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# $2^{ND}$ GENERATION WASTE PACKAGE DESIGN & OPERATING MODE FOR THE YUCCA MOUNTAIN REPOSITORY

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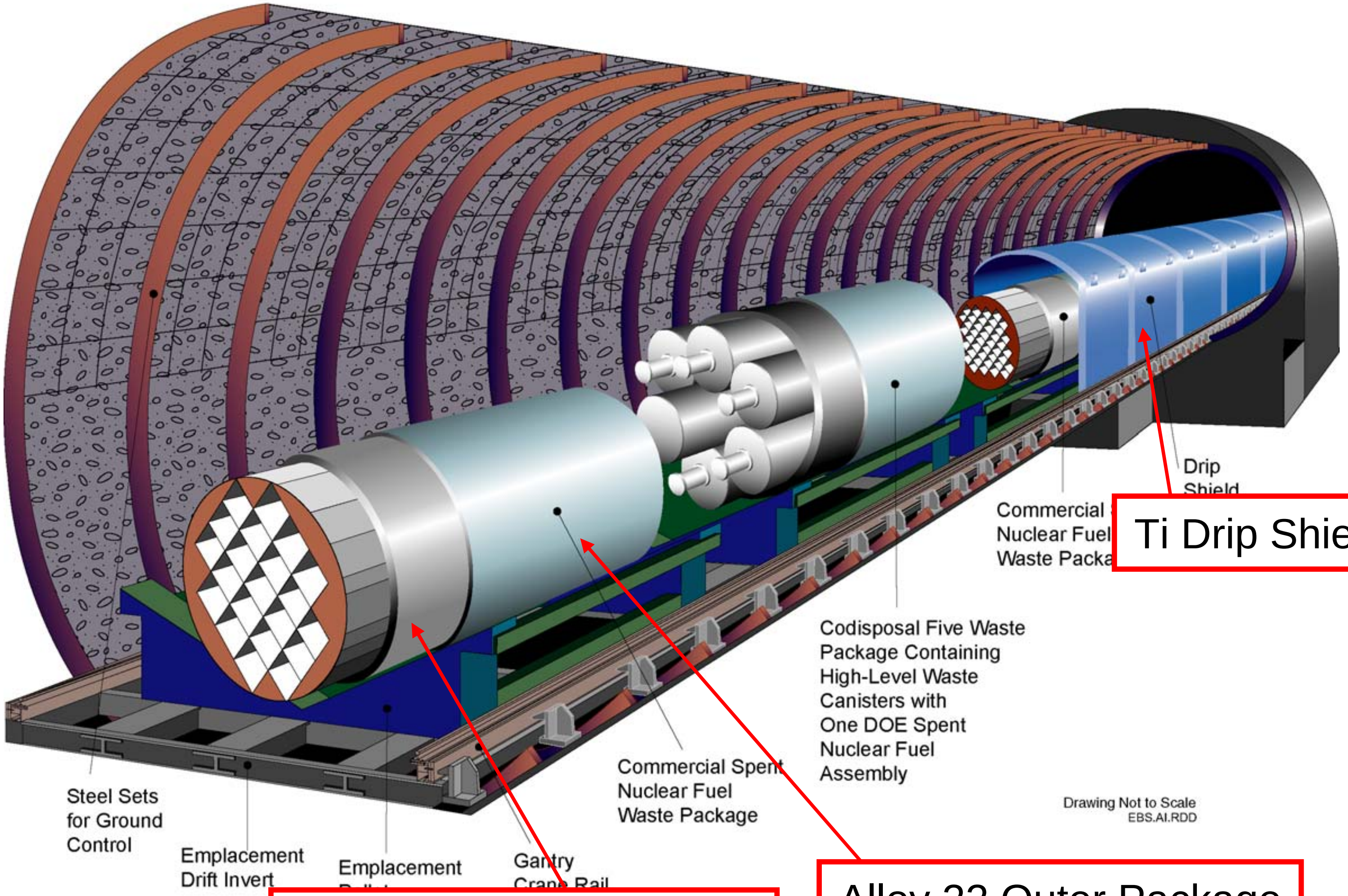


Ti Drip Shield

Alloy 22 Outer Package

316 NG Inner Package

Reference (1st Generation) Design

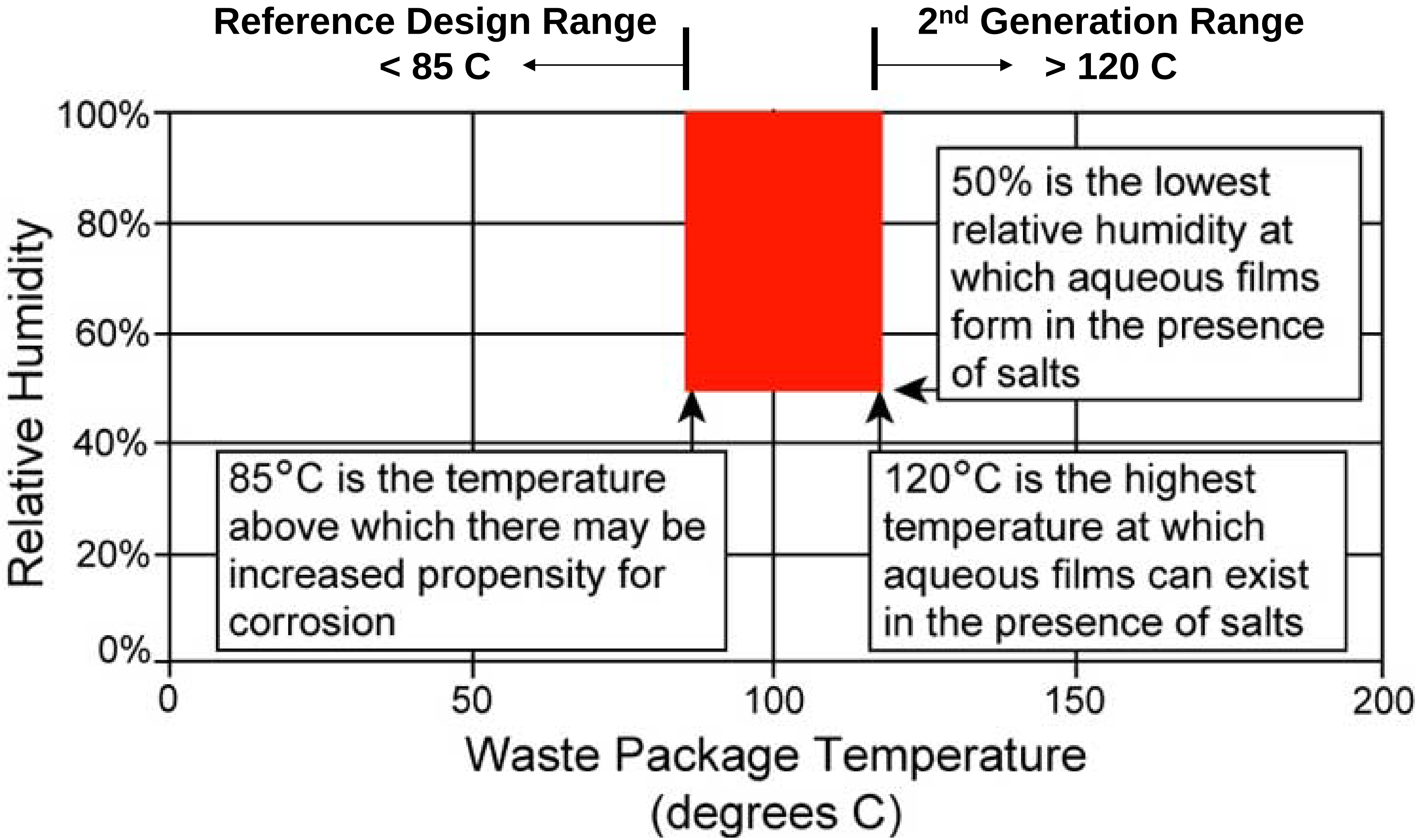
# 2ND GENERATION CONCEPT

**Amend the Yucca Mountain design and operating license to:**

- Permit operation at higher temperatures
- Permit use of larger, lower cost waste packages
- Eliminate Titanium drip shields

## Benefits

- Delays risk of aqueous corrosion by extending post-closure hot, dry period.
- Reduces the required number of waste packages.
- Eliminates excessive conservatism in current waste package and drip shield designs
- Extends life of Yucca Mountain and reduces costs by more than five billion dollars
- Compatible with GNEP initiative



50% is the lowest relative humidity at which aqueous films form in the presence of salts

85°C is the temperature above which there may be increased propensity for corrosion

120°C is the highest temperature at which aqueous films can exist in the presence of salts

Hypothetical range of vulnerability of Alloy 22 to localized corrosion by deliquescent salts.

# 2ND GENERATION WASTE PACKAGE DESIGN

- Waste Package size increased
  - Internal diameter of BWR waste package increased from 1.54 m to 1.65 m to contain 55 % more BWR assemblies
  - Internal diameter of PWR waste package increased from 1.51 m to 1.65 m to contain 38 % more PWR assemblies

- Alloy-22 waste package and Titanium drip-shields replaced by COR-TEN B (ASTM A588) carbon steel.
  - The10 cm thick A588 outer package exceeds the combined strength of Alloy 22 outer package and Ti drip shields
  - The A588 outer package in combination with mineral backfill protects the inner package from rock falls and provides a generous oxidation and corrosion allowance.

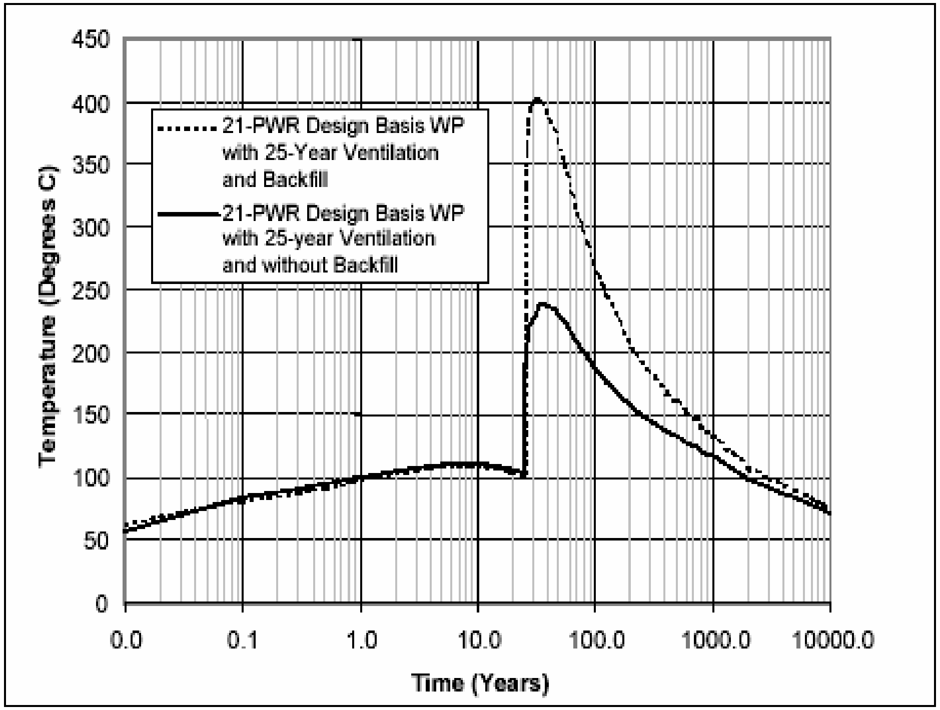
# Cor-Ten Steel Compositions

| Trade Name | ASTM | | Chemical Composition | | | |
|---|---|---|---|---|---|---|
| | | Cu | Cr | Ni | V | |
| | | | | max | | |
| USS Cor-Ten A | A242 | 0.25-0.55 | 0.50-1.25 | 0.65 | | |
| | | | | | | |
| USS Cor-Ten B | A588 | 0.25-0.40 | 0.40-0.65 | 0.4 | 0.02-0.1 | |
| | | | | | | |
| USS Cor-Ten C | A871 | 0.25-0.40 | 0.40-0.70 | 0.4 | | |
| | | | | | | |
| USS Cor-Ten B-Q | A852 | 0.25-0.40 | 0.40-0.65 | 0.4 | | |
| | | C | Mn | P | Si | S |
| | | max | | | | max |
| USS Cor-Ten A | A242 | 0.12 | 0.2-0.5 | 0.07-0.15 | 0.25-0.75 | 0.05 |
| | | | | | | |
| USS Cor-Ten B | A588 | 0.19 | 0.8-1.25 | .04 max | 0.3-0.65 | 0.05 |
| | | | | | | |
| USS Cor-Ten C | A871 | 0.19 | 0.8-1.35 | .04 max | 0.3-0.65 | 0.05 |
| | | | | | | |
| USS Cor-Ten B-Q | A852 | 0.19 | 0.8-1.25 | .04 max | 0.3-0.65 | 0.05 |

# Comparison of reference (DOE) and 2nd generation waste package designs

| WPs, design types | | Number of assemblies | Increase in holding capacity (%) | Materials | Yield strength (MPa) | Tensile strength (MPa) | Wall (cm) |
|---|---|---|---|---|---|---|---|
| BWR, Reference | Outer diameter - 1.67 m | 44 | - | 316 NG, inner | 205 | 515 | 5 |
| | | | | Alloy-22, outer | 207 | 460 | 2 |
| | Inner diameter – 1.53 m | | | Ti – Grade 7, drip | 480 | 550 | 1.5 |
| BWR, Second generation | Outer diameter - 1.95 m | 68 | 54.5 | 316 NG, inner | 205 | 515 | 5 |
| | Inner diameter – 1.65 m | | | A588 , outer | 345 | 435 | 10 |
| PWR, Reference | Outer diameter - 1.67 m | 21 | - | 316 NG, inner | 205 | 515 | 5 |
| | Inner diameter – 1.53 m | | | Alloy-22, outer | 207 | 460 | 2 |
| | | | | Ti – Grade 7, drip | 480 | 550 | 1.5 |
| PWR, Second generation | Outer diameter - 1.95 m | 29 | 38.1 | 316 NG, inner | 205 | 515 | 5 |
| | Inner diameter – 1.65 m | | | A588, outer | 345 | 435 | 10 |

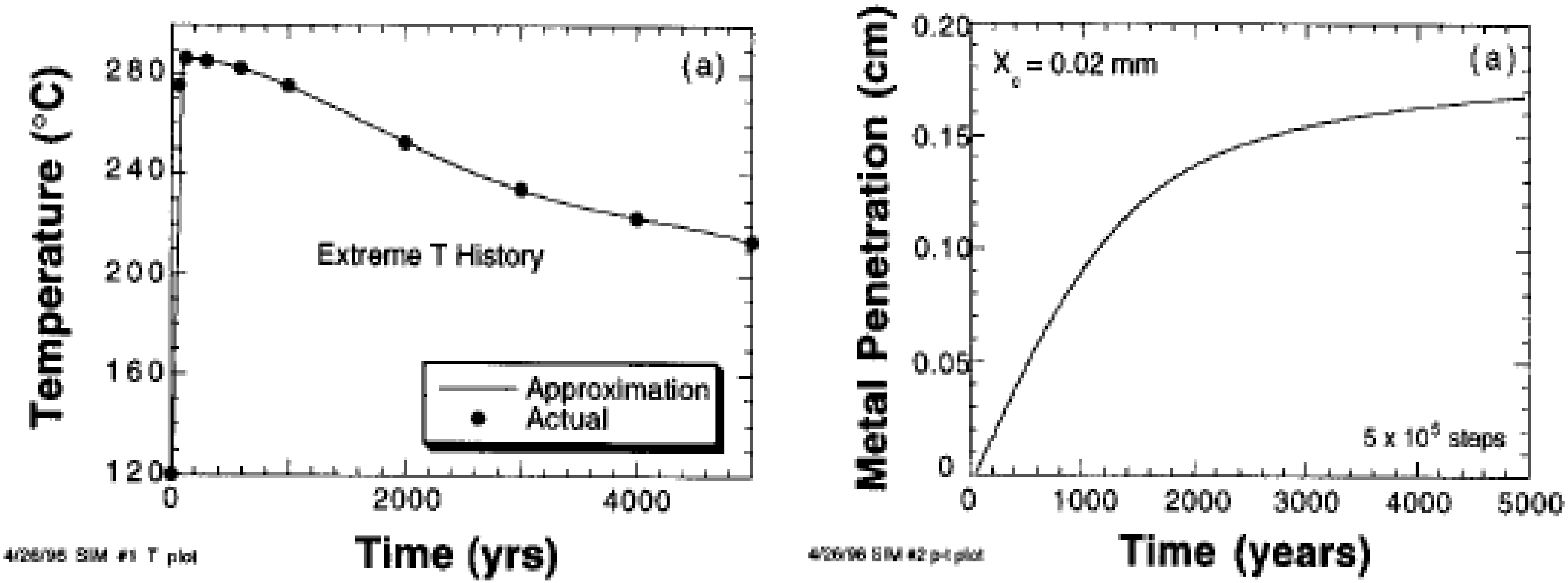
# Waste Package Surface Temperature Increase with Backfill



Source: CRWMS M&O 2000r

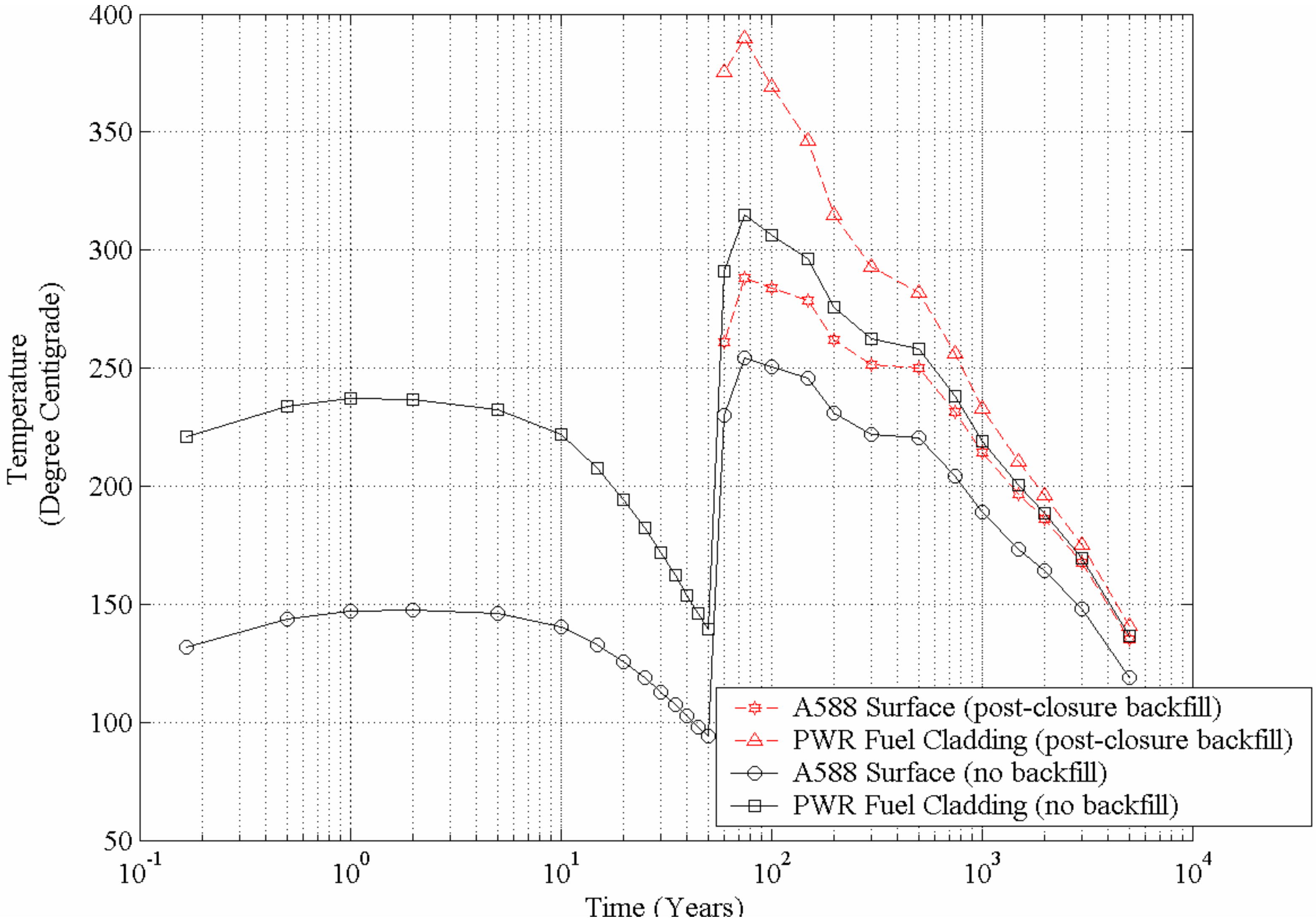
Figure 3-7a. Temperature of the WPOB Surface as a Function of Time for the Hottest Waste Package

- Greater than 120 °C for 2000 years.
- Localized corrosion not possible
  - Stress Corrosion Cracking
  - Crevice Corrosion
  - Pitting Corrosion
  - Microbial Corrosion
- Consequences of later breach minimized by radioactive decay.
- But… fuel cladding temperature exceeds 400 °C



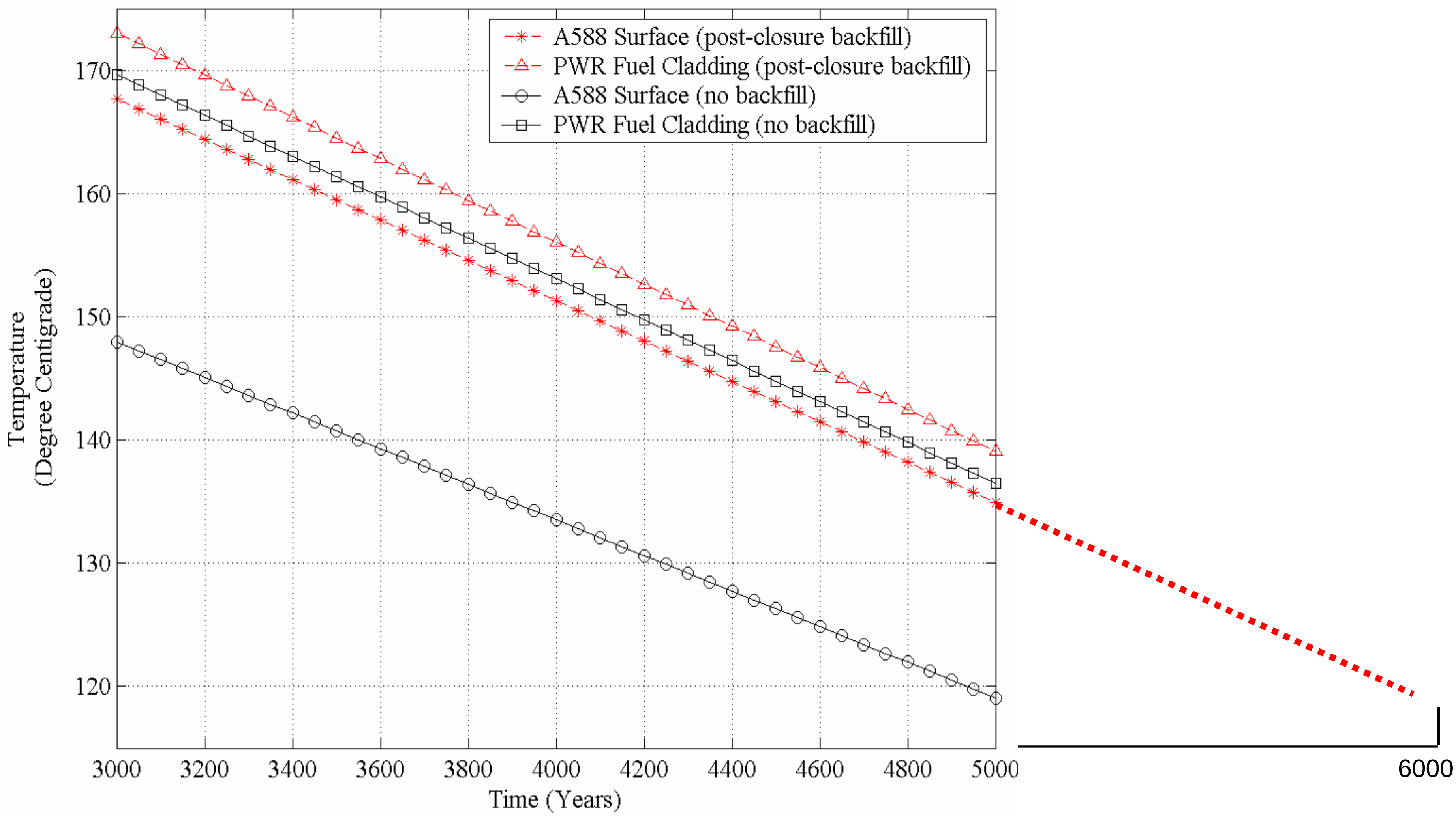
Predicted (worst case) time-dependant penetration of iron or low-carbon steel surface subjected to a thermal history similar to 2nd generation concept. Cracking of protective iron oxide assumed at 20 microns.

From G.A Henshall, Materials Research Society Symposium Proceeding, vol. 465, 1997



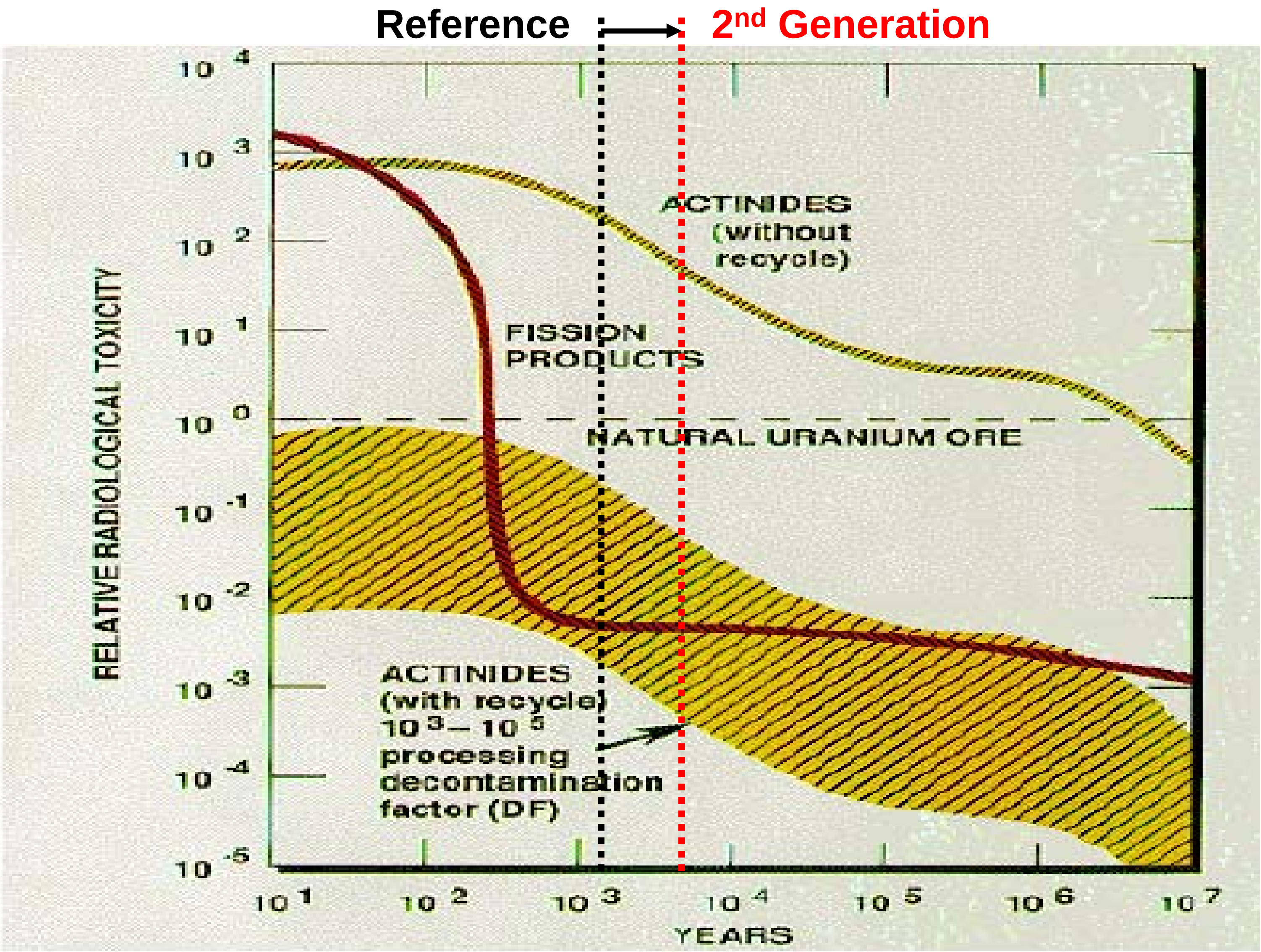
Thermal analysis of the 29 PWR 2nd Generation waste package design.

- Larger heat source from more assemblies combined with backfill extends post-closure dry (> 120 C) period to 6000 years
- Peak fuel cladding temperatures maintained below 400 C

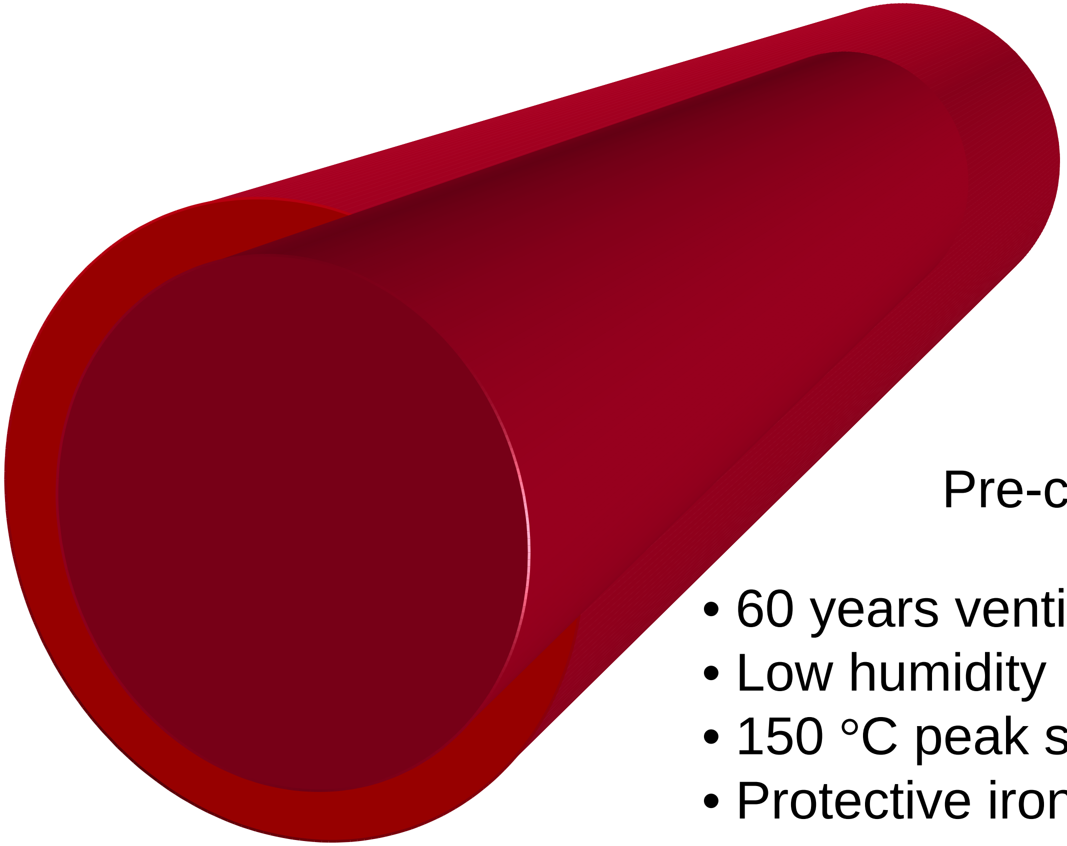


Thermal analysis of the 29 PWR 2nd Generation waste package design.

- Surface temperature >120 C extended to 4900 years without backfill
- Surface temperature >120 C extended to 5900 years with backfill

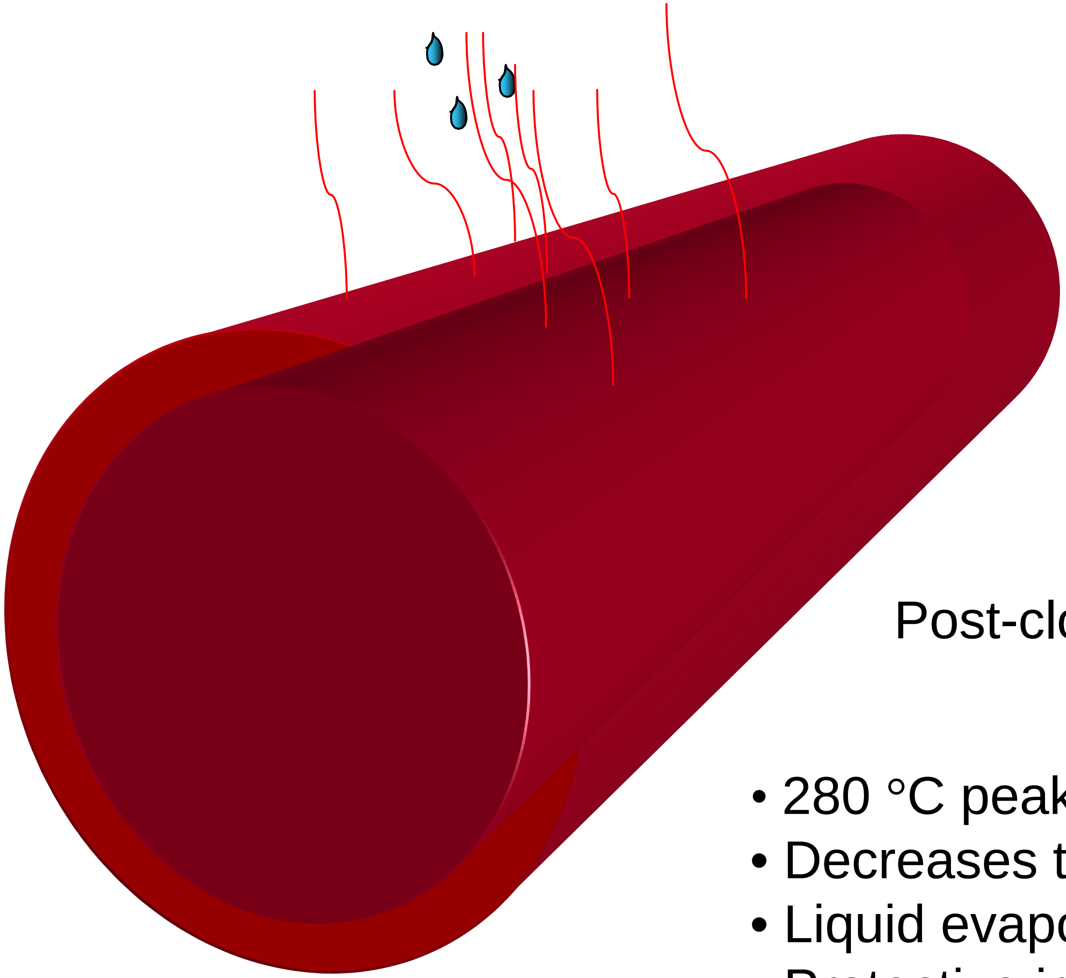


Time phased relative waste toxicity in spent LWR fuel.
2nd Generation concept extends time for decrease in actinide toxicity prior to risk of aqueous corrosion.



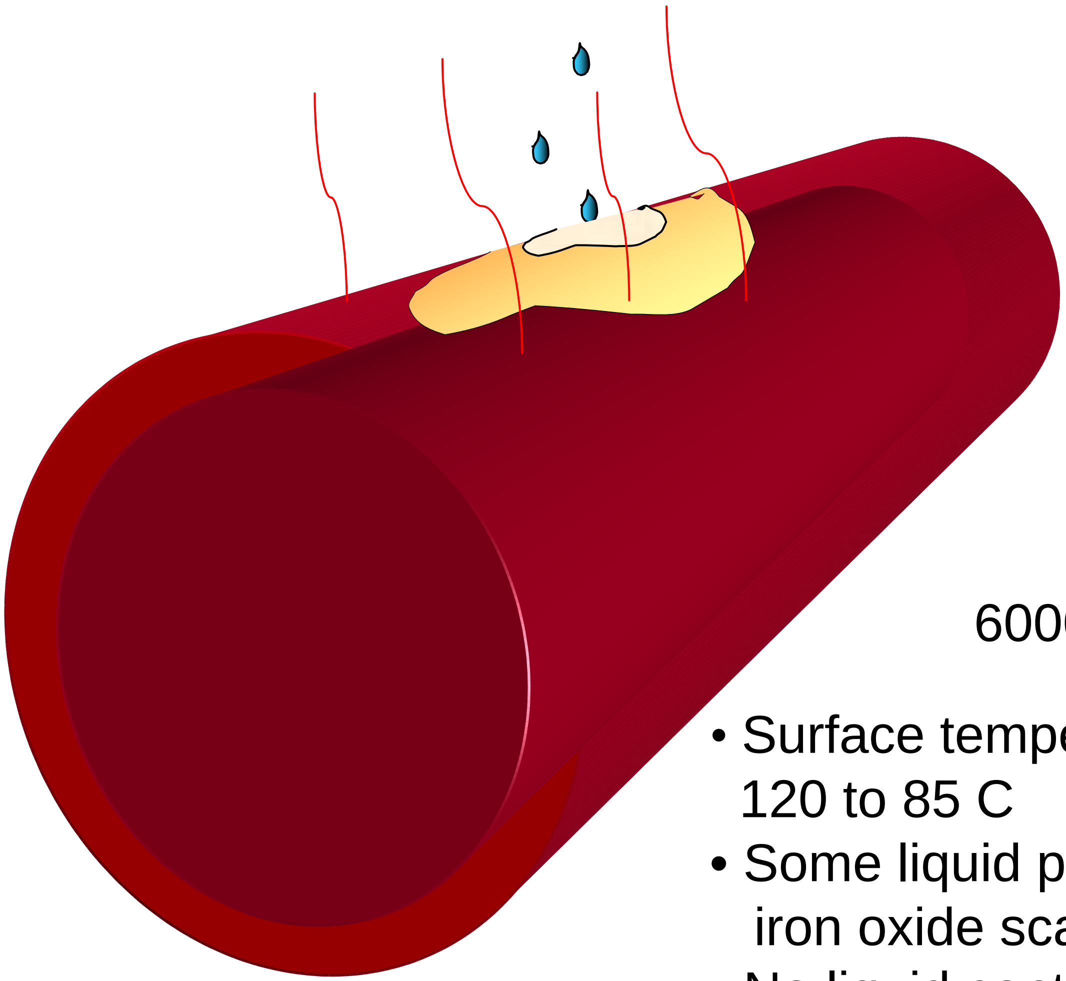
Pre-closure

- 60 years ventilation
- Low humidity
- 150 °C peak surface temperature
- Protective iron oxide layer forms



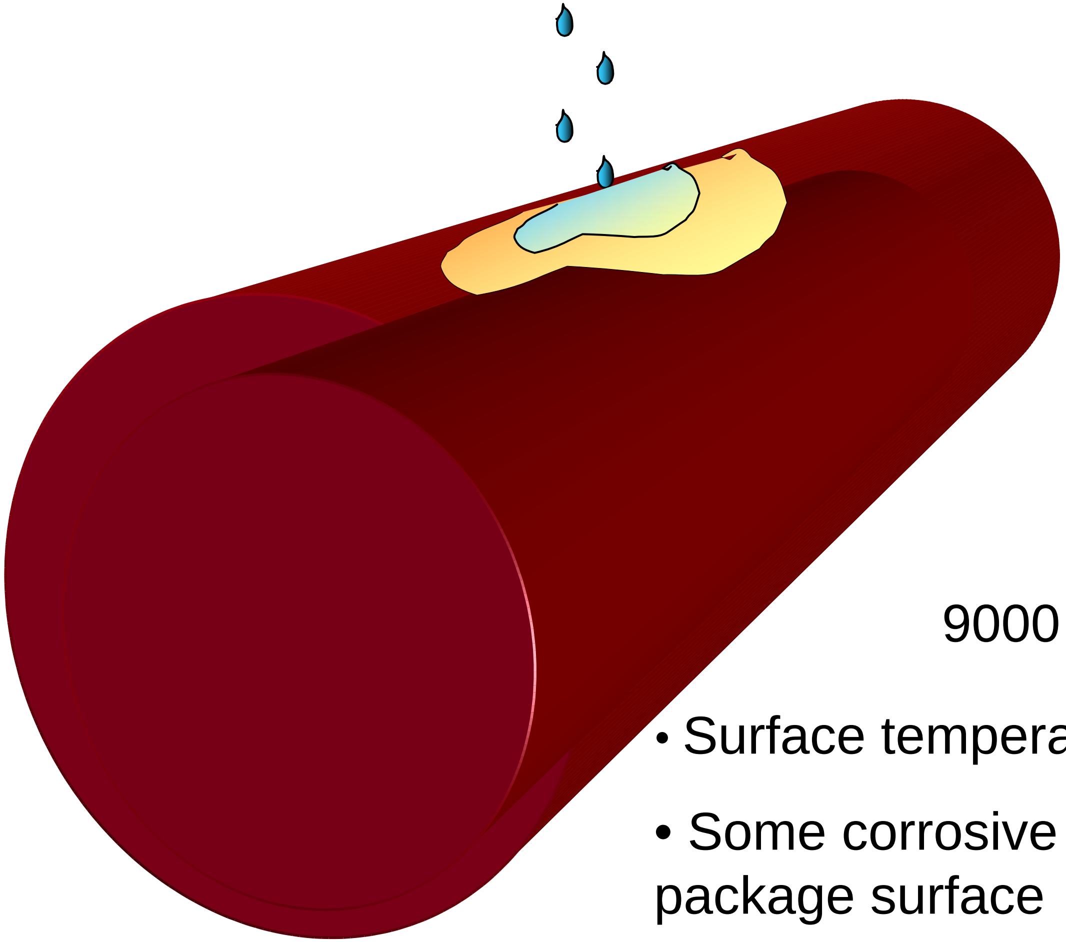
Post-closure (60 to 6000 years)

- 280 °C peak surface temperature
- Decreases to 120 C
- Liquid evaporates in air or backfill
- Protective iron oxide layer grows
- A588 metal loss 0.01 to 0.2 cm



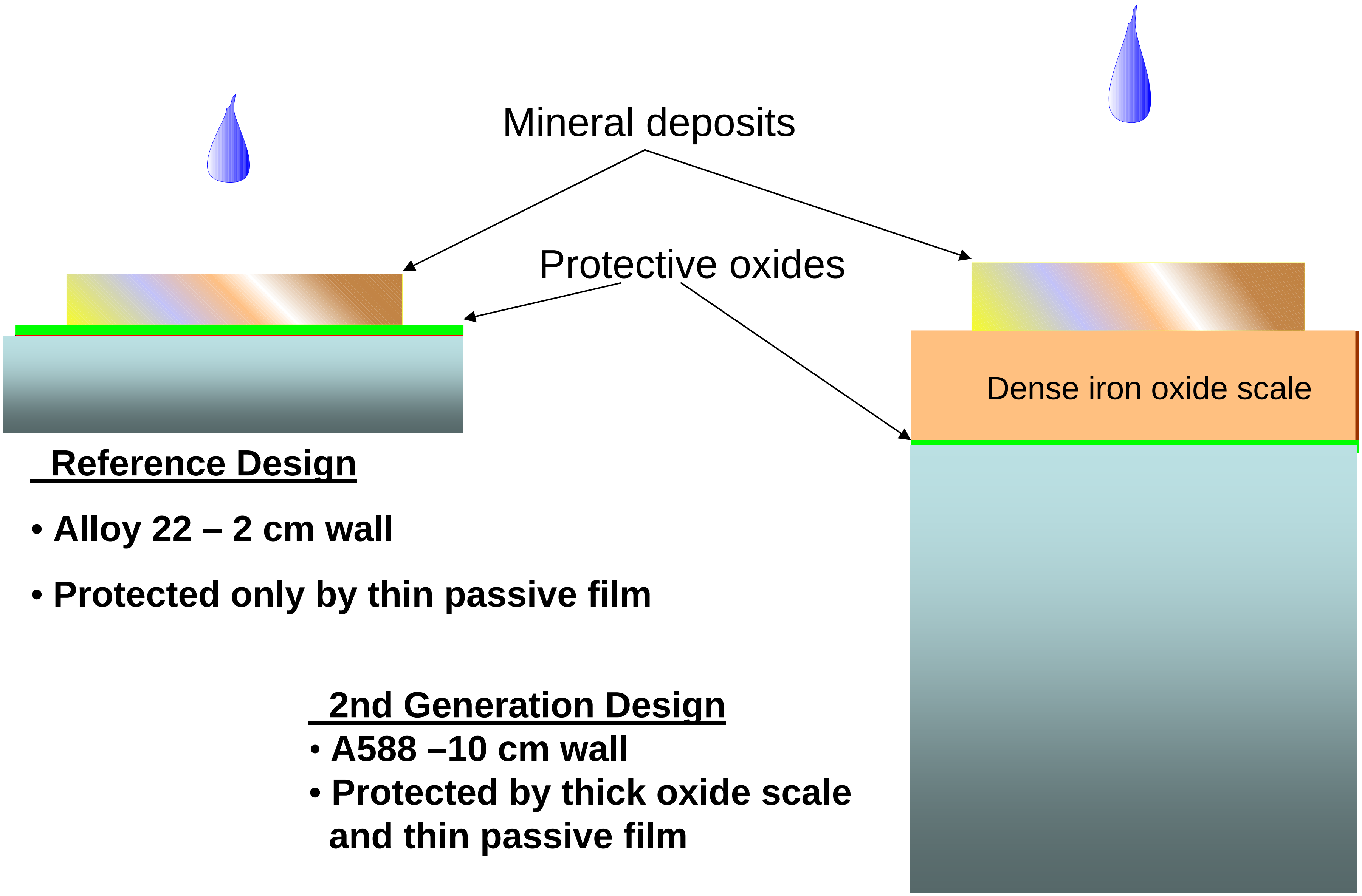
6000 to 9000  years

- Surface temperature decreases from 120 to 85 C
- Some liquid phase may reach surface iron oxide scale and form mineral deposit
- No liquid contact with metal
- A588 metal loss 0.1 to 2 mm



9000 years and beyond

- Surface temperature decreases < 85 C
- Some corrosive liquid may form on waste package surface
- Liquid separated from metal by mineral deposit and thick iron oxide scale
- Temperature too low for significant corrosion



**Reference Design**

- **Alloy 22 – 2 cm wall**
- **Protected only by thin passive film**

**2nd Generation Design**

- **A588 –10 cm wall**
- **Protected by thick oxide scale and thin passive film**

***Iron spikes and nails from Inchtuthil.***

- The most convincing evidence that even unalloyed iron has remarkable long term corrosion resistance during exposure at varying temperatures in wet and dry soil has been found at the archeological site of Inchtuthil in Scotland.
- Over 875,000 iron spikes and nails of varying dimensions were buried by Roman soldiers in 87 A.D. and remained undiscovered for more than 1900 years.
- These unprotected, unalloyed nails suffered negligible metals loss, retained their shape and sharp points and were fully functional.

# CONCLUSIONS

Yucca Mountain cost savings in excess of $5 billion are possible by:

- increasing capacity of individual spent fuel packages
- maintaining a hot dry environment by loading more spent fuel and backfilling after closure
- replacing Alloy 22 with an A588 steel outer container
- eliminating titanium alloy drip shields by using a 10 cm outer container and mineral backfill.

Thermal analyses demonstrate that :

- higher waste package surface temperatures can be maintained without exceeding 400 °C peak fuel cladding temperature
- dry storage period can be extended by ~ several thousand years thus eliminating aqueous corrosion risk during period of greatest radiological toxicity

Acceptable corrosion resistance of A588 steel to Yucca Mountain environment supported by:

- literature reviews and analyses by Henshall and others
- 1900 year unprotected exposure of wrought iron artifacts

# Backup Slides

# Design for Dry or Wet Environment ?

## International Peer Review of YMP TSPA-SR

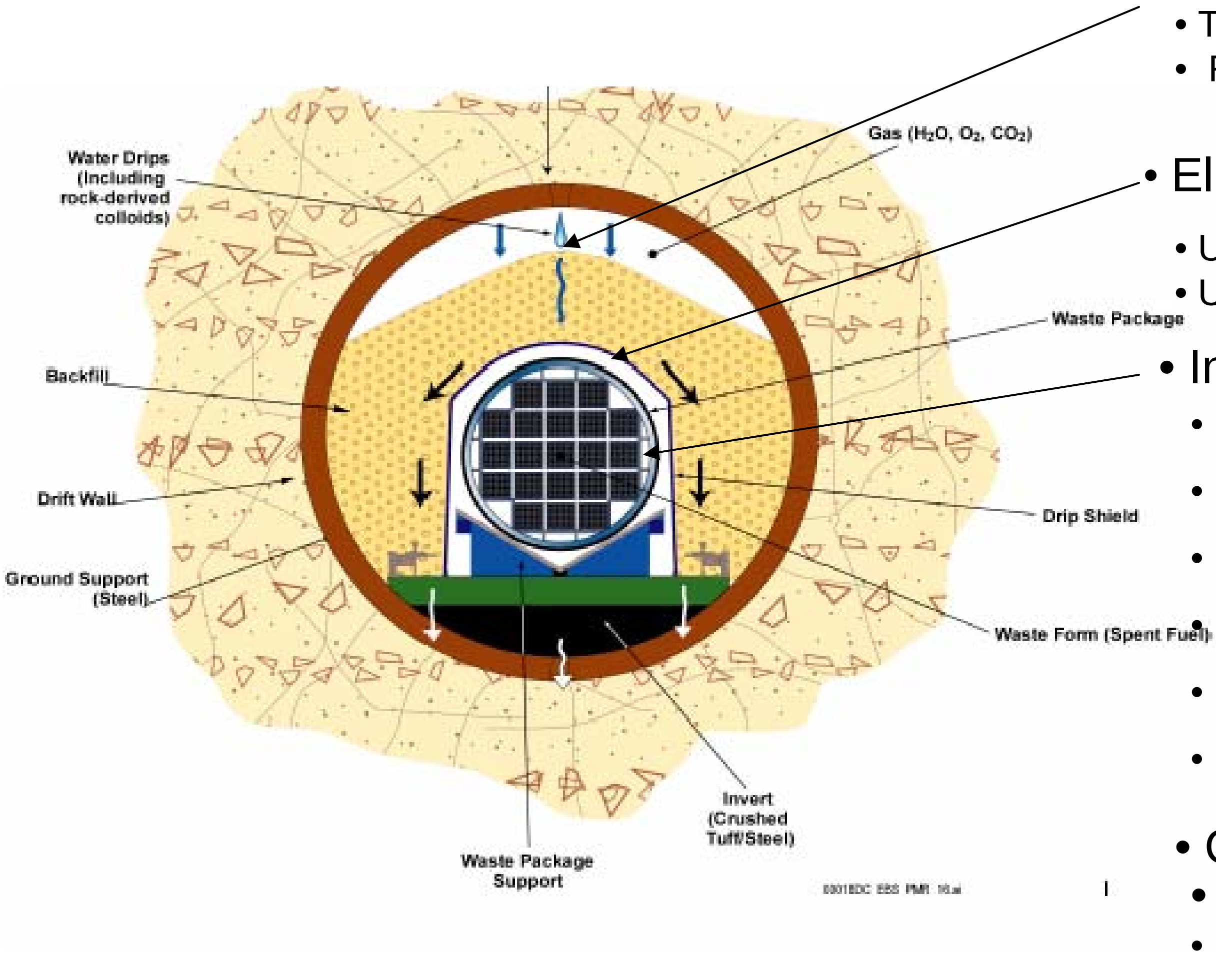
- " Moreover, natural dripping of groundwater from fractures or pores in the matrix has never been observed."

- "The evaporation potential of water due to the decay heat of the waste is in fact substantial, exceeding 1000 liters per year per container before 10,000 years and will still be of the order of 100 liters per year per container at 100,000 years.

## Recommendation by Secretary of Energy

- " The amount of water that eventually reaches the repository level at any point in time is very small, so small that capillary forces tend to retain it in small pores and fractures in the rock."

- " It is noteworthy that all our observation so far indicate that no water actually drips into the tunnels at this level and all of the water is retained in the rock."

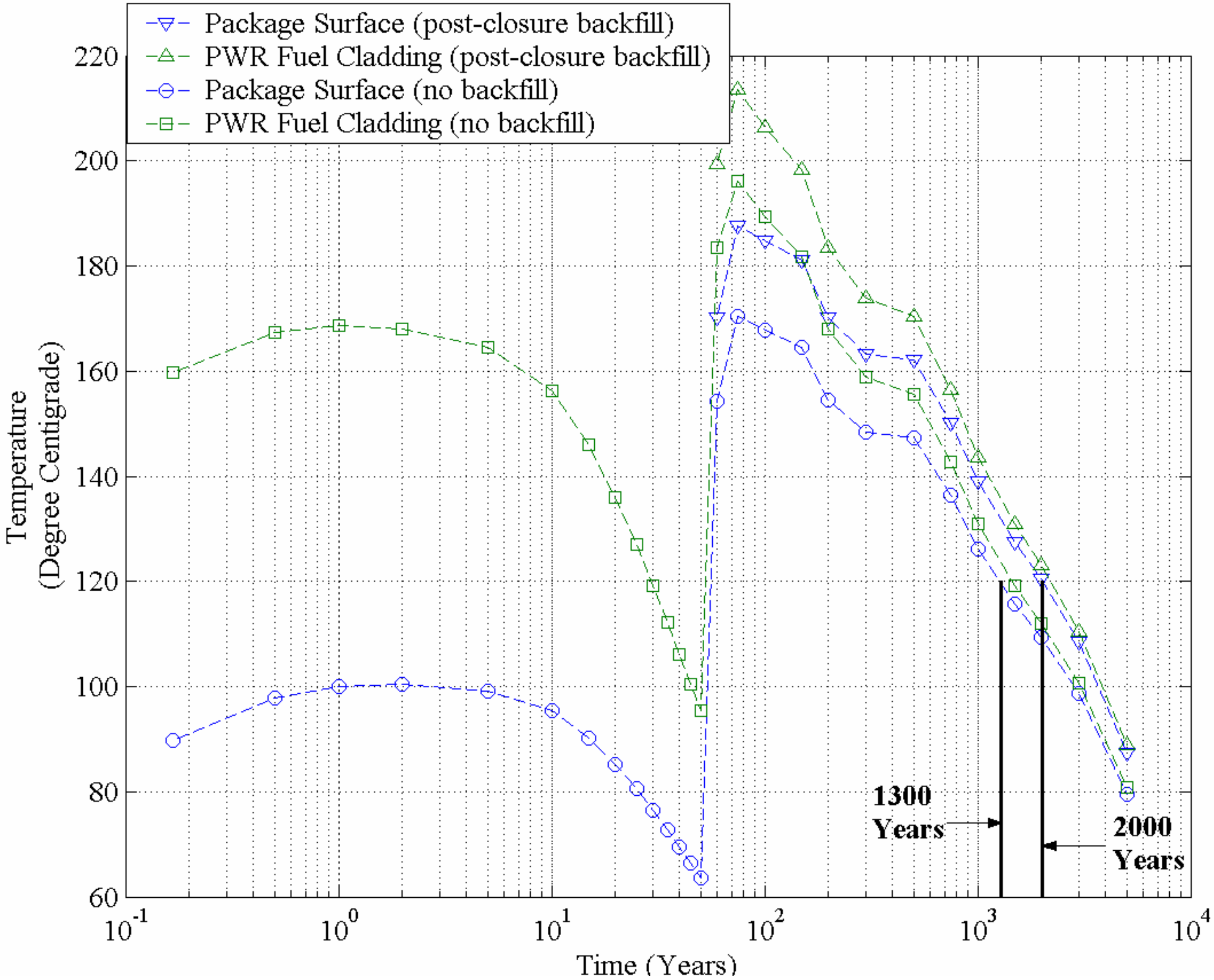


Proposed 2nd Generation Approach

- Challenge Assumptions
  - Technical basis
  - Realism
- Eliminate Drip Shield
  - Use robust outer package
  - Use mineral backfill
- Increase WP diameter
  - More spent fuel assemblies
  - Fewer waste packages
  - Higher surface temperatures
  - Higher radiation levels
  - Extended dry environment
  - Delay aqueous corrosion risk
- Change WP Material
  - Eliminate localized corrosion
  - Lower material cost
  - Lower fabrication cost

# Alloy 22 Waste Package Mockup: Solution Anneal and Water Quench

- Full-scale diameter, Quarter-scale Length
- Solution Anneal Temperature:  1150 °C
- ANSYS model predictions consistent with measurement
    - Quenching from outer surface results in surface compression

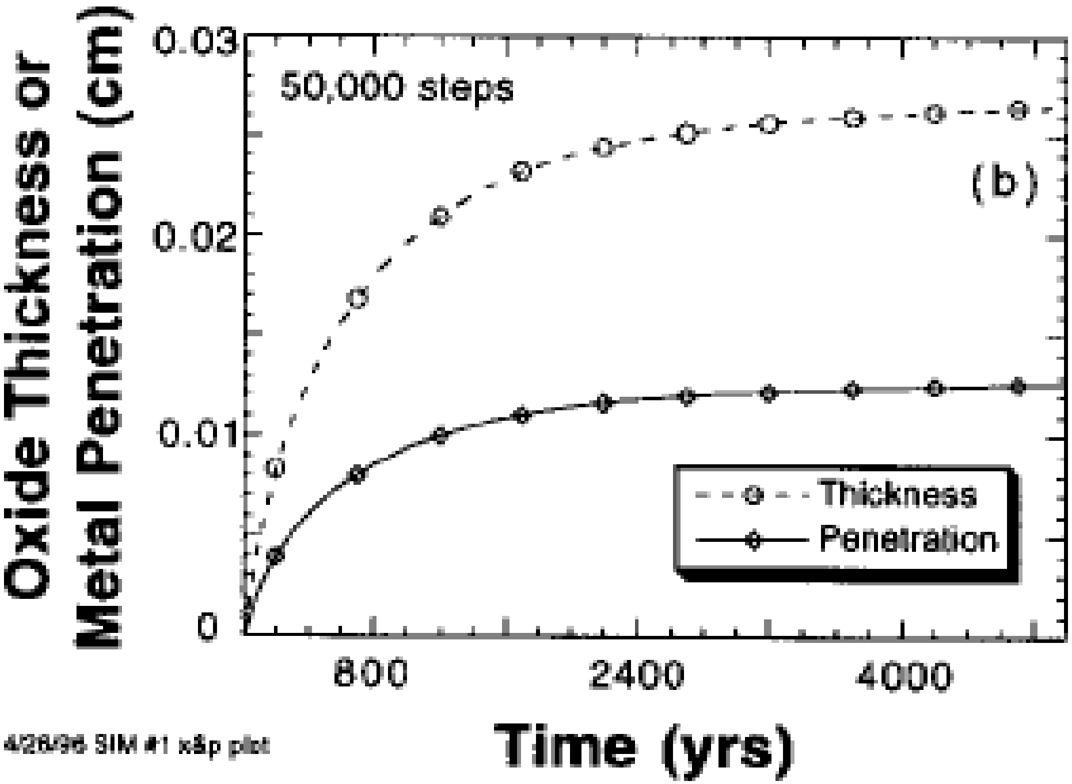


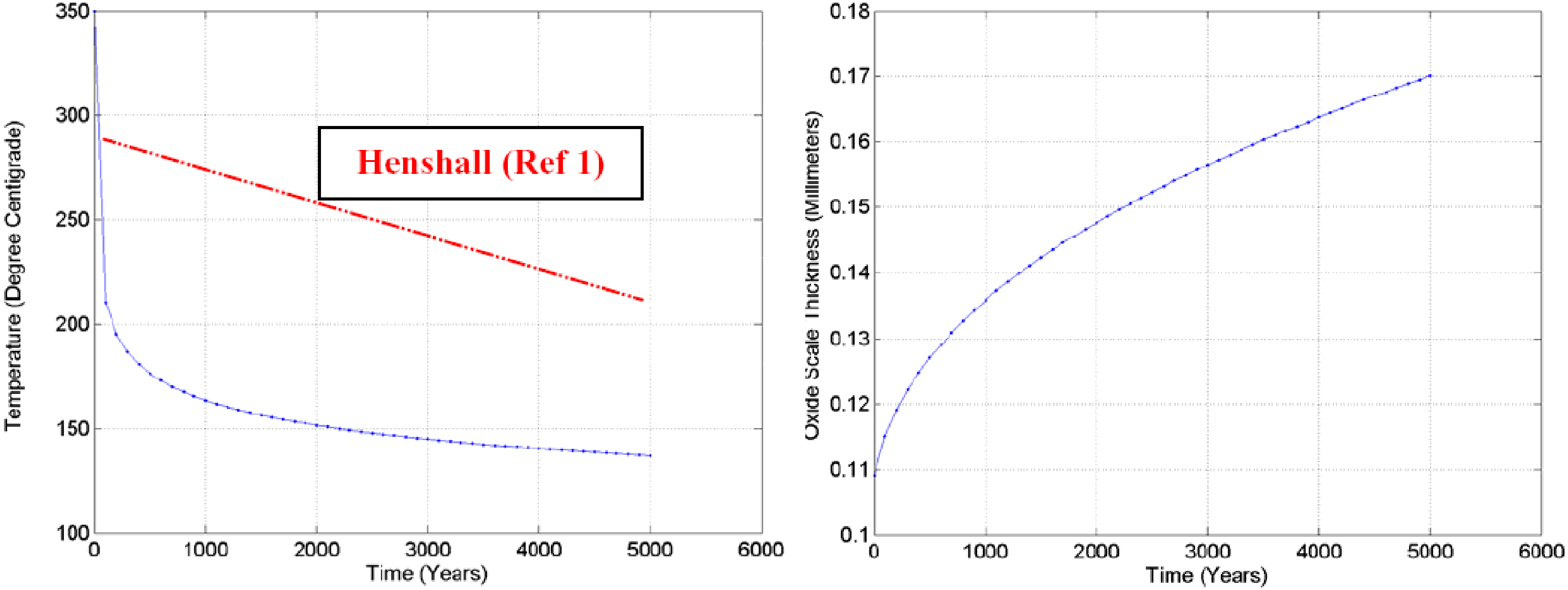
Thermal analysis of the 21 PWR reference (current DOE) waste package design.

- **Without backfill,** waste package surface temperature drops below 120 C at year 1300.
- **With backfill,** waste package surface temperature drops below 120 C at year 2000.

2nd Gen Waste Package Design Study
Technical Approach

- Calculate maximum oxide thickness and metal losses for A588 and Alloy 22 for identical 10,000 year time-temperature transient.

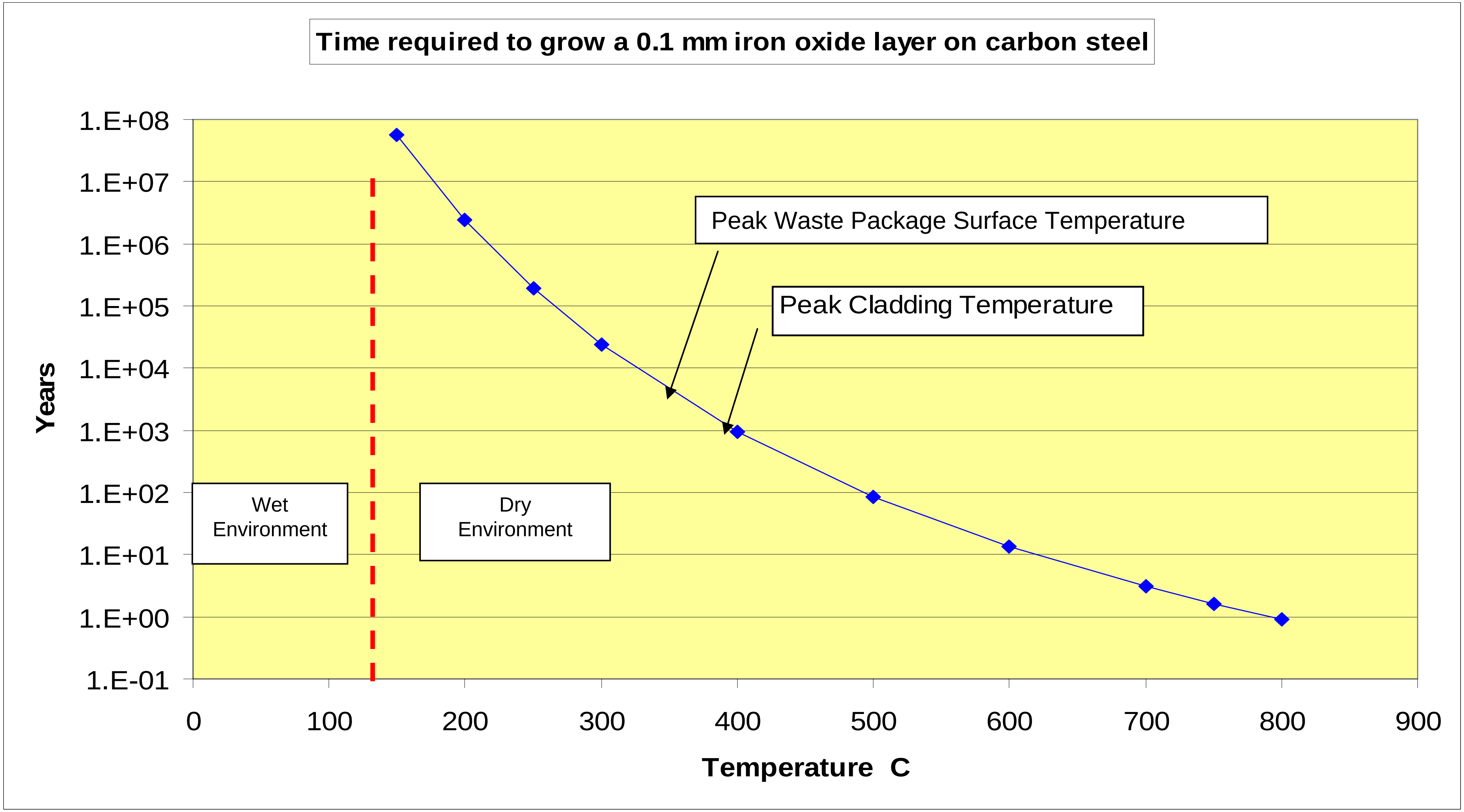




(a)

(b)

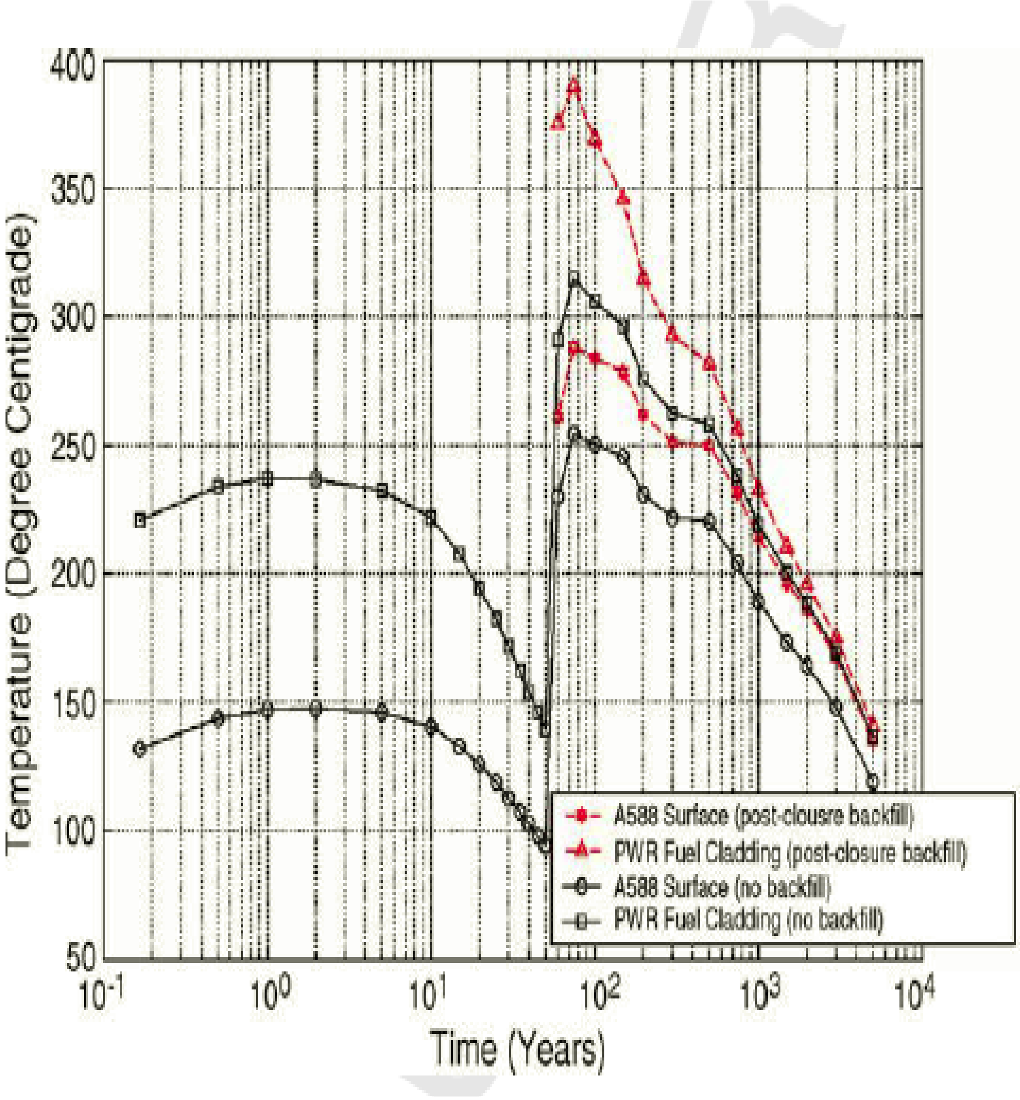
**Figure 5. (a) Temperature profile of the surface of the Second Generation waste packages during the first 5000 years of emplacement, and (b) the corresponding oxide scale thickness.**



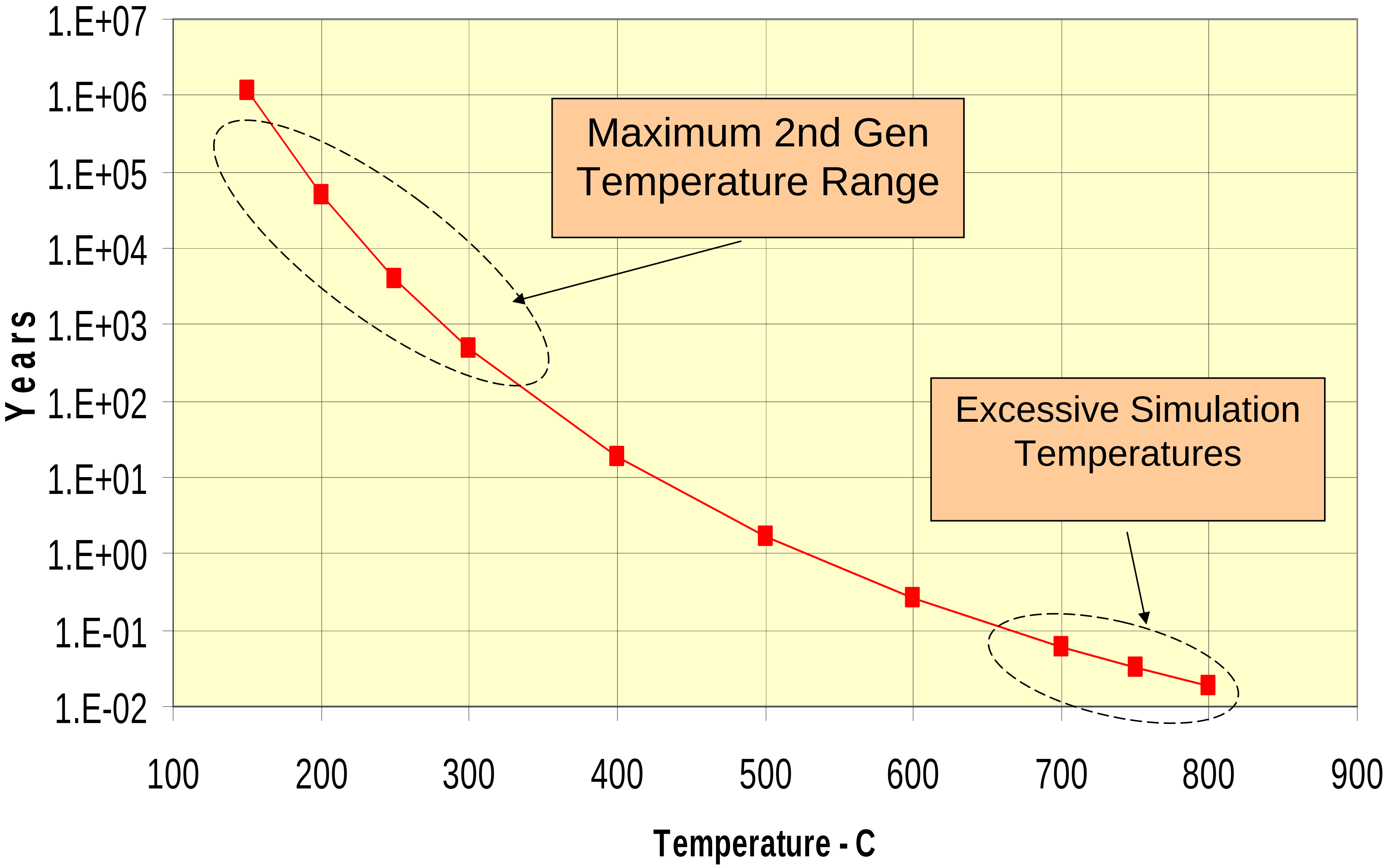
Time required to grow a 0.1 mm iron oxide layer on carbon steel

# 2nd Gen Waste Package Design Study Technical Approach

- Calculate post-closure time-temperature transients
  - Standard YMP waste package
  - Second generation waste package
- Document dry period extension

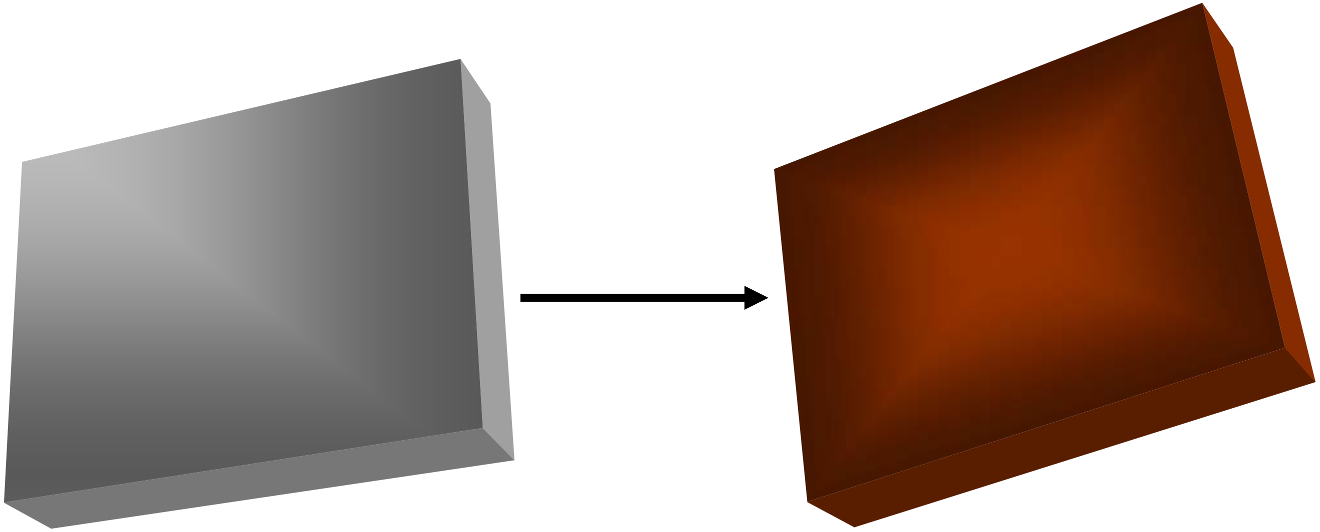


# Time Required to Form 0.1 mm Oxide on Carbon Steel



# 2nd Gen Waste Package Design Study
# Technical Approach

- Oxidize A588 samples at high temperatures to produce layer expected from 10,000 year 2nd generation transient.A588 and Alloy 22
- Assess electrochemical and microstructural properties
- Test materials under intermittent dripping conditions



# 2nd Gen Waste Package Design Study
Technical Approach

- Test pre-oxidized specimens under intermittent dripping at 100 C
- Test pre-oxidized specimens under hygroscopic salt at 120 C
- Assess damage to oxide and metal
  - Changes in microstructure and electrochemical properties
  - Metal loss

# Composition of Dilute Yucca Mountain Relevant Waters

| Constituent | J-13 Well Water (mg/l) | 'Perched' Water (mg/l) | Pore Waters** (mg/l) |
|---|---|---|---|
| $Na^+$ | 45.80 | 36.0 | 20-65 |
| Si(aq) | 28.5 | 37.0 | 26-39 |
| $Ca^{++}$ | 13.0 | 25.0 | 43-125 |
| $K^+$ | 5.04 | 1.7 | 2-4 |
| $Mg^{++}$ | 2.01 | 2.2 | 9-24 |
| $F^-$ | 2.18 | 0.7 | ~1 |
| $Cl^-$ | 7.14 | 6.3 | 34-170 |
| $NO_3^-$ | 8.78 | 4.0-17 | 2-81 |
| $SO_4^=$ | 18.4 | 15.0 | 48-260 |
| $HCO_3^-$ | 128.9 | 147.0 | 74-220 |
| pH | 7.41 | 8.1 | 6.2-7.5 |
| Molar ratio | 0.56 | 0.76 | 2.3 |

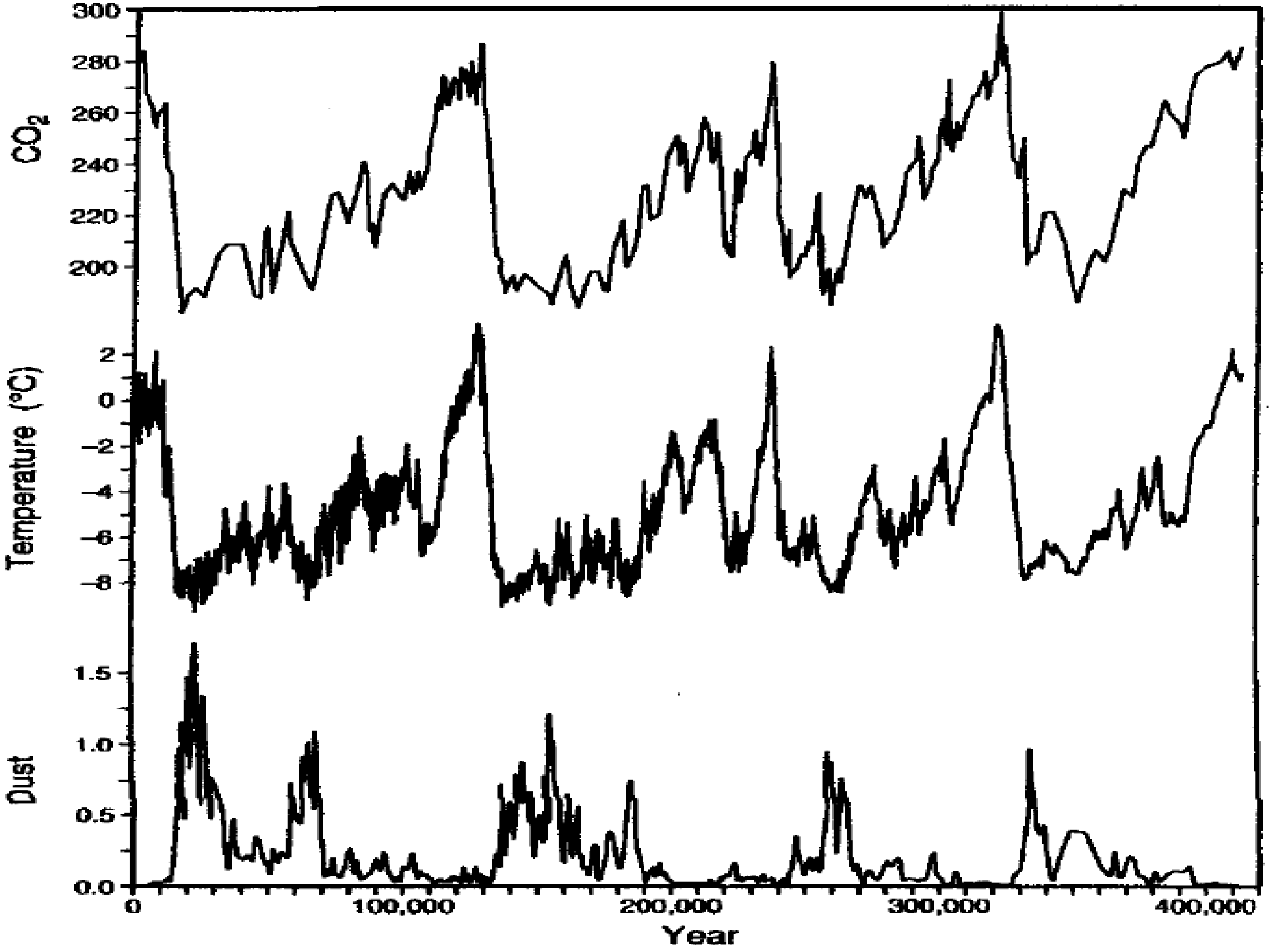


Figure 21. Data from the Antarctic ice cores at Vostok Station show that temperature changes (relative to the present) calculated from isotopic data and atmospheric CO$_2$ content (in parts per million) from bubbles in the ice track each other very closely. Cold glacial periods had low CO$_2$, whereas the warm interglacials had much higher values. The amount of dust in the ice, on the other hand, is highest during the cold periods, signifying generally windier conditions. These graphs are based on data from a paper by J. R. Petit et al. in the journal *Nature,* June 3, 1999.