Substrate

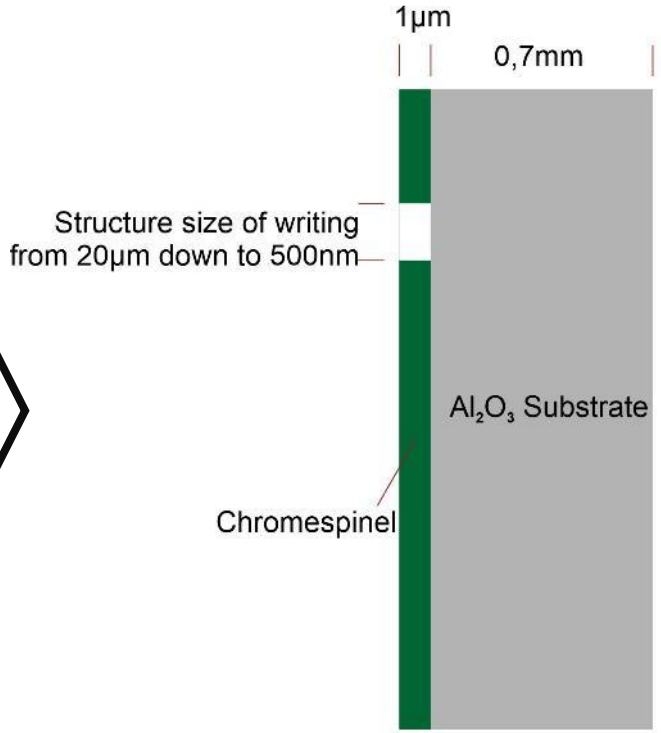


+

PVD coating

+

Tempering



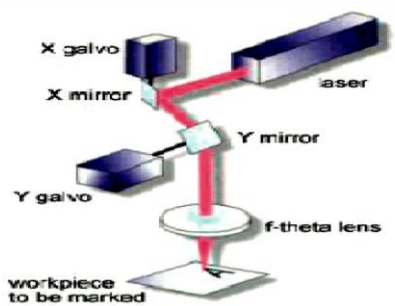
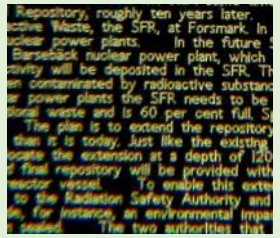
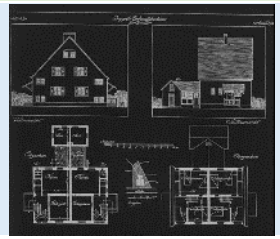
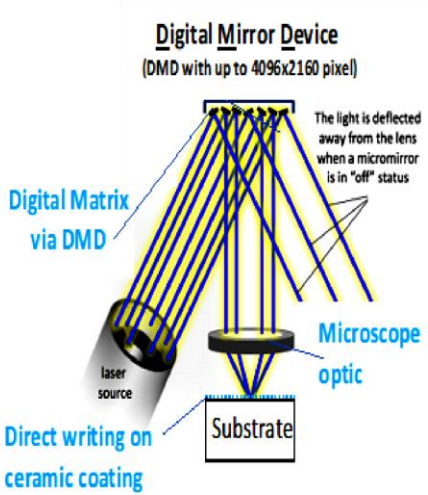
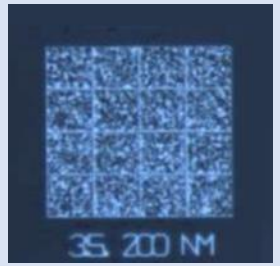
The clue for durable data carriers is a ultra thin and ultra hard coating for the data layer.

The thin data layer is also from ceramic material and even harder (18 Gpa) than the substrate material itself (17 Gpa).

The structural robustness is around 500 Mpa.

The European, US and Taiwan patent comprises method and materials.
Patent released 4/2021.

Laser Technology

		Process size	Writing speed / Availability	Example	Equivalent on 10x10 cm	
Nanosecond Laser 	Galvo writing 	20 µm	10 KB/s Existing conventional Laser Engraver	1 mio characters	3 MB	
Picosecond Laser 	Multi-beam matrix writing	1 µm	10 KB/s 1 MB/s 2022 (10x10 multi beam)	900 plans of A0 format	1,25 GB	
Femtosecond Laser 		500 nm	10 MB/s 2023 (32x32 multi beam)	50 000 dpi, 100 x capacity of polyester microfilm	5 GB	
		200 nm	1 GB/s 2024 (100x100 multi beam)	digital data matrix	31 GB	

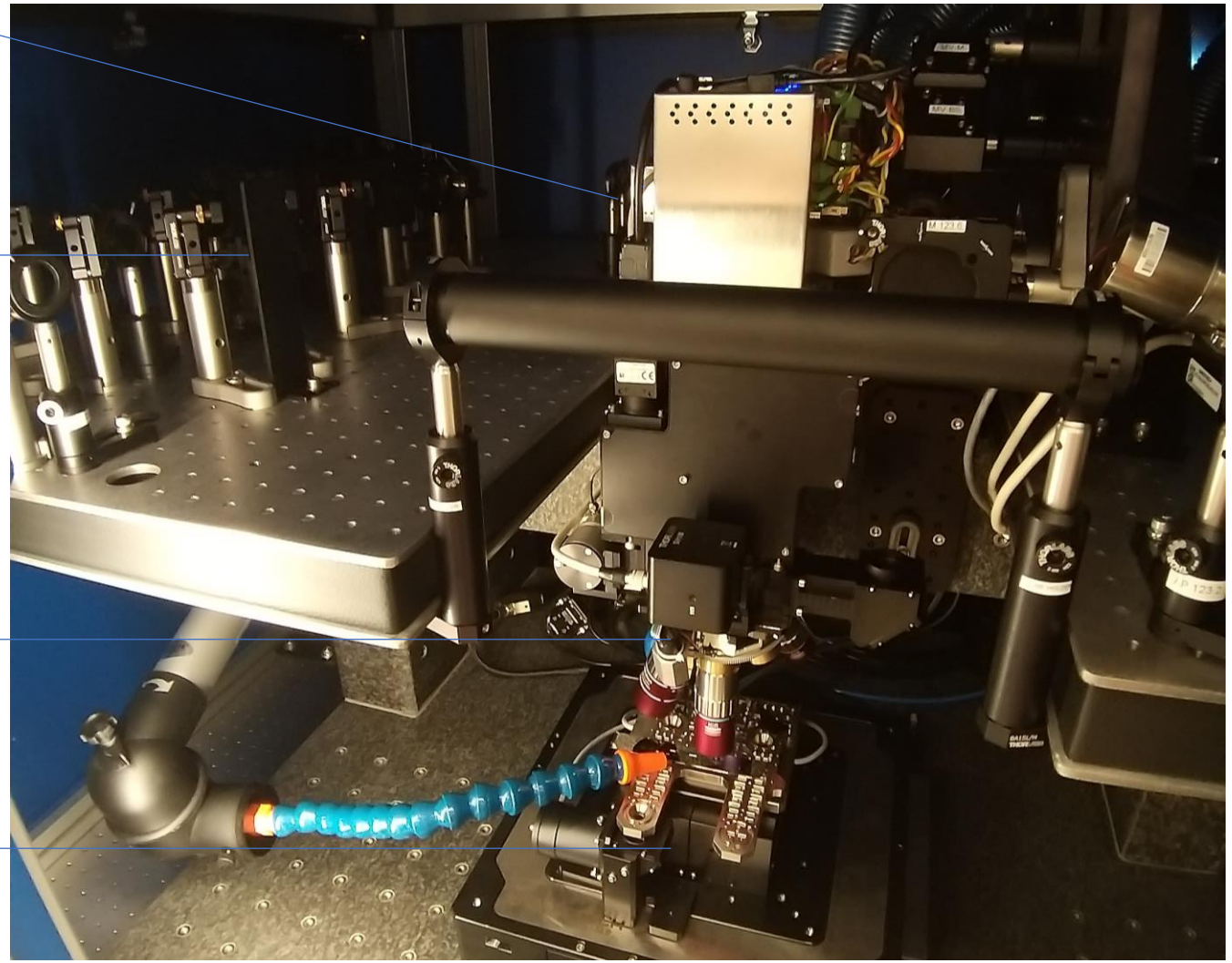
Operation of the test machine at the Photonics Center at the Technical University in Vienna Sept. 2021

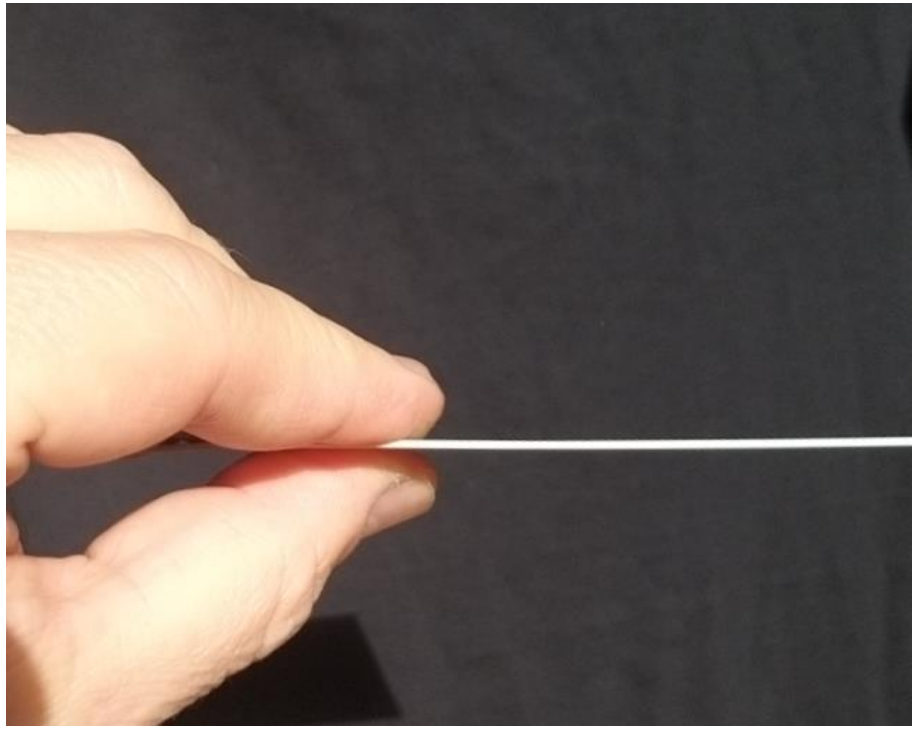
Femtosekunden Laser

Beam shaping

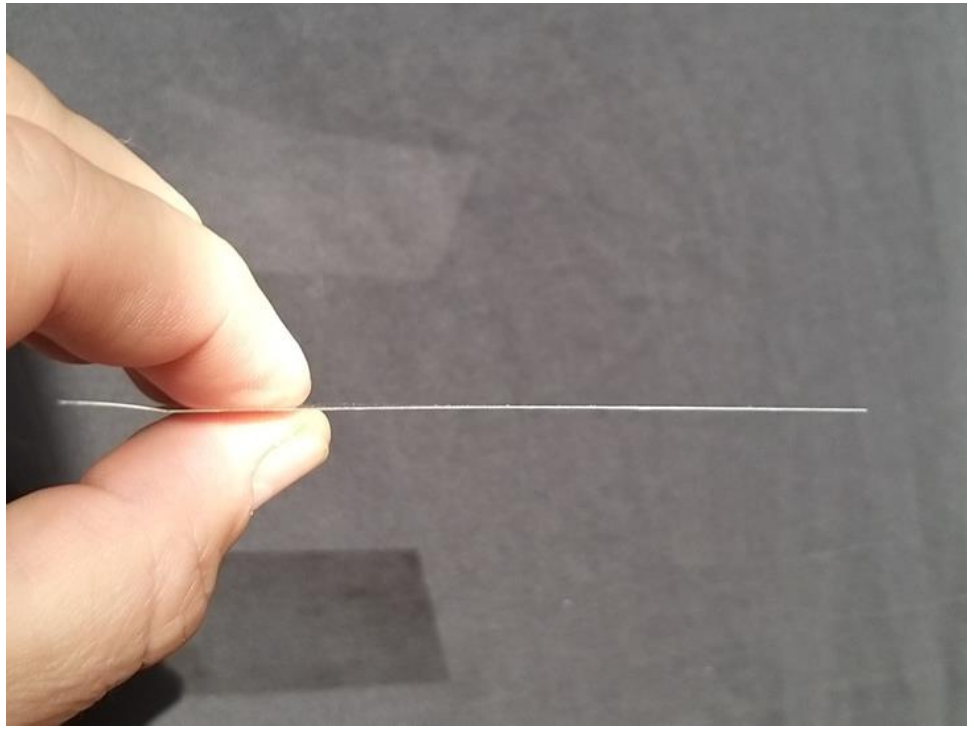
Mikcroskope-optics
for writing and reading

x/y/z stage





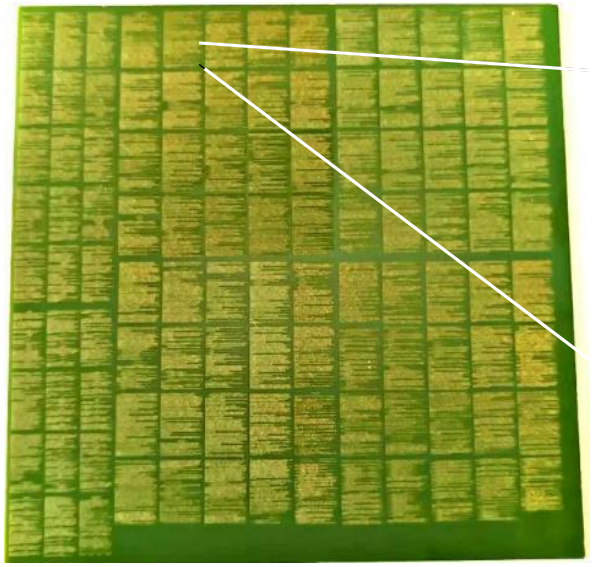
Ceramic Microfilm
Aluminium-Substrate basis
thickness 0,6 mm

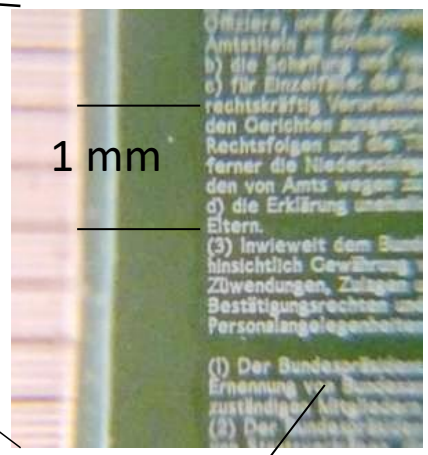


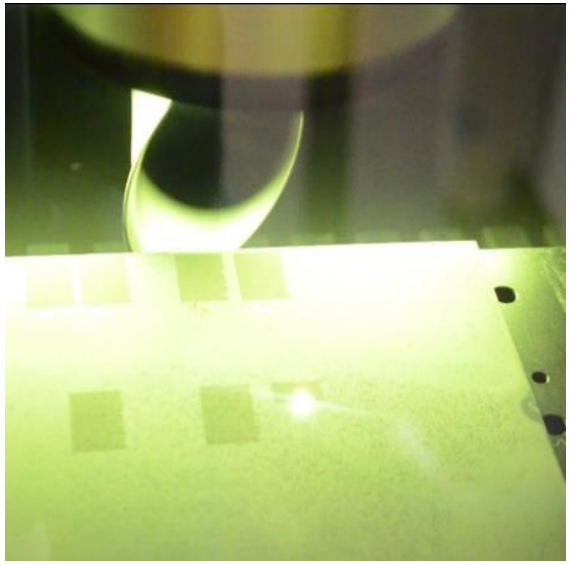
Ceramic Microfilm
Glassceramic basis
thickness 0,2 mm

100th Anniversary of the Austrian Constitution

Bundeskanzleramt







Ceramic Microfilm (10x10cm)

ca. 500 000 characters, 200 pages
writing time ca. 30 minutes

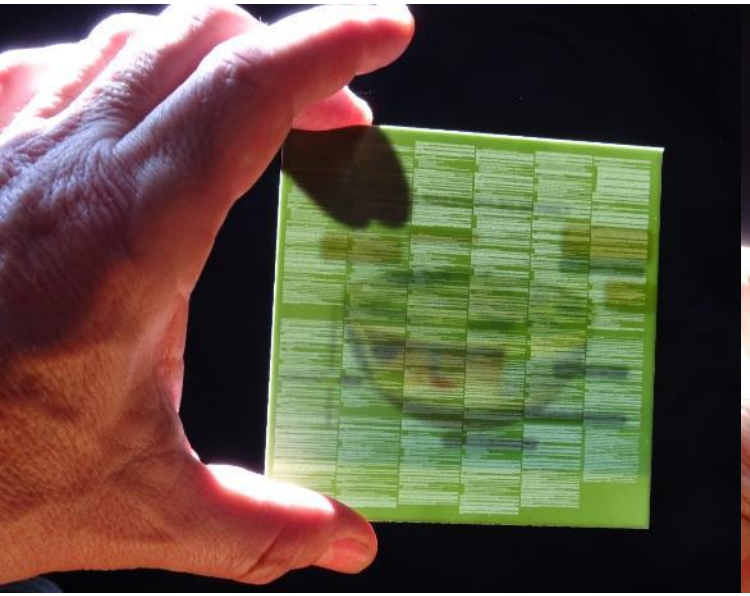
Structure size 30µm

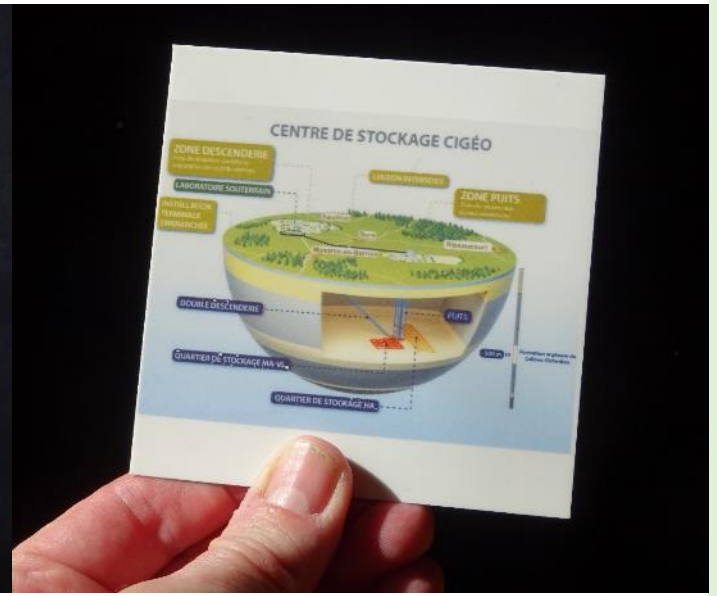
Laser writing

A first pilot project was initiated in cooperation with the Austrian Office of the Federal Chancellor on the occasion of the 100th anniversary of the Austrian Constitution.

The versions from 1920 and 2020 were stored simultaneously in the MOM archive and the Austrian data bunker in the Alps.

ANDRA
French national radioactive waste management agency

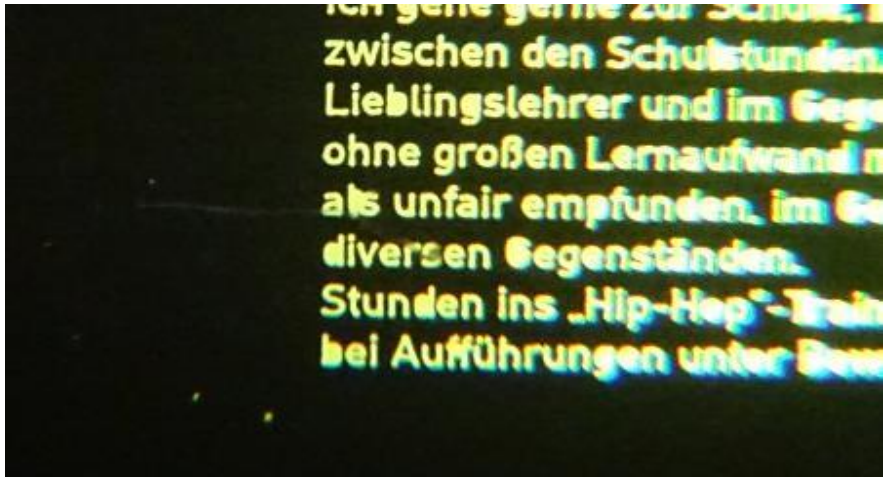




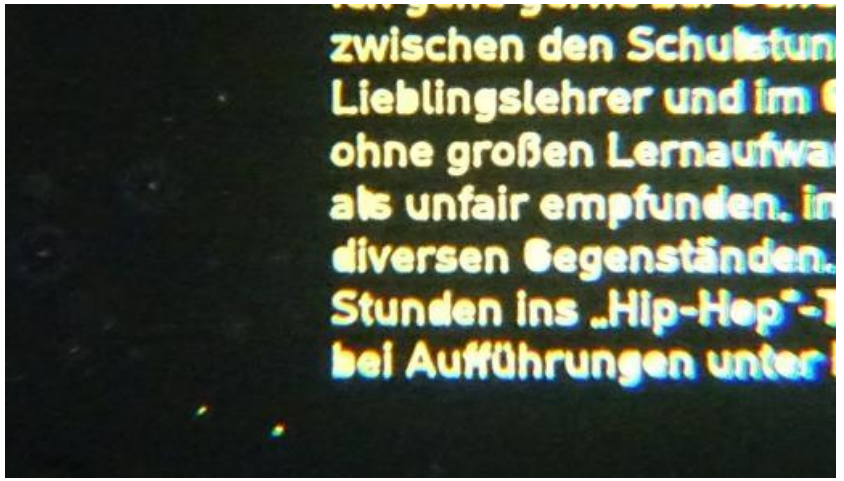
The nuclear industry, especially nuclear waste repositories, require data carriers with extreme longevity to keep the records of the radioactive material for thousands of generations, and also in a way that enables reconstruction of the knowledge in case it gets lost.

The french ANDRA is the first who adopted this technology.

After writing, **before** temperature test



After temperature test 1200°C , 15 min



The **durability** is - in terms of the life circle of a solar system - literally **eternal**.

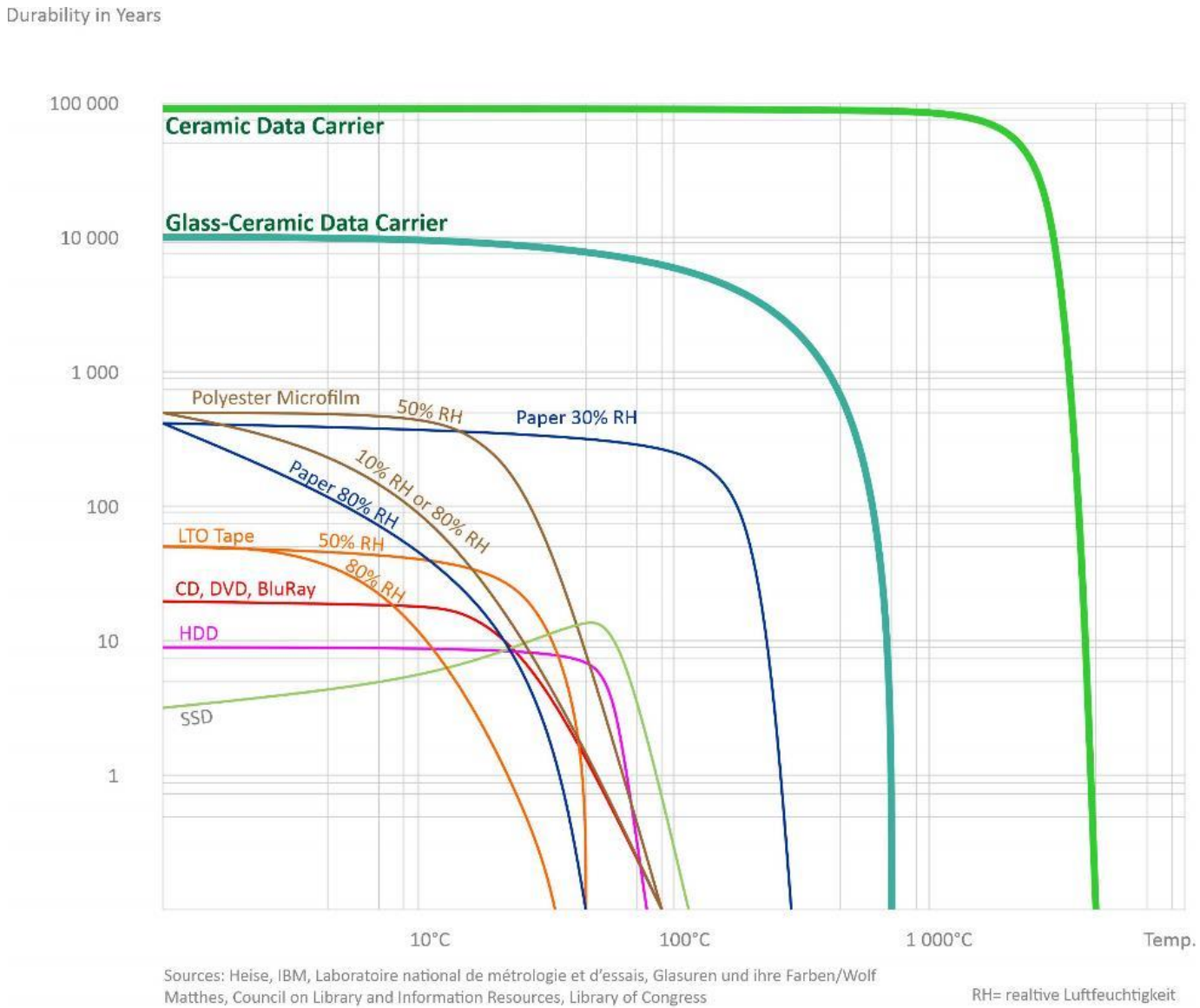
1200°C doesn´t harm the data carrier at all.
1200°C is the maximum temperature of a major fire.

The actual limit is the substrate with an operating range up to **1500**°C.

Age extrapolation**: Durability at room temperature far exceeding 10^{10} years**

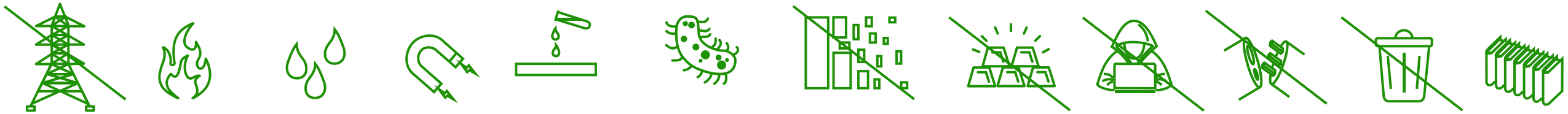
Durability

Ceramic Data Carriers



Ceramic Data Carriers in comparison to all other types of data carriers have the highest durability and also the highest temperature resistance.

The graph represents the limits from which data becomes illegible, whereas the data carrier itself in some cases may endure higher temperatures.



This finally lead to data carriers, that withstand all circumstances that conventional data carriers destroy.

- no energy demand
- fire proof
- waterproof
- insensitive to magnetism
- corrosion resistant
- non organic material

- stabile
- worthless material
- audit proof
- basic and intuitively
- non deletable
- selective

Data ≠ Information ≠ Knowledge

- **Marker**: symbols/icons
- **KIF**: Key Information : analog text and figures , with decoding- toolbox
- **SER** , Essential Records/documents: digital with manual

Now, when we can solve the problem of durable data carriers that withstand the ravages of time, the question is: what kind of „data format“ is eligible to safekeep information for these projected time horizons in order to create Information from data and to create knowledge from information? Analog?, Digital? Symbols? Icons?

It depends on the complexity of information that needs to be transmitted into a near or remote future.

For the basic information of a marker or the fundamental description of the nature of a repository site, symbols or icons certainly are more efficient than analog text or a binary information format.

And for a greater volume of descriptions, analog text with decoding tools are helpful. An extended dataset that probably also works as basis for machine processing can be kept in a digital form with an introducing manual.

Marker: symbols/icons

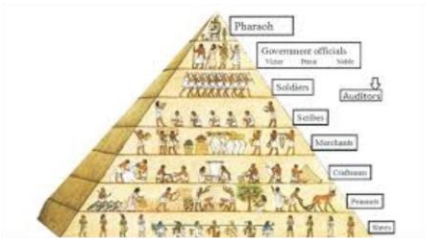
Nuclear Message

I want to continue only with the first item, since this is the main scope of the Expert Group I am working within.

How can a marker or basic information for a nuclear waste repository be designed?

Stoneage

Egyptian



Hellas

Medieval

Pre-industrial

Early-industrial

21st-century

Advanced-technical

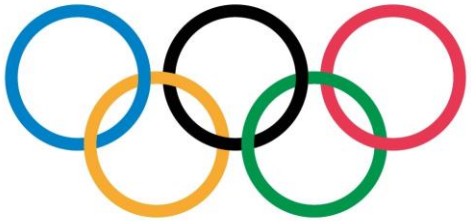
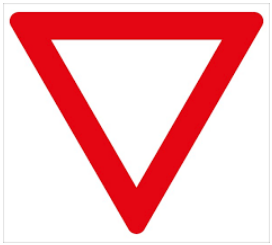
Idiocracy-like

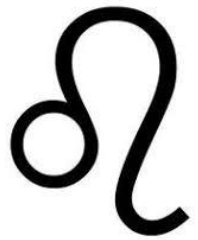
Mad Max -like

Ant-like-society

Dolphin-like

The following is under the assumption that a deep geological repository is designed in a way that it cannot be discovered or let alone opened accidentally only a society of at least a similar technical level comparable to ours from the 1970ies can actually access it: Must haves are: capabilities of deep drilling, ground radar, seismic experience, understanding of geological processes etc



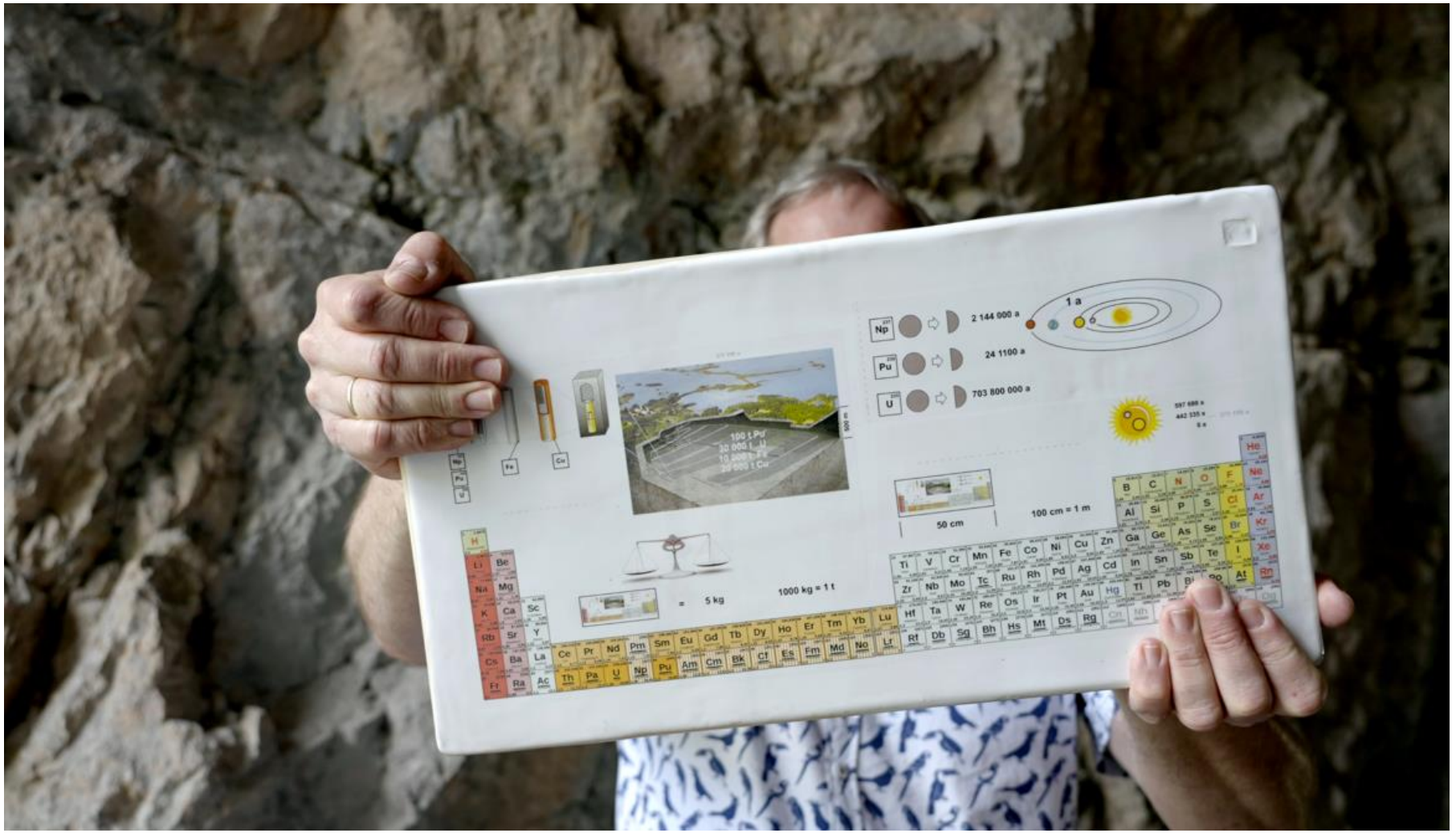
First of all we must acknowledge that most symbols or icons we use have an arbitrary meaning,
In order to understand them a prerequisite knowledge is required.
These symbols barely are useful for a message across thousands of generations.

However, there are some symbols which have a literally universal meaning.

A hammer will look the same throughout the universe, it is never a soft ball on a string.

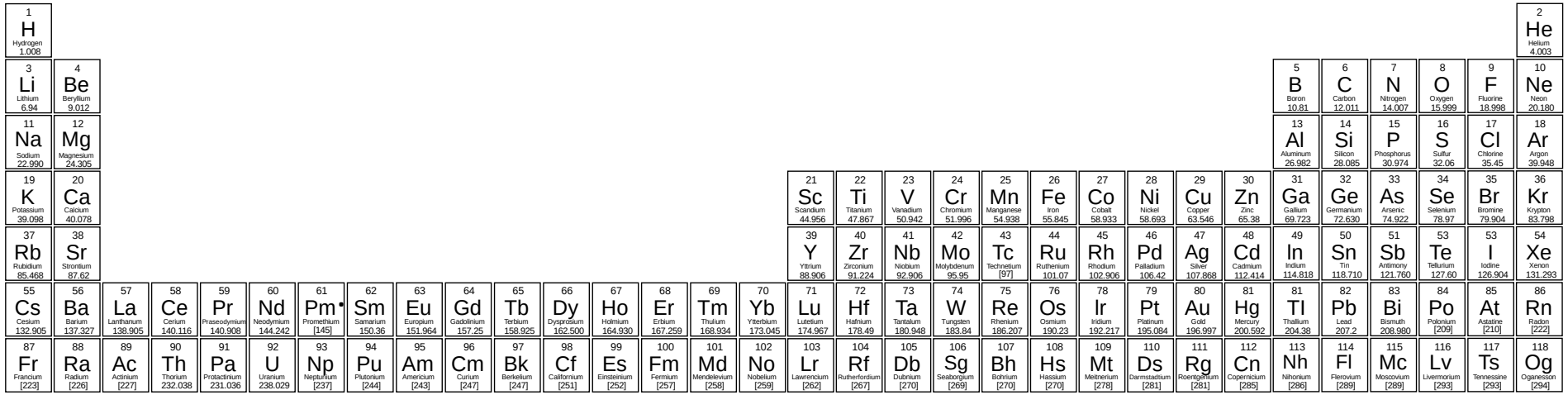
The Nuclear Message

A simple but efficient method to describe a nuclear waste repository



The **Nuclear Message**, a 3cm solid ceramic plate with a ceramic color print below a hard glazed surface.

The Order of Matter is Universal

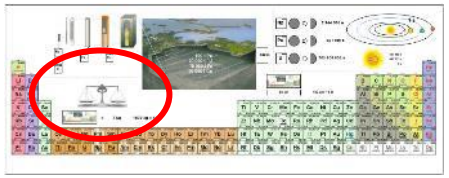


The principle which is behind the **periodic table** of elements was detected concurrently twice on earth. This is not a coincident – it is a natural, **universum-wide order of the elements**.

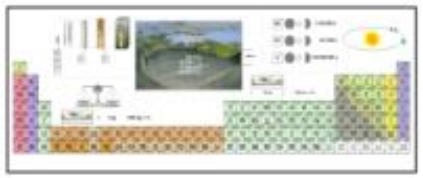
As soon as a civilisation recognises this order, the configuration as table is only a consequence.

The Periodic Table simultaneously explains our **numeral system** which in consequence allows to describe **isotopes**.

No matter how a future writing system looks like, the mere *position* in the table defines the respective element.



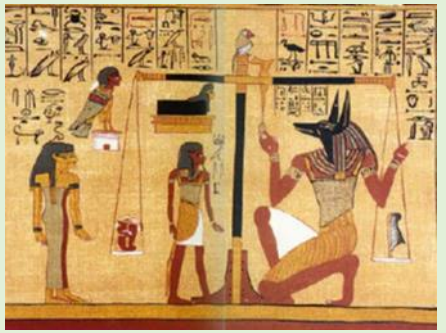
definition of weight

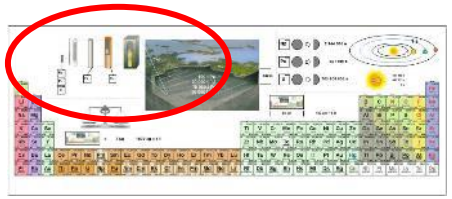


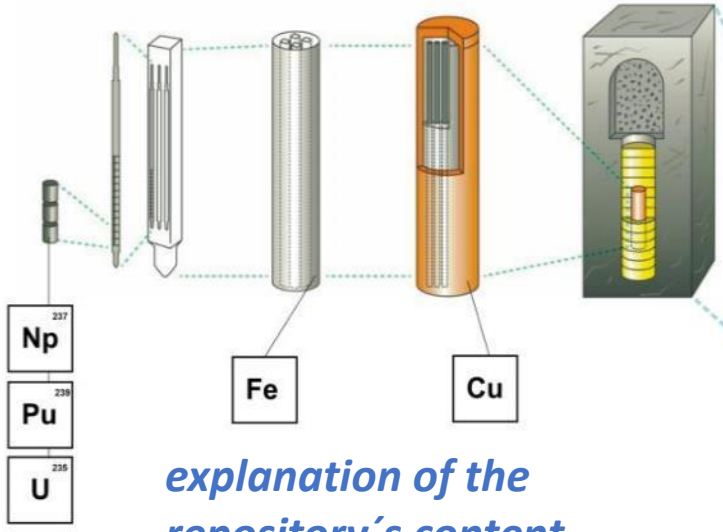
= **5 kg** **1000 kg = 1 t**

The plate itself works as a rough **“unit” for weight**.

From early human civilization, a balance looks identic. *Everywhere*, where gravity exists, a balance has a similar design.

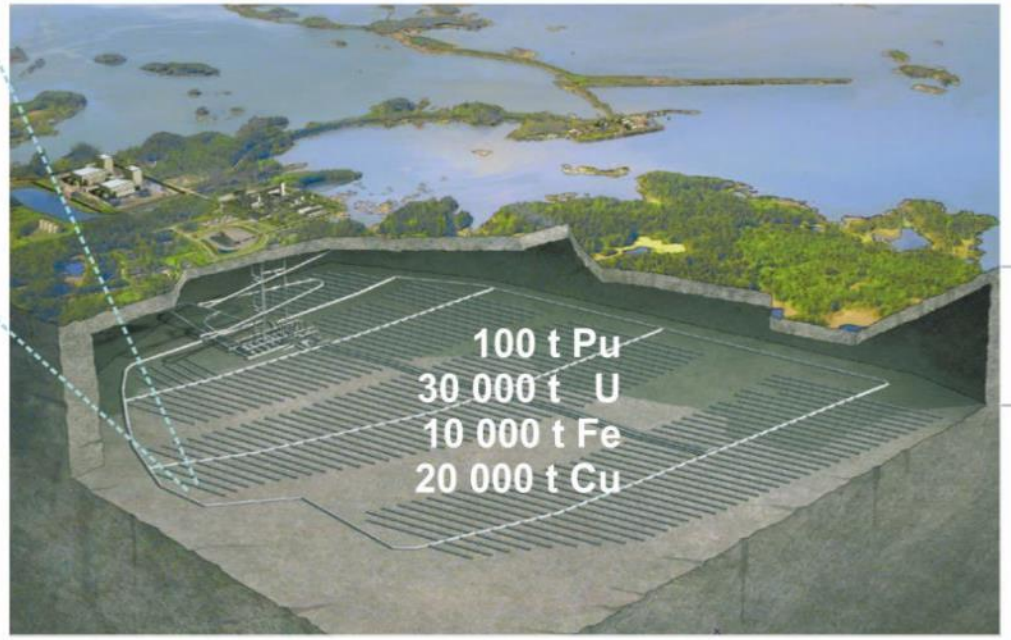






explanation of the repository´s content

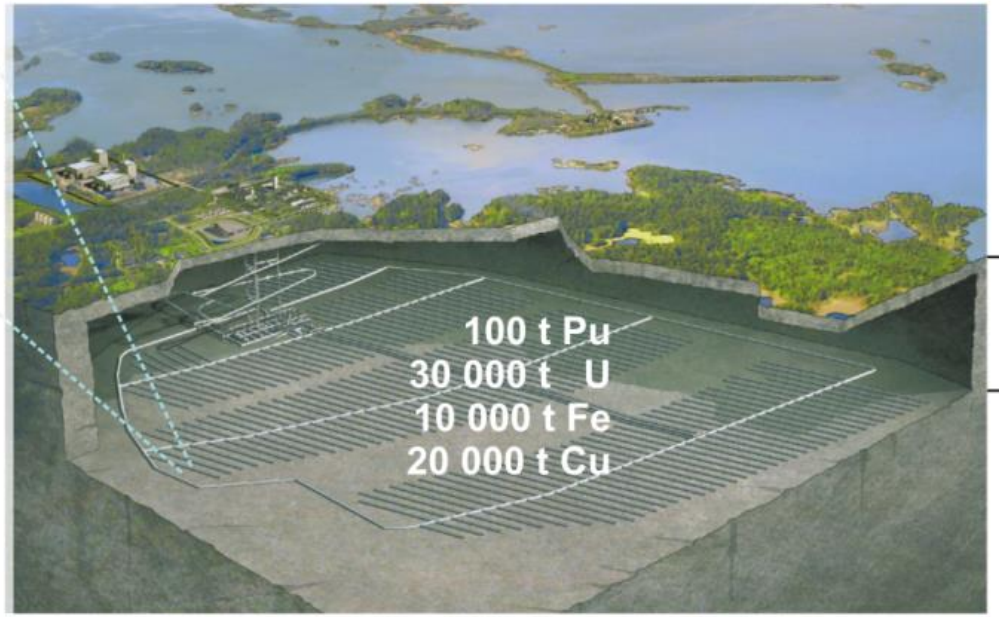
illustration of the deposit



amount of the content

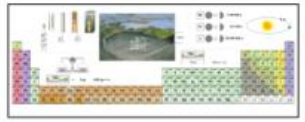
The containers and the **material** from which they are made, and the respective **isotopes** are indicated.

As well as a depiction of the repository itself and the **amount** of material stored there.



description of the depth

500 m



50 cm

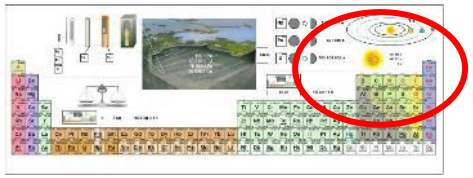
100 cm = 1 m

unit for lenght

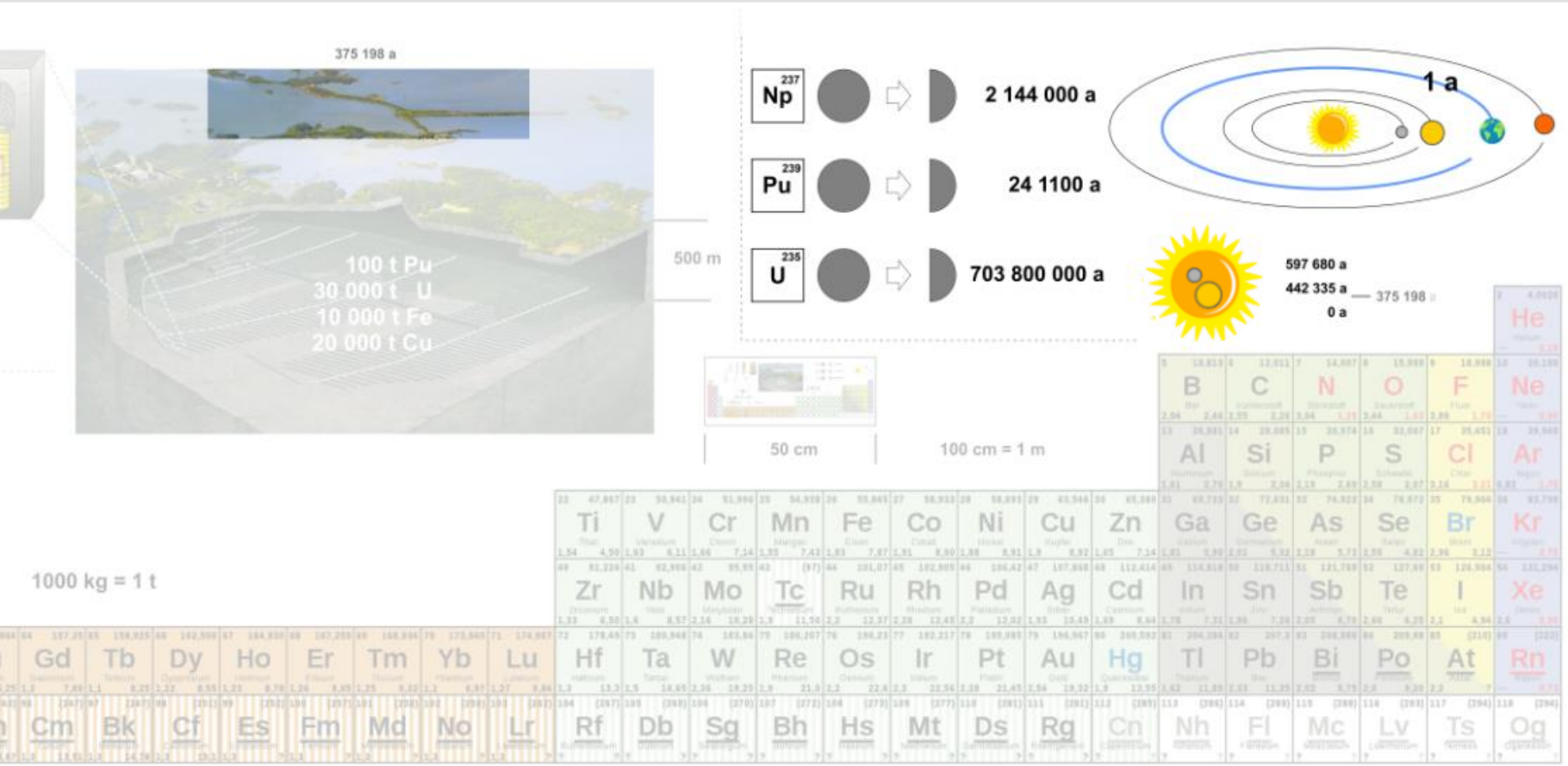
kg

1000 kg = 1 t

The size of the plate serves as a rough **unit for length**.



Definition of one year and double-check via half-life periods. Explaining our present era by rare astronomical events.



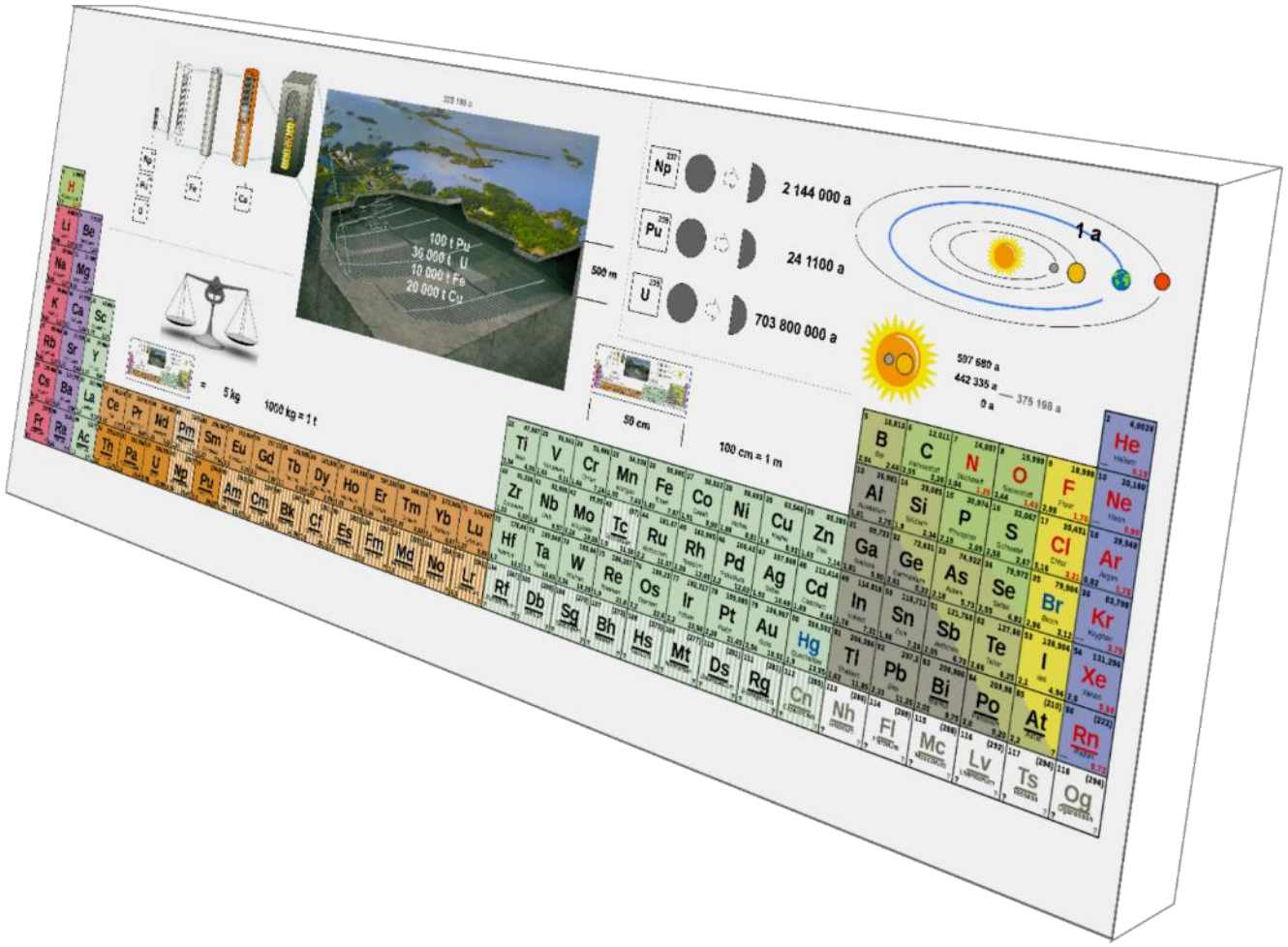
One year as unit for time is defined by the depiction of the earth`s orbit around the sun. This can be **double-checked** by the half-life period of some radioactive elements.

To explain, ***when*** **our current presence** is, a very rarely occurring constellation is chosen to assist:
Simultaneous transits of Mercury and Venus (the event when both planets are exactly between the sun and the earth and appear as dark spots in front of the solar disc).

The last one occurred in 373 173 BC and the next will be in the year 69 163 and the next but one in 224 508.

Hence the last one is 375 198 years ago. This number is also positioned on top of the illustration of the repository site.

Nuclear Message with built-in chronometer



Ceramic material is a „clock“:
Silicate containing material indicates its “age” by **thermoluminescence**.

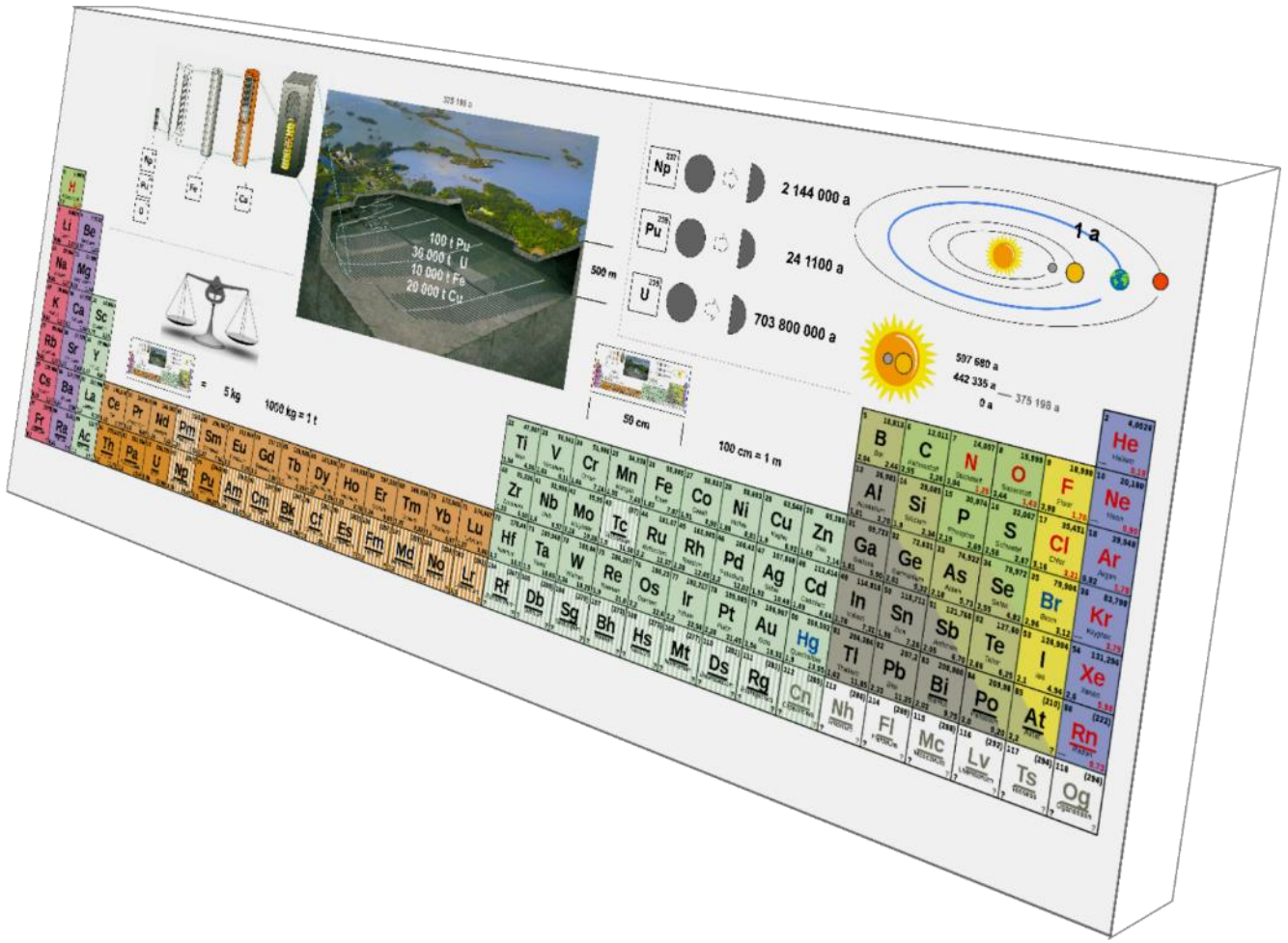
Thermoluminescence dating shows how much time have passed by, since the material was last heated over 600°C.
We know the effect of thermo-luminescence since 1950 and it is used to determine the age of rock or ceramics.

Because the plate is produced at 1200°C, the clock is now “set to zero”.

The calculated age of the plate can be **doublechecked** with the astronomical events of the simultaneous transits.

In 50 000 years in the future, scientists can figure out the age of this ceramic object (namely 50 000 years).

They can then estimate the rate of decrease of radioactivity and the nature of the content at that point in time.

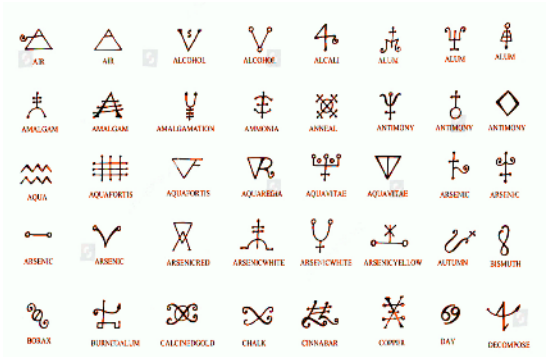


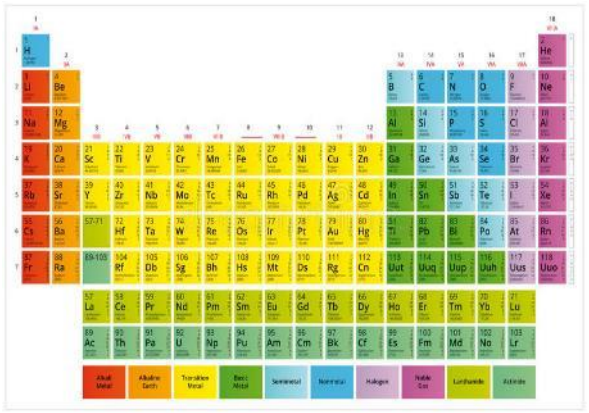
The Nuclear Message is a 3 cm solid ceramic plate with ceramic color print below a hard glazed surface

Even if the surface got opaque (by wind-sand erosion) - once fired at 1200°C the glaze becomes transparent again and reveals the images.

Similar to the method which the MOM-Token uses, the backside has information about the exact **position** by using landmarks such as coastlines, peaks or lakes. Those landmarks will change significantly, e.g. by rising sea level. But future finders, who can decode the front side will have the insight about geological processes and can therefore reconstruct a former coastline at a particular point in time.

The continental drift is about 1 cm/year. This sums up to 1km per 100.000 years and has no sigificant impact on the continent´s shape within 1 Mio years.





?

We know that we don´t comprehend 95% of the universe´s matter and energy.

It´s very likely that new insights lead to a substantially different understanding of matter, energy and time, or the fundamental forces.

However, even if a highly advanced society finds the Nuclear Message, the knowledge which is behind the Nuclear Message must have been part of their epistemological path.

Because it is very unlikely that quantum physics is invented before the steam machine…

Conclusion:

- The **position** can be described by landmarks
- The **content** is explained by the Periodical System of the Elements
- Our **decimal system** is shown by the numbering of the elements
- The **amount** of the respective materials can be derived from the Nuclear Message´s weight serving as unit
- The **depth** is defined by the Nuclear Message`s size
- A **year** is defined by
    - half-life periods of selected nuclides
    - depiction of the inner solar system and the earth´s orbit
- The **age** of the repository is shown by
    - thermoluminescence of the Nuclear Message`s material
    - astronomical constellations which happen only three times within 500.000 years
- The respective **current content** at any point in time can be calculated by the time passed by since construction
- The Nuclear Message is **inexpensive** and can be distributed in large amounts in the region of the repository