Ageing Management for Long Term Interim Storage Casks

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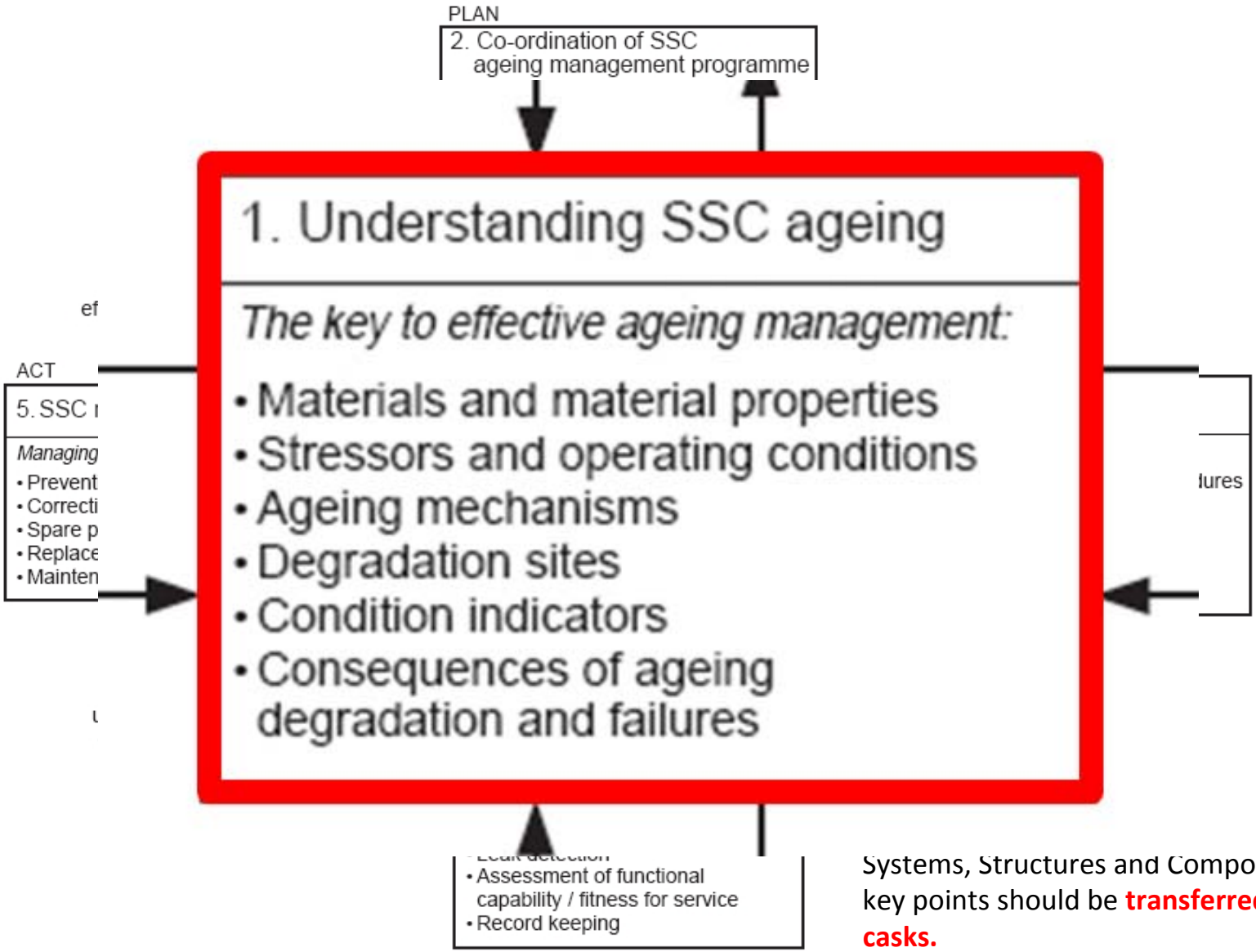
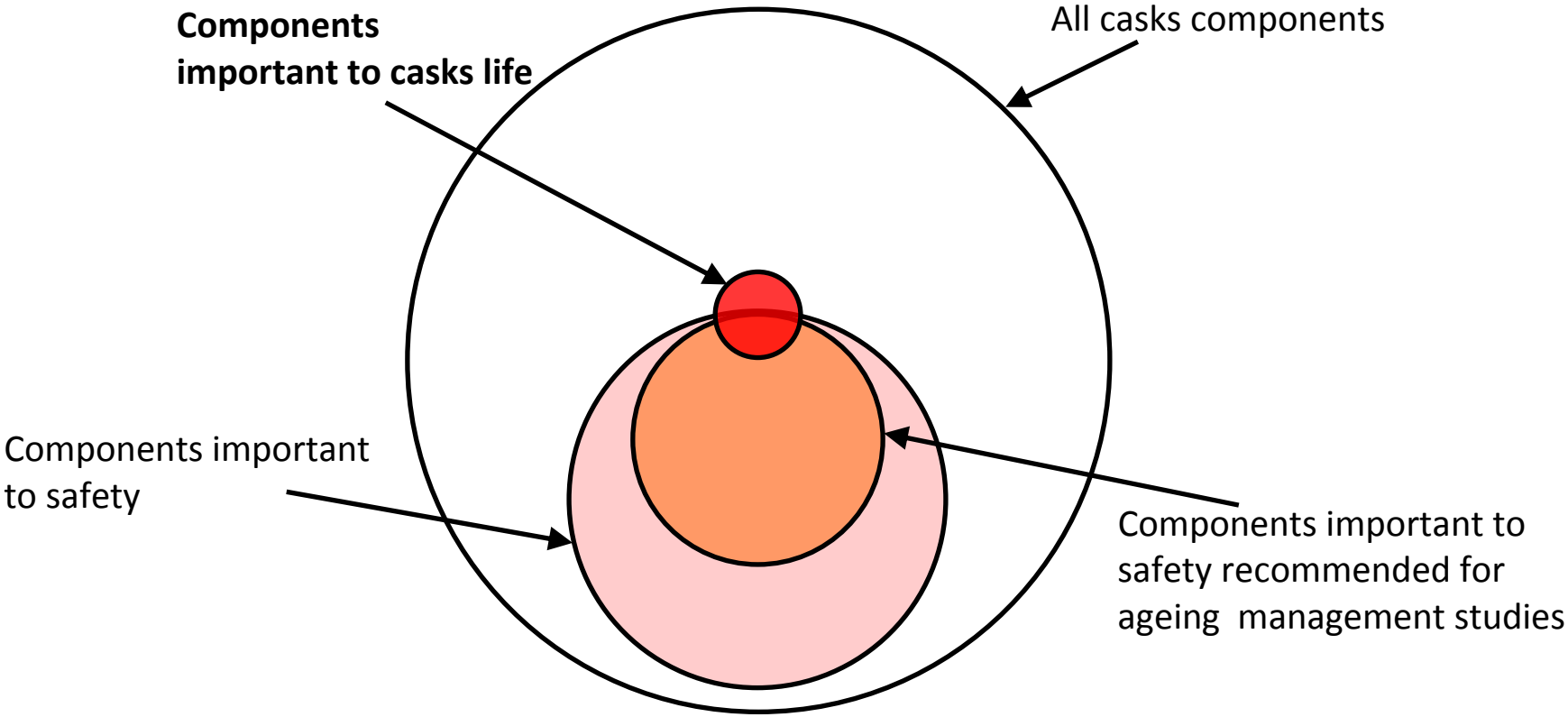
Definition:

- Ageing management is a program for monitoring and maintaining safety-related functions and components, which are subject to wear and other age-related changes.
- The goal is to control age-related degradation and prevent equipment failures caused by ageing, by maintaining this equipment in “as new” condition so it always operates at peak performance.

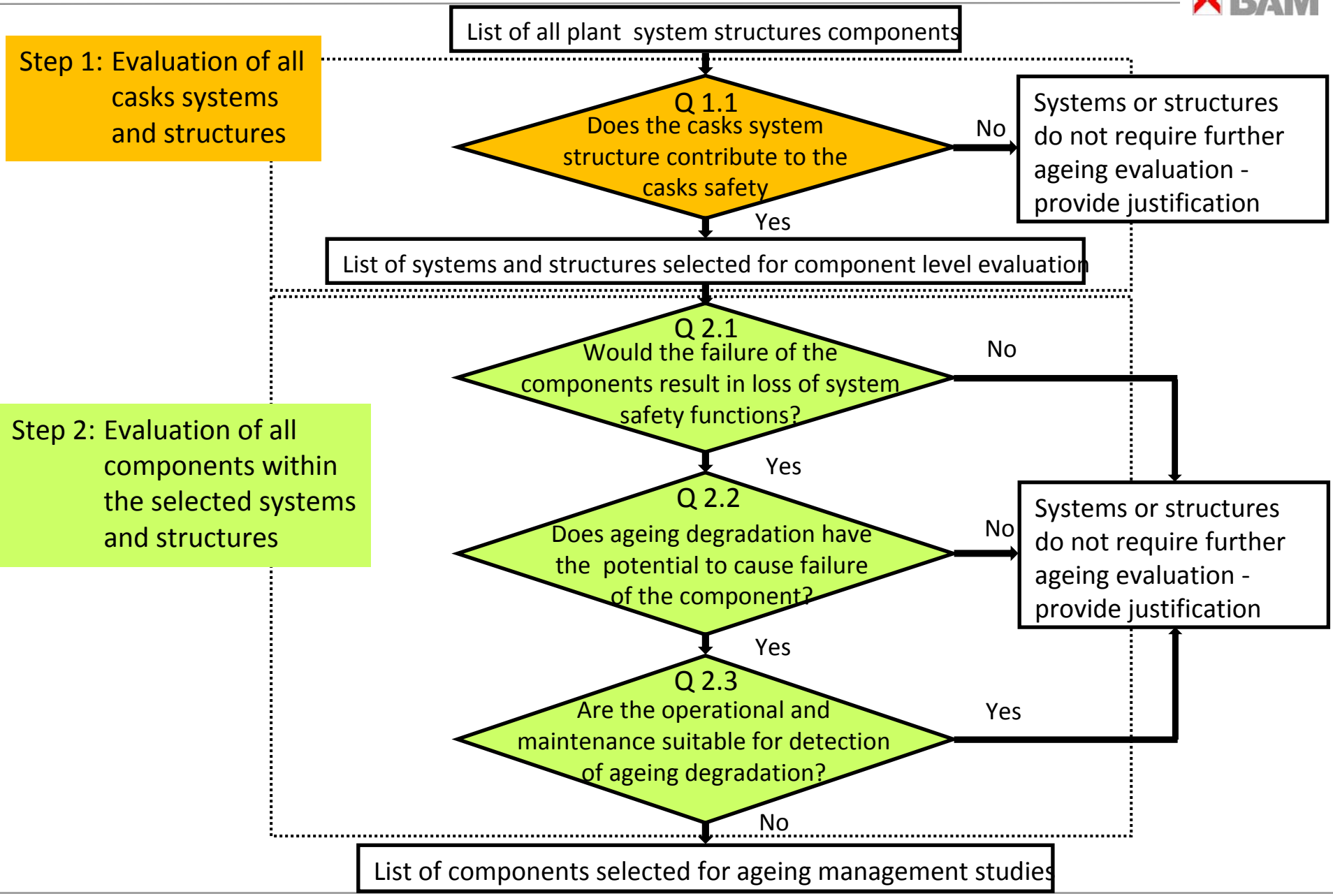
Systematic of an Ageing Management Process (origin IAEA Report)



Systems, Structures and Components (SSC), key points should be **transferred to storage casks.**



- The first step must be: Identification and categorization of safety functions and components in **active** (e.g. valves, filters) **or passive**. Because of the passive oriented dry interim storage concept safety-related active components are not part of the casks.
- Safety important functions are those, which must be performed throughout the lifetime in the interim storage facility, as there are safe enclosure, sub criticality, shielding and decay heat removal.


Step 1: Evaluation of all casks systems and structures
List of all plant system structures components
Q 1.1
Does the casks system structure contribute to the casks safety
No
Systems or structures do not require further ageing evaluation - provide justification
Yes
List of systems and structures selected for component level evaluation
Step 2: Evaluation of all components within the selected systems and structures
Q 2.1
Would the failure of the components result in loss of system safety functions?
No
Yes
Q 2.2
Does ageing degradation have the potential to cause failure of the component?
No
Systems or structures do not require further ageing evaluation - provide justification
Yes
Q 2.3
Are the operational and maintenance suitable for detection of ageing degradation?
Yes
No
List of components selected for ageing management studies

Categories

Group 1 Components:

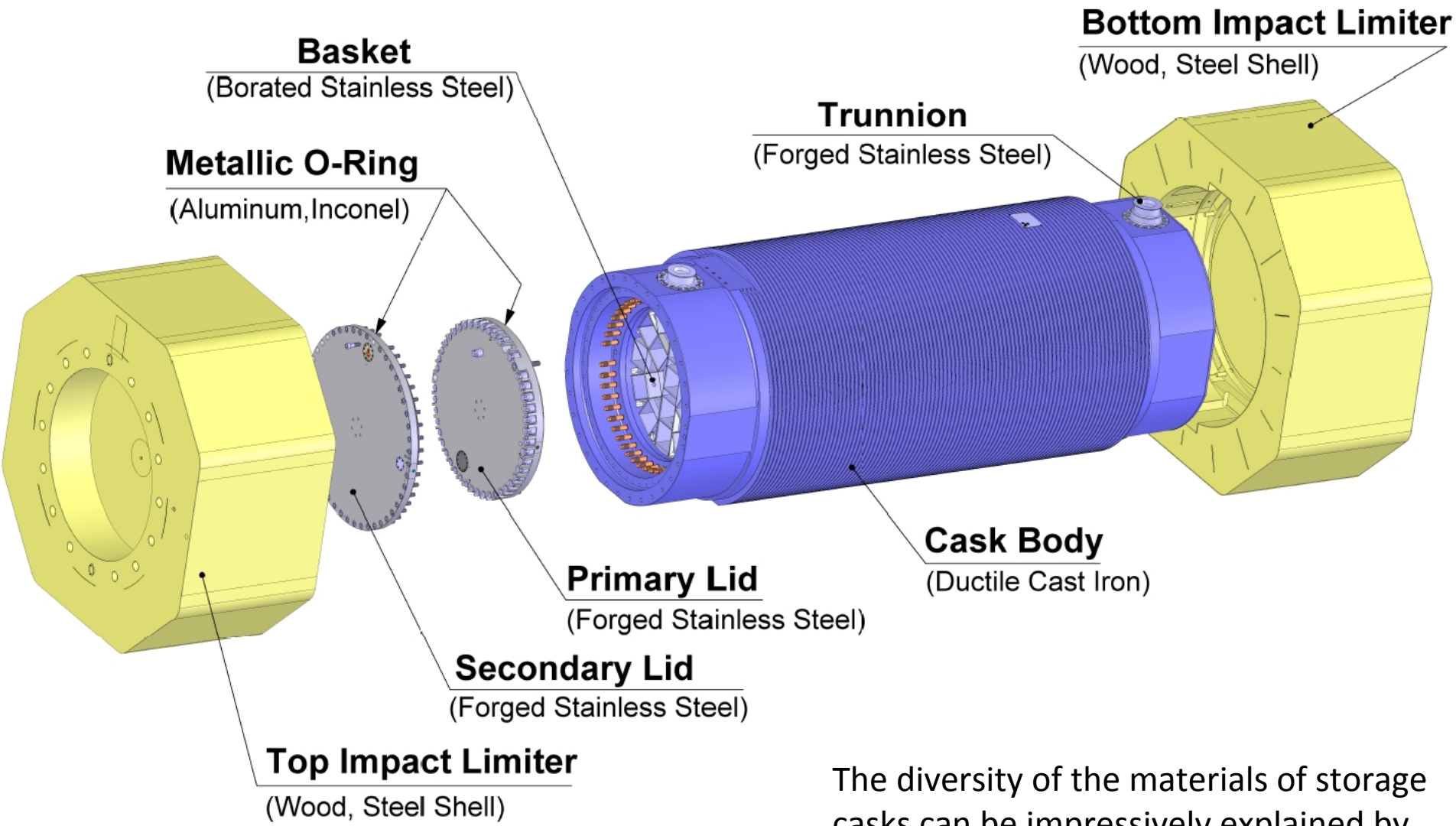
All safety relevant components, those are important to casks life. These are components their failure or loss of function exceeds a design criteria event, leads to malfunction or the agreed number of redundant systems is no longer available. Further safety functions of auxiliary systems and constructions must be taken into consideration for these components. Such components are e.g. cask body and lids, fuel basket, trunnions, metal seals, neutron absorbers.

Group 2 Components:

All safety relevant components which are not associated with group 1. The safety function as well as the needed auxiliary systems and construction must be regarded.

Group 3 Components:

This group covers all components, which are not part of group 1 or 2. These components are subject to the general maintenance procedure.



CASTOR® design by GNS

The diversity of the materials of storage casks can be impressively explained by viewing the drawing.

Ageing Mechanisms

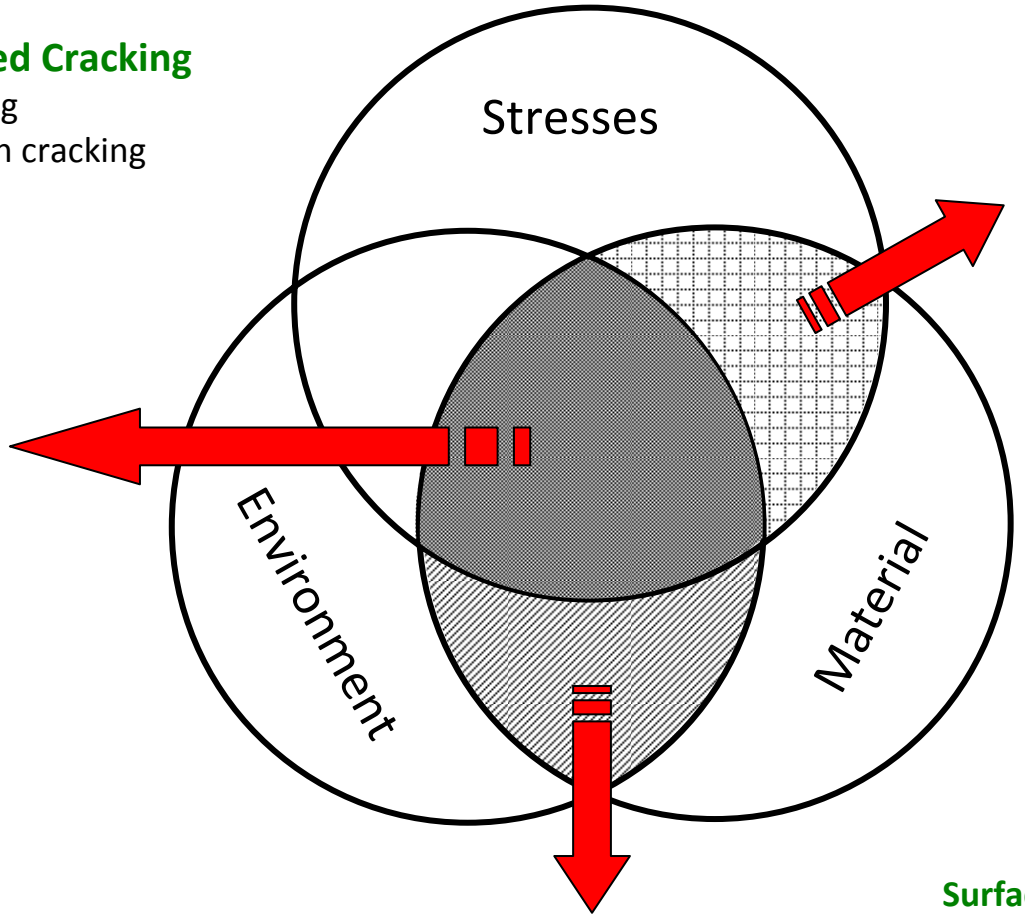
As the diversity of the materials, also the ageing mechanisms have wide diversities to affect the casks. Nevertheless, **three general ageing mechanisms** must be taken into consideration.

- **Physical and chemical ageing through loads and environment conditions**,
- **Technological ageing through change of knowledge,**
- **Conceptual ageing through change of requirements or specifications.**

One of the main goals of ageing management is the acquisition and evaluation of ageing mechanism data and the systematic damage prevention. **All of the three ageing mechanisms are of particular importance.**

Environmental Assisted Cracking
- Stress corrosion cracking
- Strain induced corrosion cracking
- Corrosion fatigue

- Unfavourable state of material
- Local stresses
- Unfavourable (local) environment

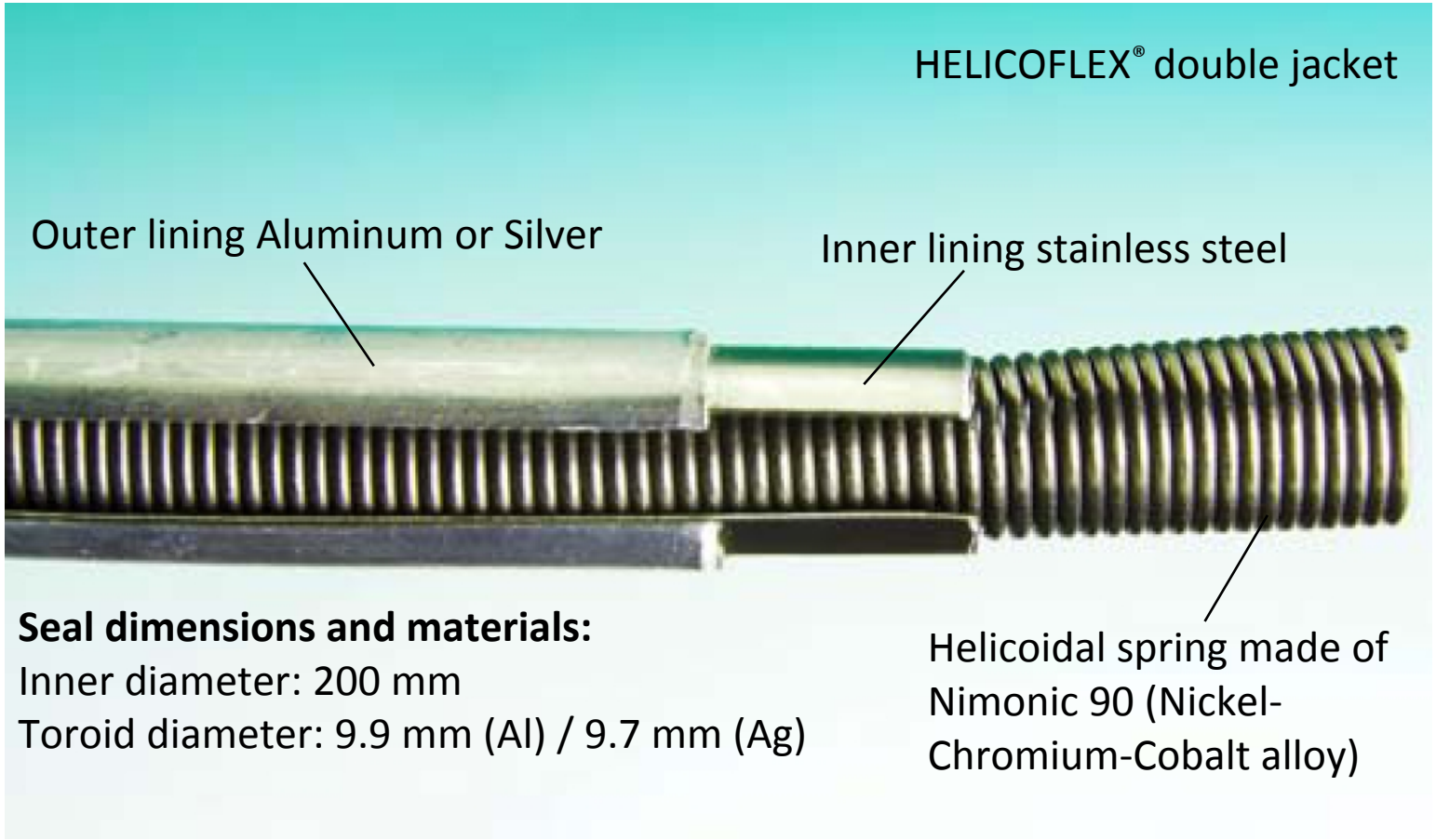


- Mechanical and thermal loads
- Material degradation caused by operation

Plastic Deformation
- Deformation
- Ratcheting (cycle creep) fatigue

- Material not resistant
- Electrochemical attack

Surface corrosion
Pitting
Selective corrosion
Erosion corrosion



Worldwide activities to overcome long-term dry storage of radioactive material are on the way. In this context, storage periods from 40 years up to 300 years are under discussion. One of the major questions deals with the long-term leak tightness of screwed lid systems with different kinds of metal seals. Such seals, e.g. of the HELICOFLEX® type with an inner helical spring and two outer metal jackets have to guarantee leak-tightness and safe enclosure of the radioactive cask inventory over the entire storage period.

Evaluation of long-term performance and leak-tightness of such seals by **Larson-Miller Parameter**

The basis for this formula is that the creep rate is equivalent to the reaction constant in the chemical kinetic and a function of the temperature, as written in the equation below (Arrhenius equation):

$$\dot{\varepsilon} = Ae^{-\frac{\Delta H}{RT}}$$

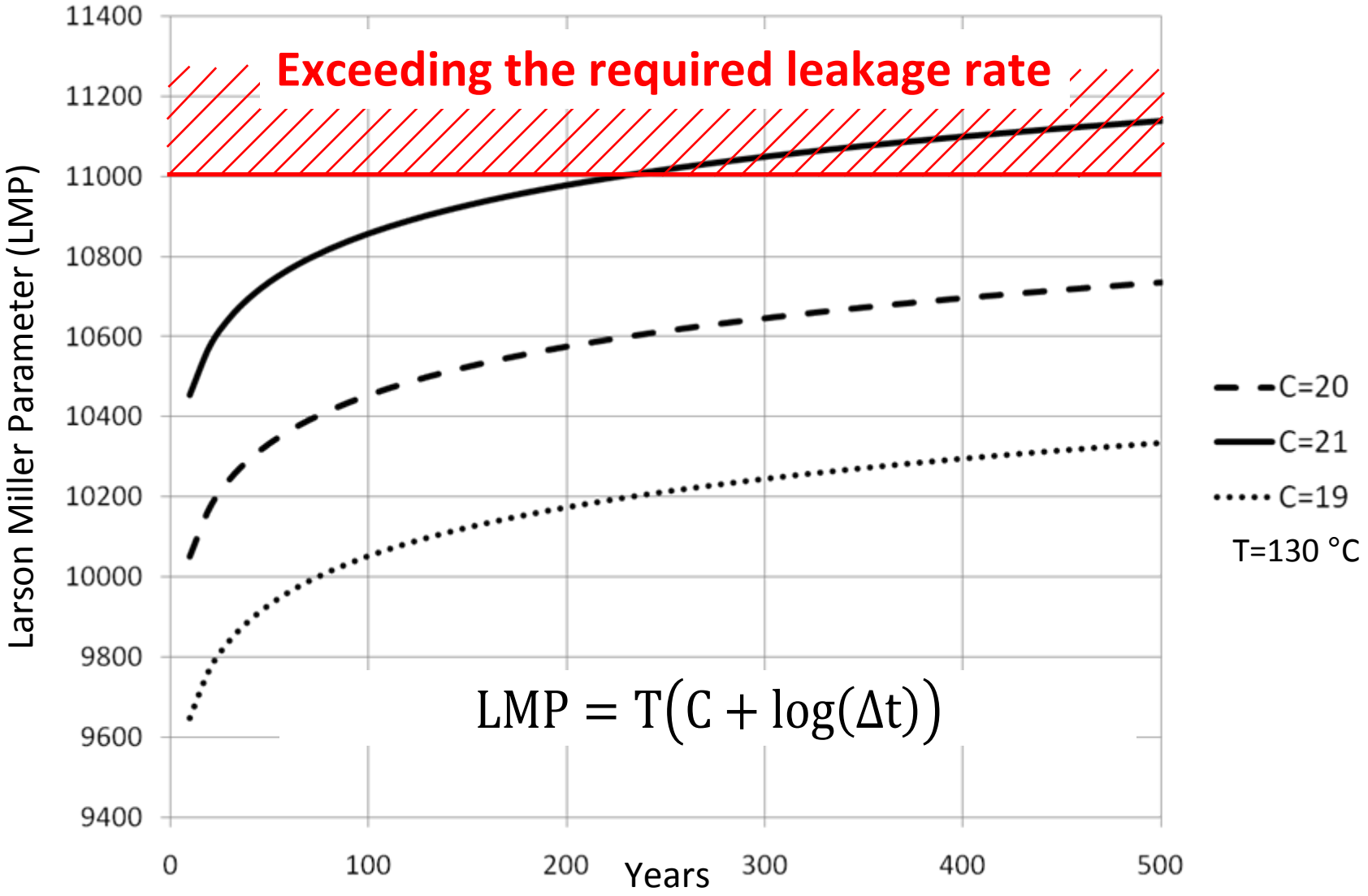
Where $\dot{\varepsilon}$ is the creep process rate, A is a constant, R is the universal gas constant, T is the absolute temperature, and ΔH is the activation energy for the creep process

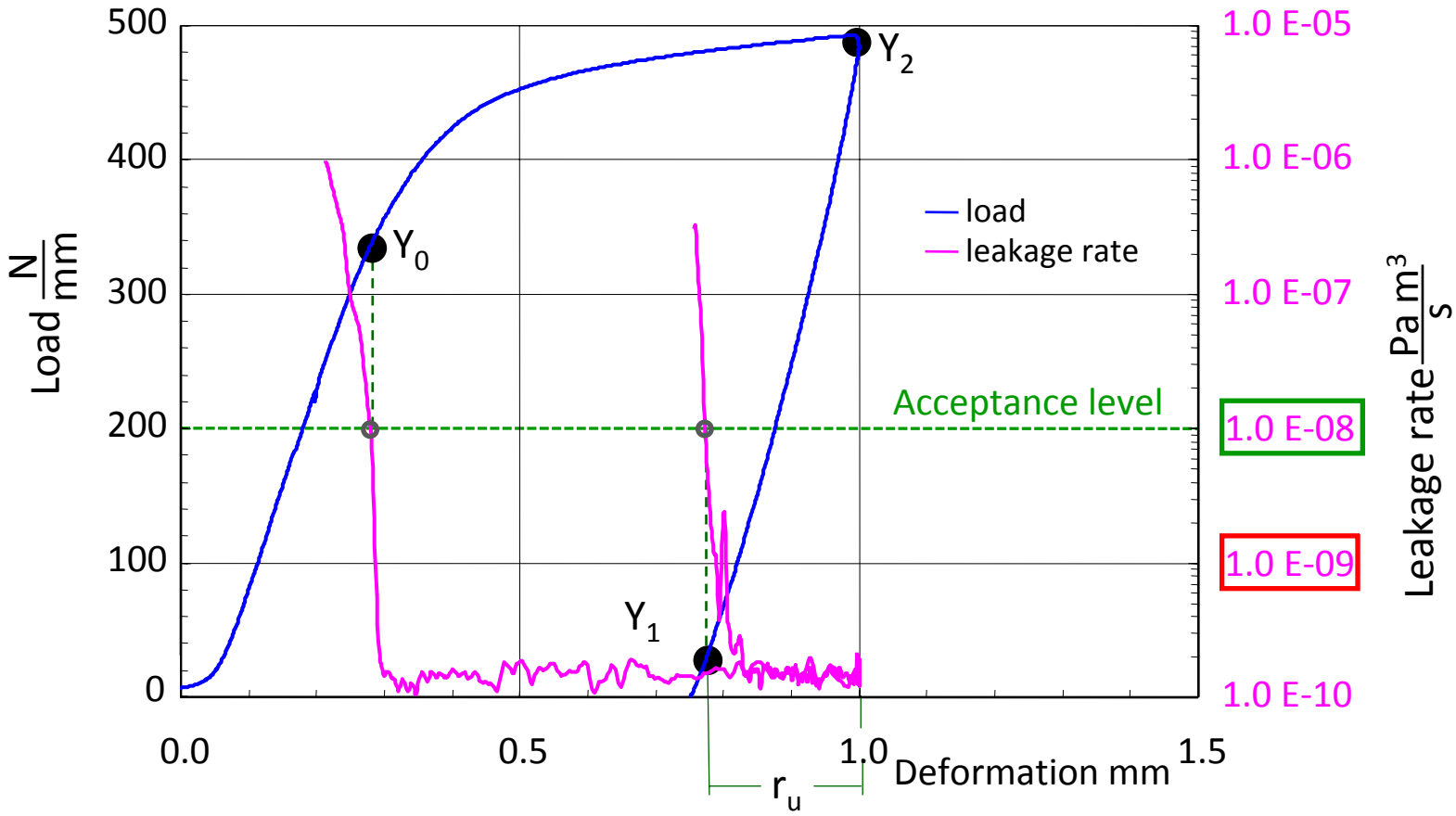
Larson and Miller where using the assumption that the creep rate is inversely proportional to time, than the equation above can be written as:

$$\frac{\Delta l}{\Delta t} = Ae^{\frac{-\Delta H}{RT}}$$

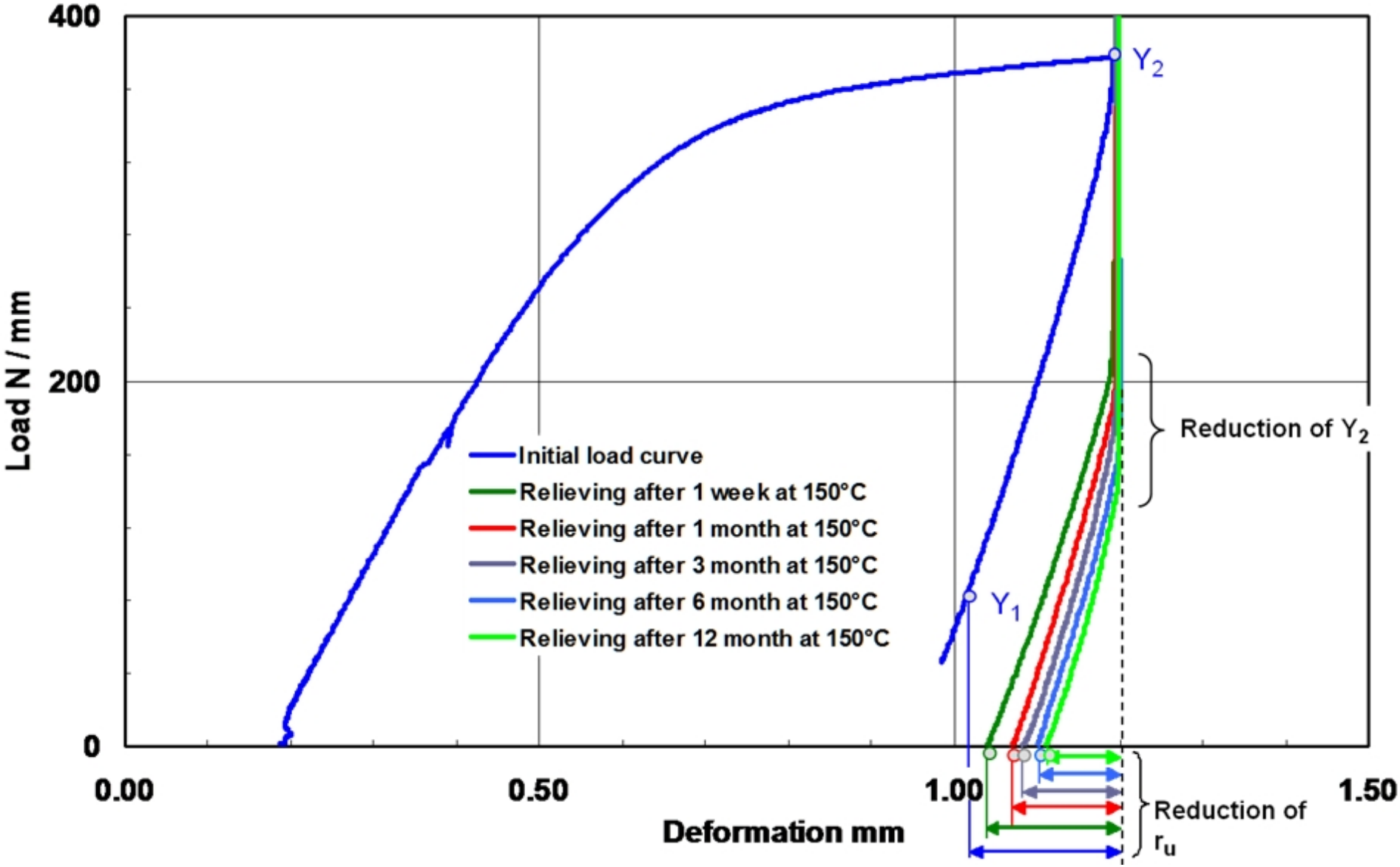
Taking the logarithm of this equation under the consideration that $C = logA - log(\Delta l)$, then the received equation has the form of the **Larson-Miller-Parameter** (LMP) whereat t is in hours. *The material depending parameter **C** must **always be determined experimentally***.

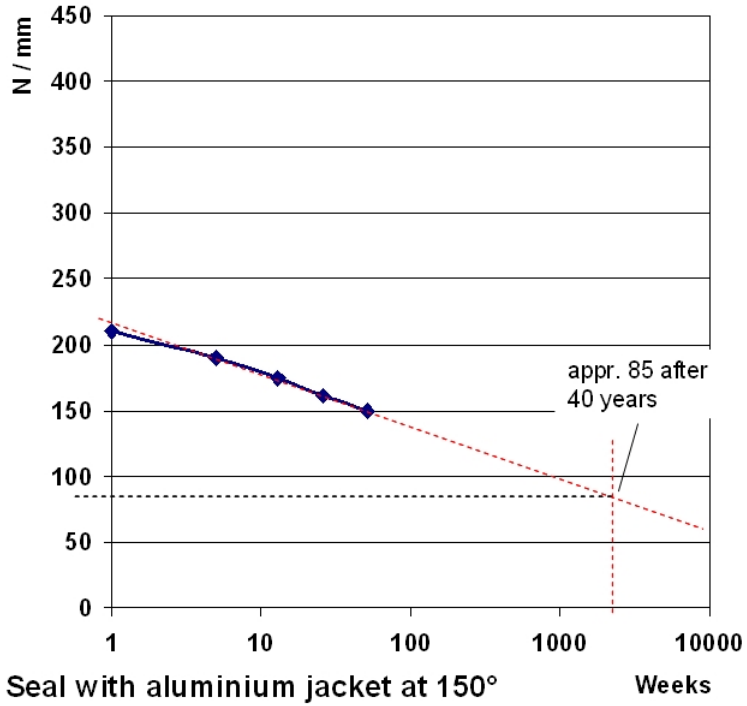
$$LMP = T\left(C + \log(\Delta t)\right)$$


Exceeding the required leakage rate
Larson Miller Parameter (LMP)
11400
11200
11000
10800
10600
10400
10200
10000
9800
9600
9400
0
100
200
300
400
500
Years
C=20
C=21
C=19
T=130 °C
LMP = T(C + log(Δt))

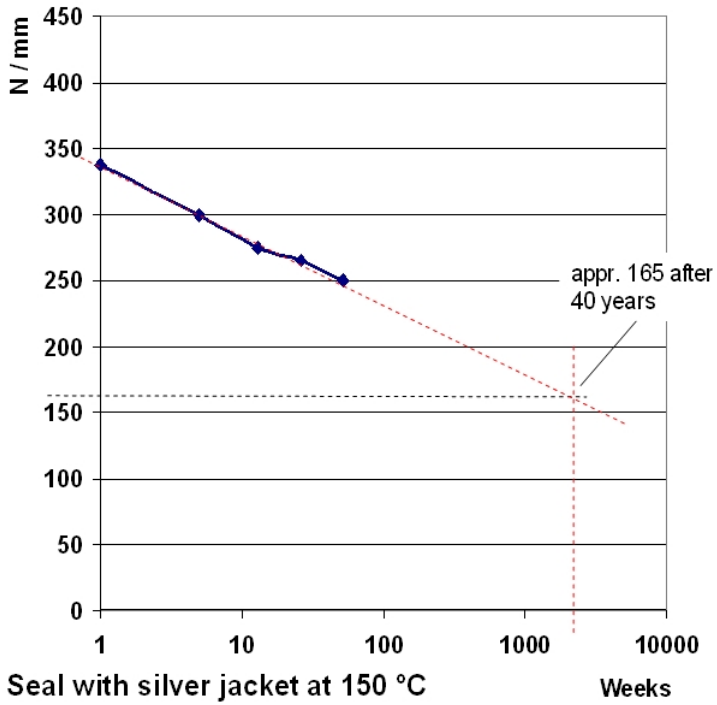


An essential parameter of a metal seal under relevant stress conditions is the useable resilience r_u as the difference in vertical seal dimension between the assembling configuration at operating point Y_2 and point Y_1, where the leakage rate by means of external load relieving exceeds the specified value of 10^{-8} Pa·m^3·s^{-1}


400
200
0
Load N / mm
0.00
0.50
1.00
1.50
Deformation mm
Initial load curve
Relieving after 1 week at 150°C
Relieving after 1 month at 150°C
Relieving after 3 month at 150°C
Relieving after 6 month at 150°C
Relieving after 12 month at 150°C
Y2
Y1
Reduction of Y2
Reduction of ru



Seal with aluminium jacket at 150°



Seal with silver jacket at 150 °C

- Predict the development of plastic seal deformation and Y_2 reduction over a period of 40 years BAM has extrapolated the test results using logarithmical scale.
- A linear correlation seems to be appropriate and with an extrapolation until 40 years, Y_2 will be reduced to 85 N/mm for seals with outer aluminium jacket and to 165 N/mm for seals with outer silver jacket, respectively 22 % and 33 % of the initial values.
- Assuming parallel displaced load relieving curves the r_u values will decrease from 0.18 mm to 0.05 mm for seals with outer aluminium jacket and down to 0.08 mm for seals with outer silver jacket.

- Ageing management in the wide range of casks for the dry storage of spent fuel and radioactive materials is more or less at the beginning.
- International programs and cooperation are on the way and some research activities are going on or planned.
- In comparison with the ageing management of NPPs where the components are grouped in relation to their safety importance, replaceability etc., also the components of storage casks should be grouped.
- First ideas are explained in the present paper but for some material or component properties the time dependent under storage conditions are not available in enough detail for the time being.
- Extension of interim storage periods for spent fuel casks beyond the designed lifetime requires an increasing knowledge of ageing mechanisms.
- Furthermore, Larson-Miller Parameter could play an important role for ageing management of specific materials and components like seals if the time and material depending parameter C becomes more reliable.
- To overcome the mentioned lacks in the near future is a challenge for the research laboratories around the world.