ABANDONMENT TEST AT CARRESSE

Technical Class

SMRI Fall Meeting – Leipzig, Germany

October 3, 2010

MAIN OUTLINE

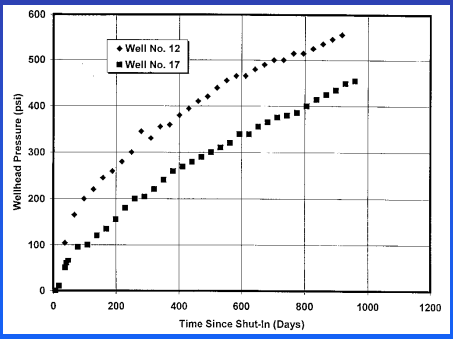
- Main issues in salt-cavern abandonment
- Carresse SPR2 cavern
- In-situ measurements
- Numerical computations
  - Computations performed by Ecole Polytechnique-BC
  - Computations performed by IUB
- Main Conclusions

2

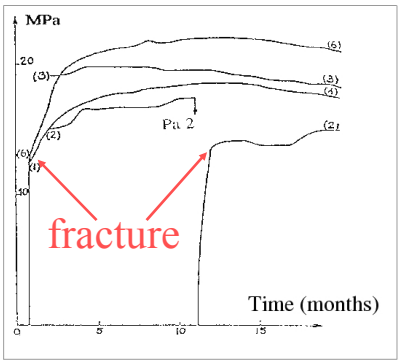
MAIN ISSUES IN SALT-CAVERN ABANDONMENT

3

PRESSURE BUILD-UP IN A CLOSED CAVERN



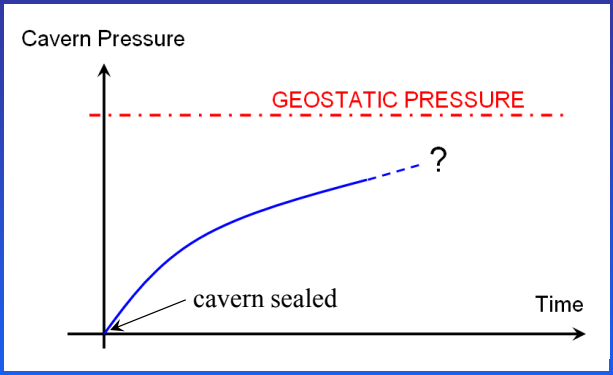
(After Van Sambeek, 1990)



Vauvert (Bérest et al., 1979)

4

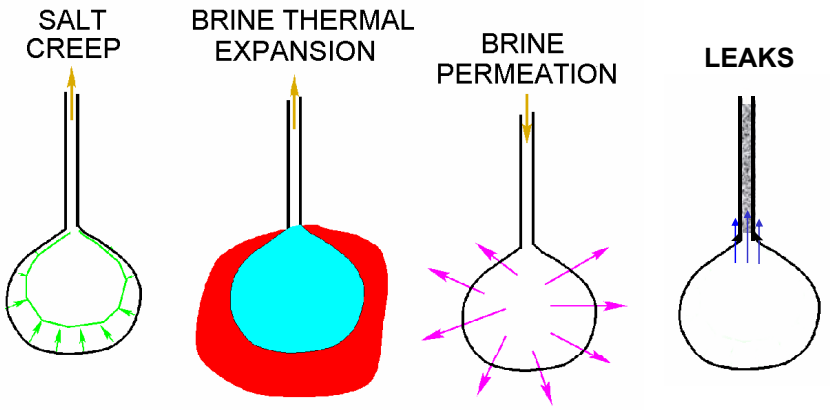
MAIN CONCERN



1. Why cavern pressure increases?
2. How can we predict cavern long-term behavior?

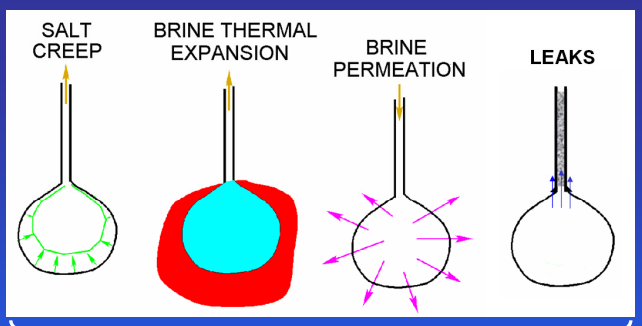
5

4 MAIN PHENOMENA



- Rock salt behaves as a fluid
- Brine warming is a very slow process
- Salt permeability is exceedingly small
- Leaks can be non negligible

6

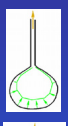


Cavern compressibility

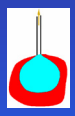
Cavern pressure increase/decrease

7

FACTORS CONTRIBUTING TO PRESSURE BUILD-UP

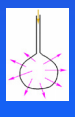


• SALT CREEP → CAVERN CLOSURE



• BRINE WARMING → THERMAL EXPANSION

FACTORS CONTRIBUTING TO PRESSURE RELEASE

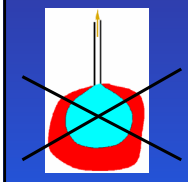


• ROCK SALT PERMEABILITY → BRINE MICRO-PERMEATION

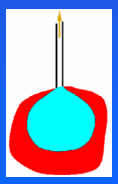
• LEAKS (through casing, casing shoe, at well-head)

8

ONE CAN DISTINGUISH 2 MAIN CASES



1. Brine thermal expansion can be disregarded
   - Cavern is not tall → final pressure smaller than geostatic
   - Cavern is tall → overpressure possible at the roof



2. Brine thermal expansion cannot be disregarded
   - Cavern is deep → it is necessary to wait for several years
   - Cavern is shallow → even a very small permeability can prevent too large a pressure build-up

9

KEY POINT FOR A LONG-TERM ABANDONMENT TEST

Accurate pressures and temperature measurements are not enough

The in situ test must be able to prove that there were

NO LEAKS

during the test, or tiny leaks that can be precisely measured or back-calculated.

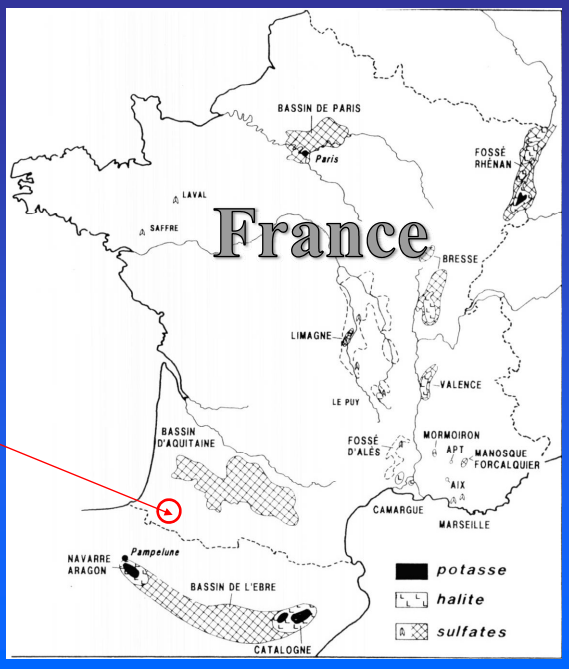
10

CARRESSE SPR2

- A small and shallow cavern -
Not at thermal equilibrium

11

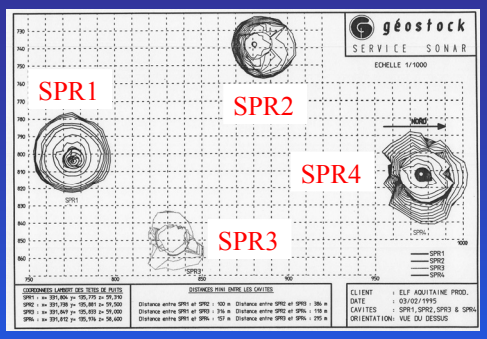
Carresse



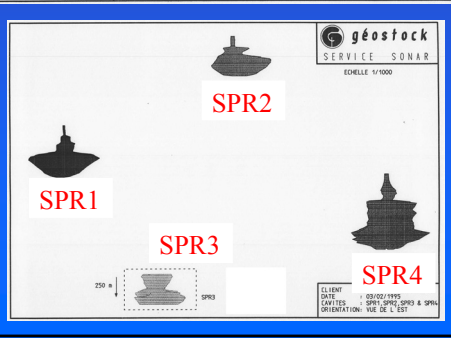
12

4 shallow caverns at Carresse

Overview



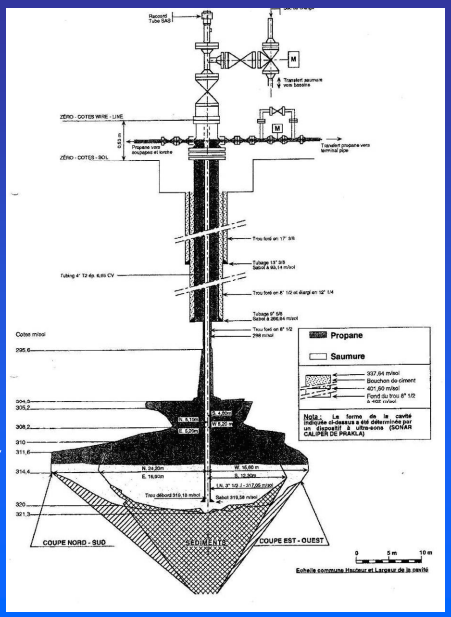
Vertical Cross-section



13

SPR2 CAVERN

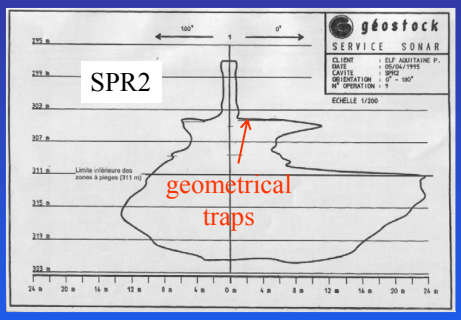
313 m (1000 ft)



9000 m^3
(56,600 bbls)

14

- SPR1, SPR2 & SPR4 were formerly used to store LPG



- Trapped propane was recover from SPR2 in 2003

[de Laguerie et al., SMRI Fall Meeting, Berlin, 2004]

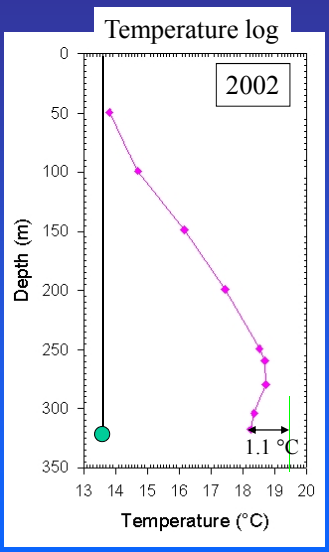
⇨ 22 metric tons of propane recovered

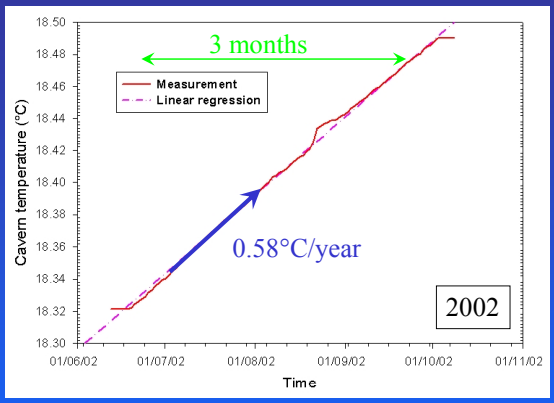
15

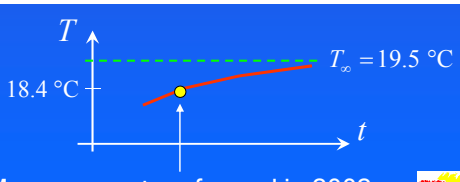
BROUARD CONSULTING

SPR2 CAVERN IS NOT AT THERMAL EQUILIBRIUM

IUB







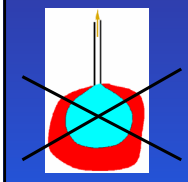
Measurement performed in 2002

TOTAL

LMS géostock

16

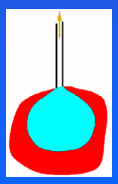
ONE CAN DISTINGUISH 2 MAIN CASES



1. Brine thermal expansion can be disregarded

   - Cavern is not tall → final pressure smaller than geostatic

   - Cavern is tall → overpressure possible at the roof



2. Brine thermal expansion cannot be disregarded

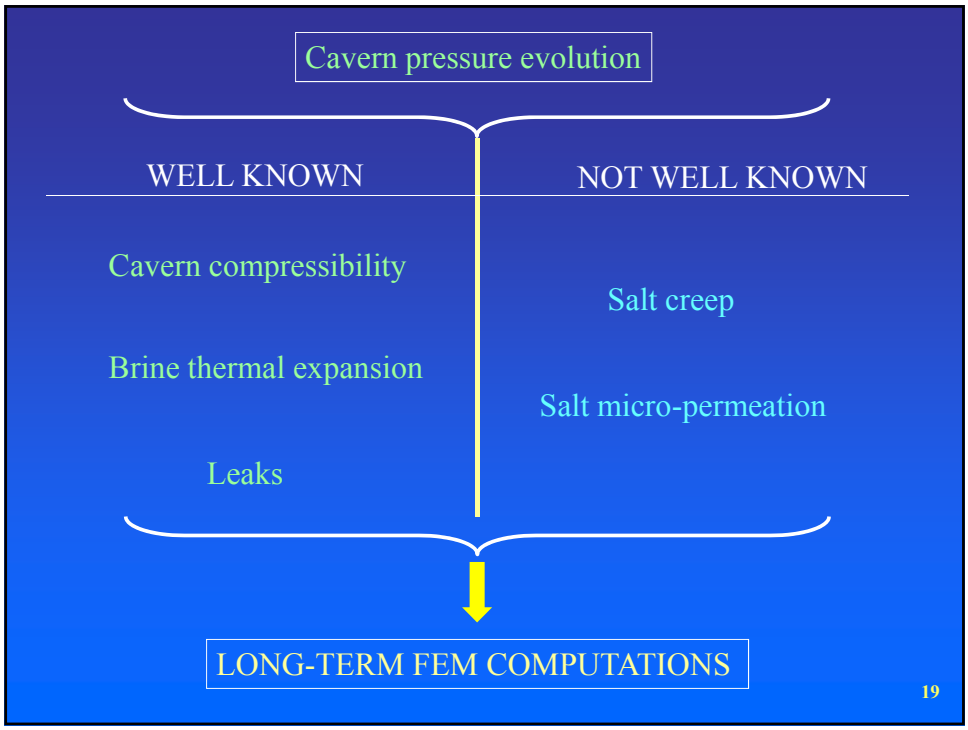
   - Cavern is deep → it is necessary to wait for several years

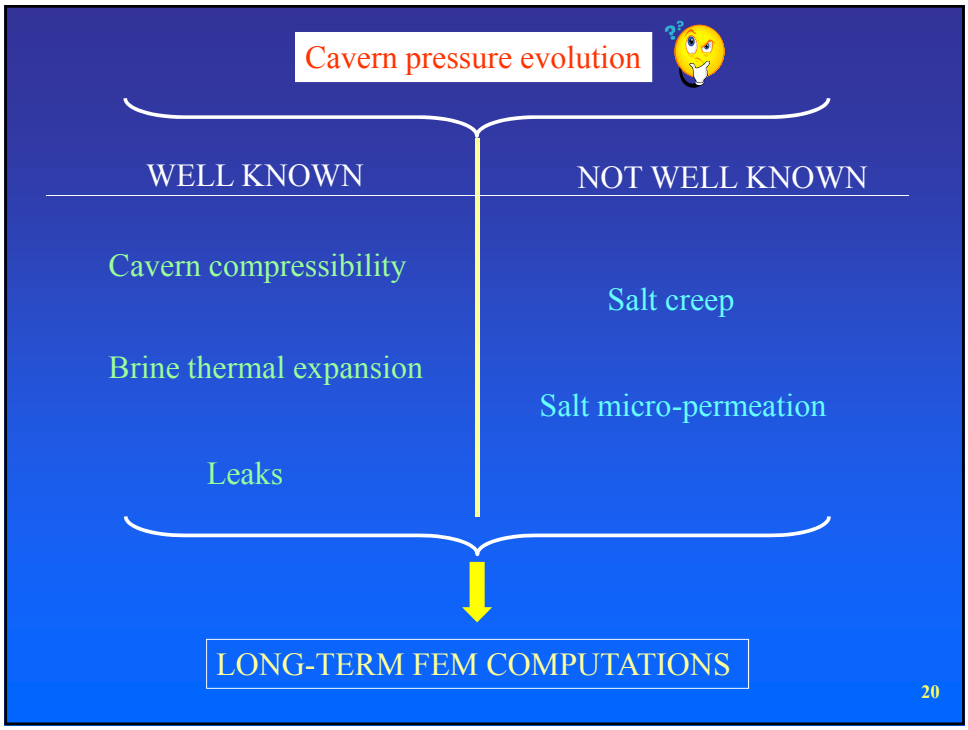
   - Cavern is shallow → even a very small permeability can prevent too large a pressure build-up

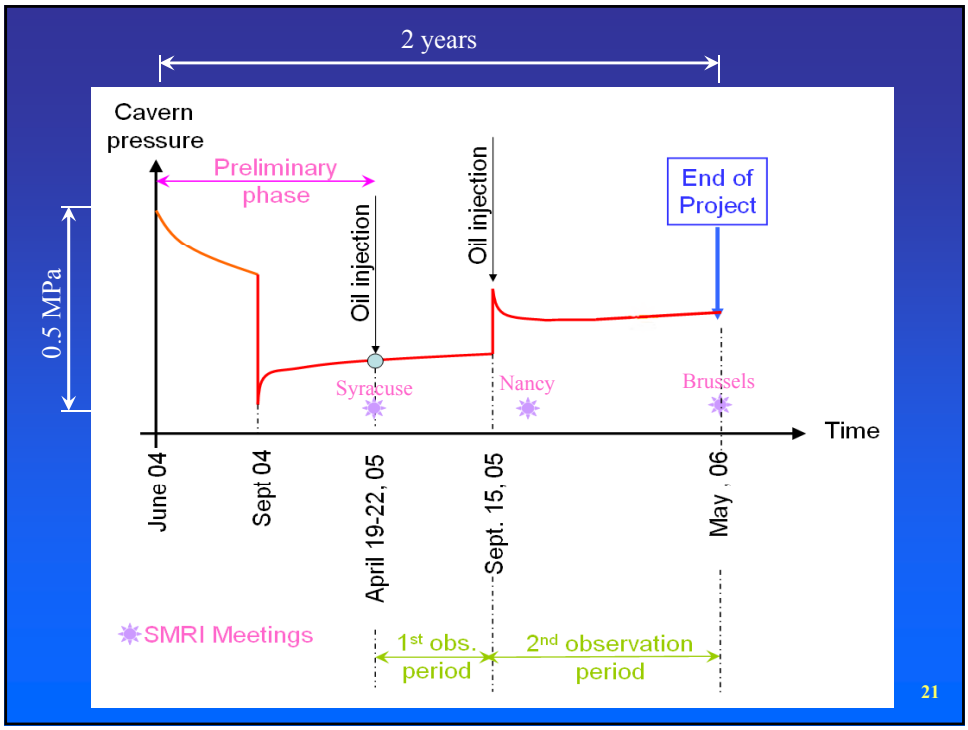
17

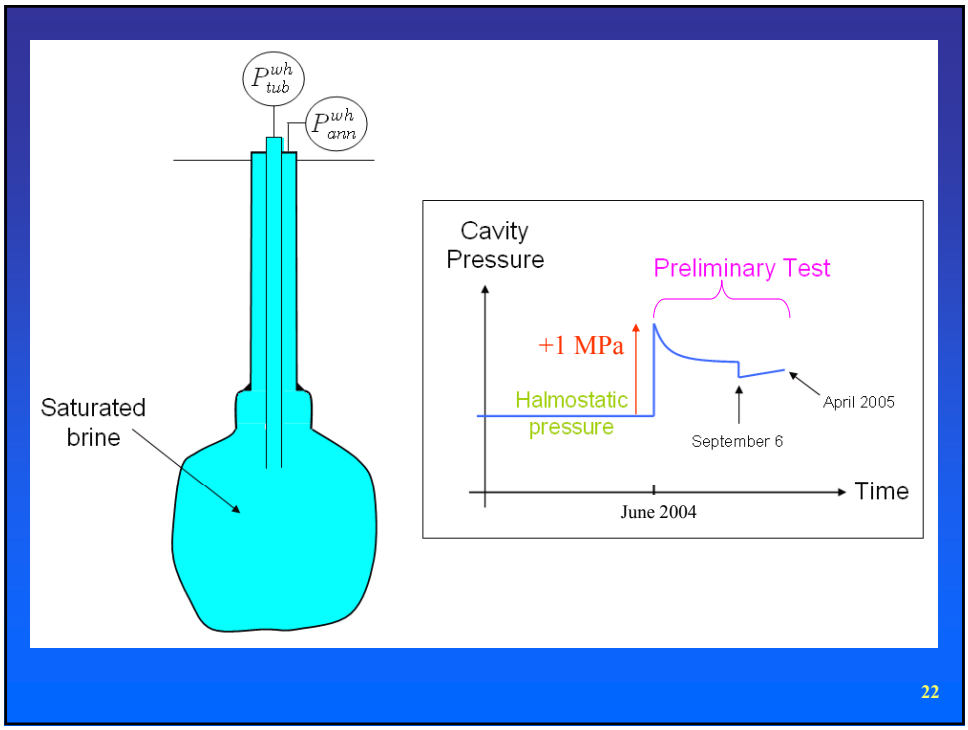
IN SITU MEASUREMENTS

18

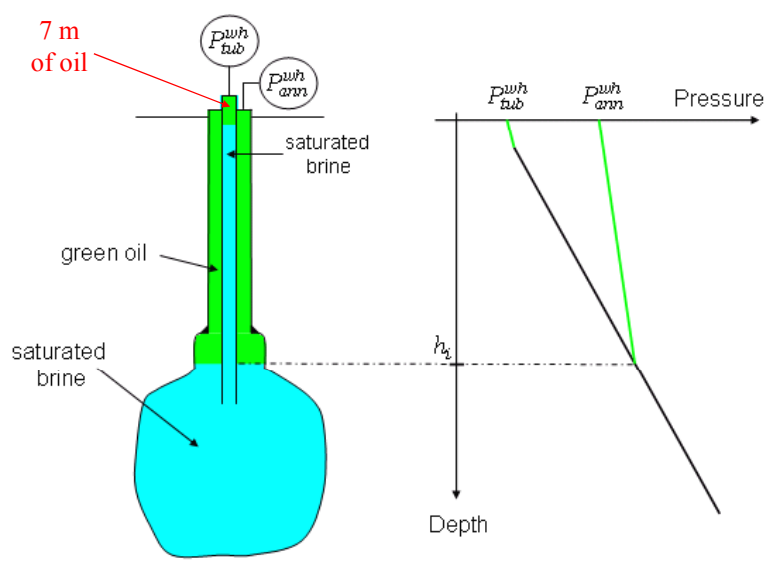

Cavern pressure evolution
WELL KNOWN
NOT WELL KNOWN
Cavern compressibility
Brine thermal expansion
Leaks
Salt creep
Salt micro-permeation
LONG-TERM FEM COMPUTATIONS
19


Cavern pressure evolution
WELL KNOWN
NOT WELL KNOWN
Cavern compressibility
Brine thermal expansion
Leaks
Salt creep
Salt micro-permeation
LONG-TERM FEM COMPUTATIONS
20


2 years
Cavern pressure
Preliminary phase
Oil injection
Oil injection
End of Project
0.5 MPa
Syracuse
Nancy
Brussels
Time
June 04
Sept 04
April 19-22, 05
Sept. 15, 05
May . 06
SMRI Meetings
1st obs. period
2nd observation period
21

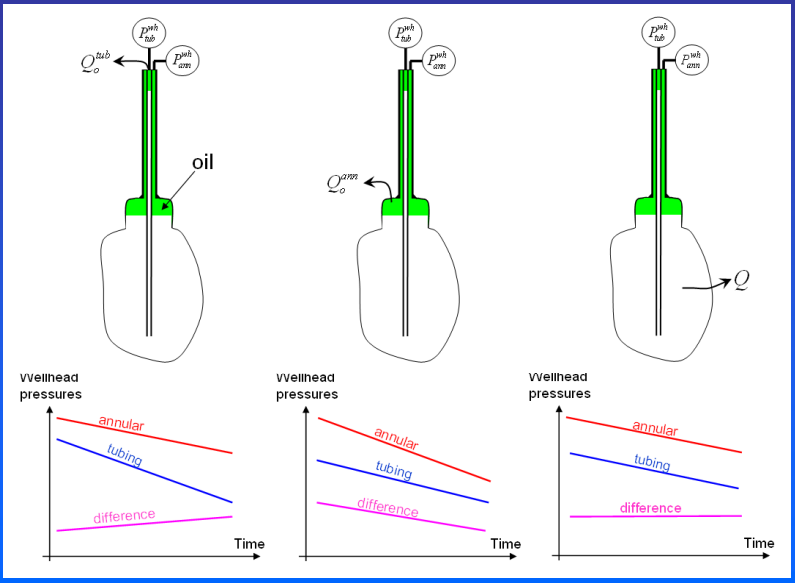

P^{wh}_{tub}
P^{wh}_{ann}
Saturated brine
Cavity Pressure
Preliminary Test
+1 MPa
Halmostatic pressure
April 2005
September 6
Time
June 2004
22

WELL STATUS FROM APRIL 22 TO SEPTEMBER 15 2005



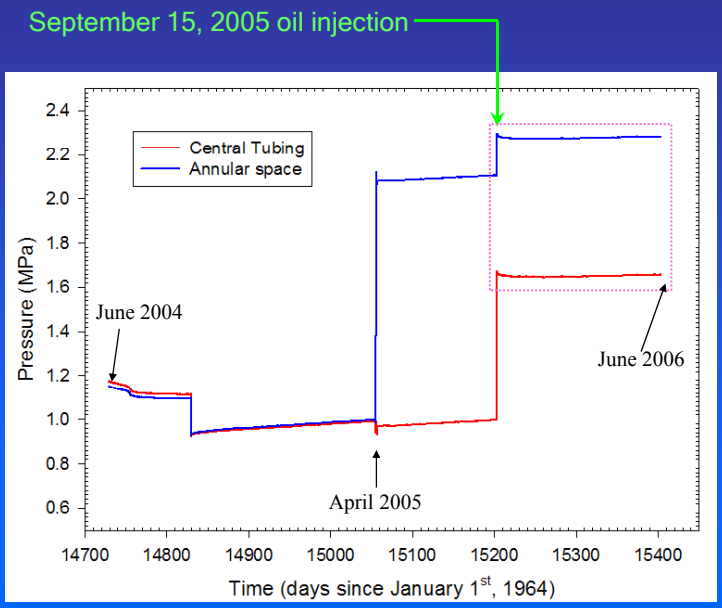
23

LEAK-DETECTION SYSTEM



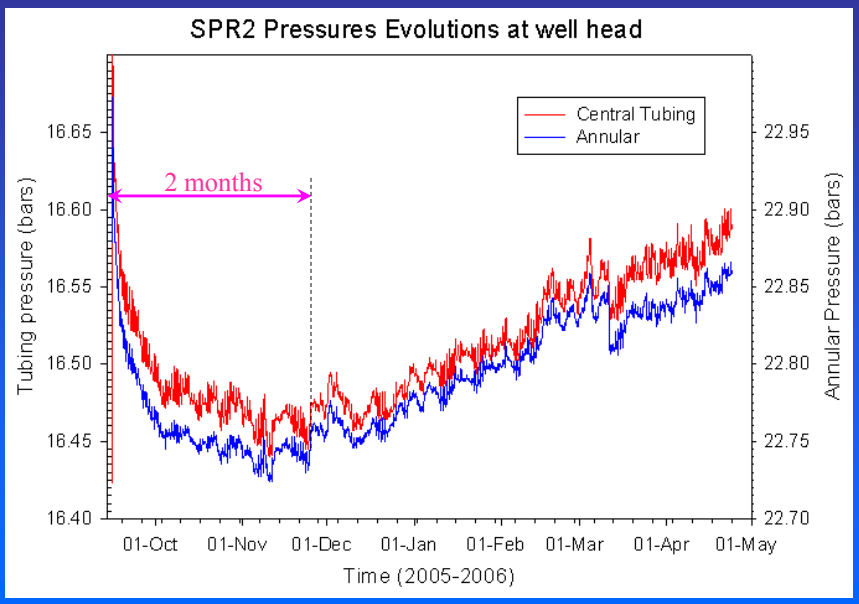
24

WELLHEAD PRESSURES



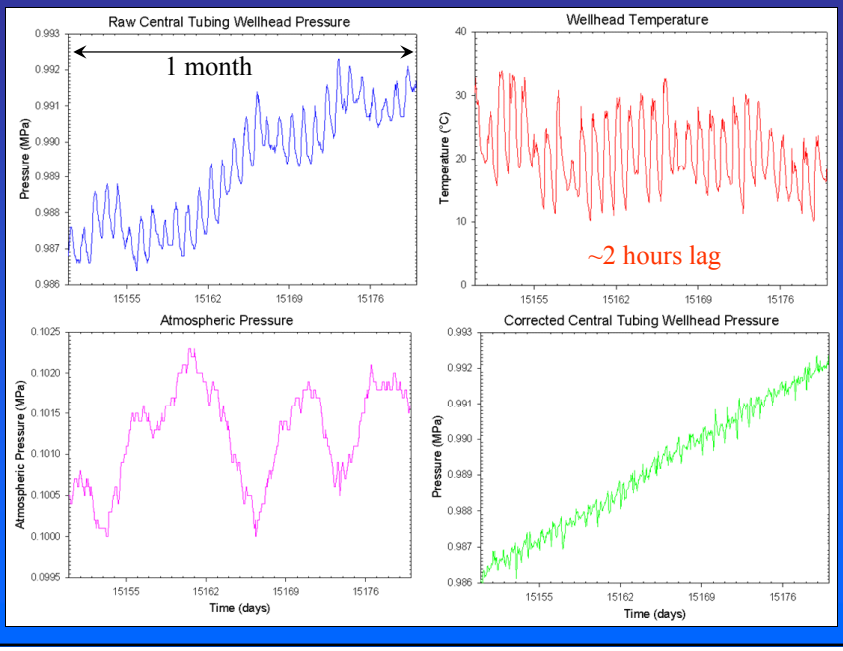
25

WELLHEAD PRESSURES FROM SEPTEMBER 15 2005 TO MAY 2006



26

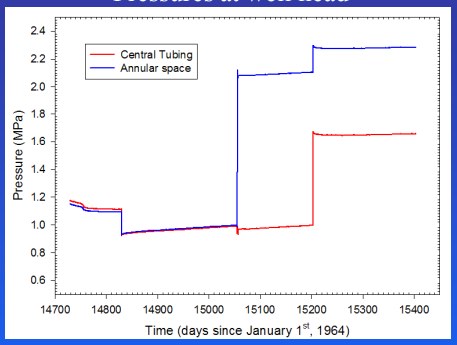
WELLHEAD PRESSURE FILTERING



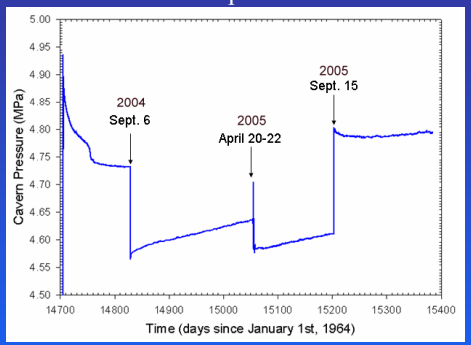
27

DETERMINATION OF CAVERN PRESSURE EVOLUTION

Pressures at well head



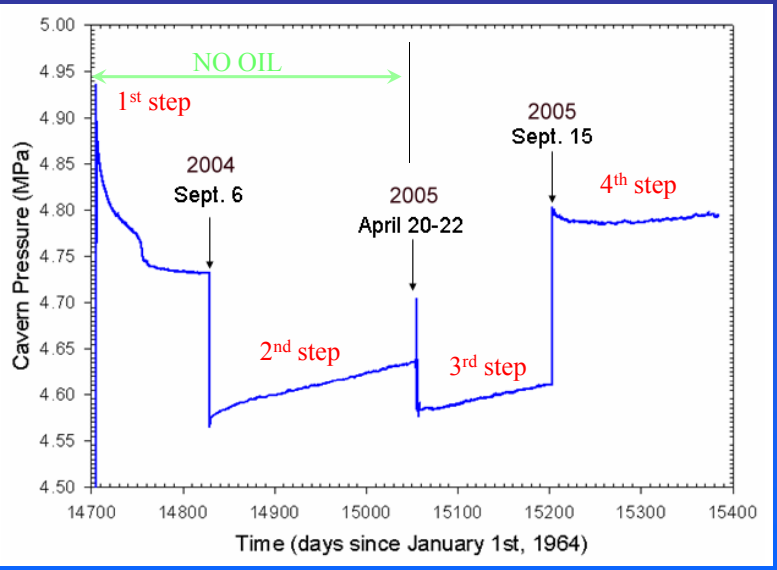
Cavern pressure



- columns composition
- temperature log
- oil/brine compressibilities
- leaks

28

CAVERN PRESSURE EVOLUTION AS COMPUTED



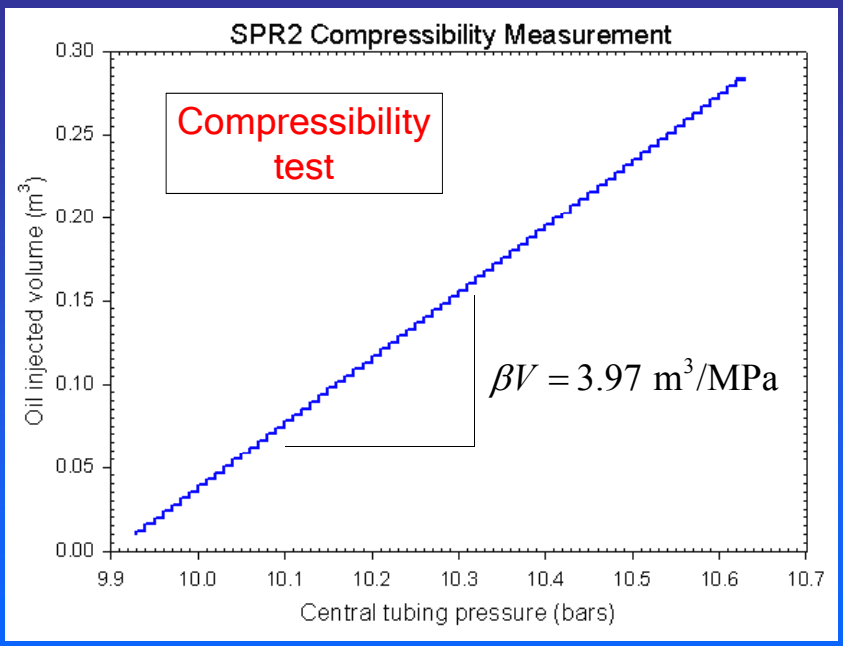
29

Cavern pressure evolution

WELL KNOWN	NOT WELL KNOWN
Cavern compressibility	Salt creep
Brine thermal expansion	Salt micro-permeation
Leaks	

LONG-TERM FEM COMPUTATIONS

30



31

SALT ELASTIC PARAMETERS BACK-CALCULATED

BC-Ecole Polytechnique

It was assumed:

$\nu = 0.25$

FEM fitting

$E \approx 16{,}500$ MPa

IUB

It was assumed:

$\nu = 0.35$

FEM fitting

$E \approx 17{,}800$ MPa

32

Cavern pressure evolution

WELL KNOWN	NOT WELL KNOWN
Cavern compressibility	Salt creep
Brine thermal expansion	Salt micro-permeation
Leaks	

LONG-TERM FEM COMPUTATIONS

33

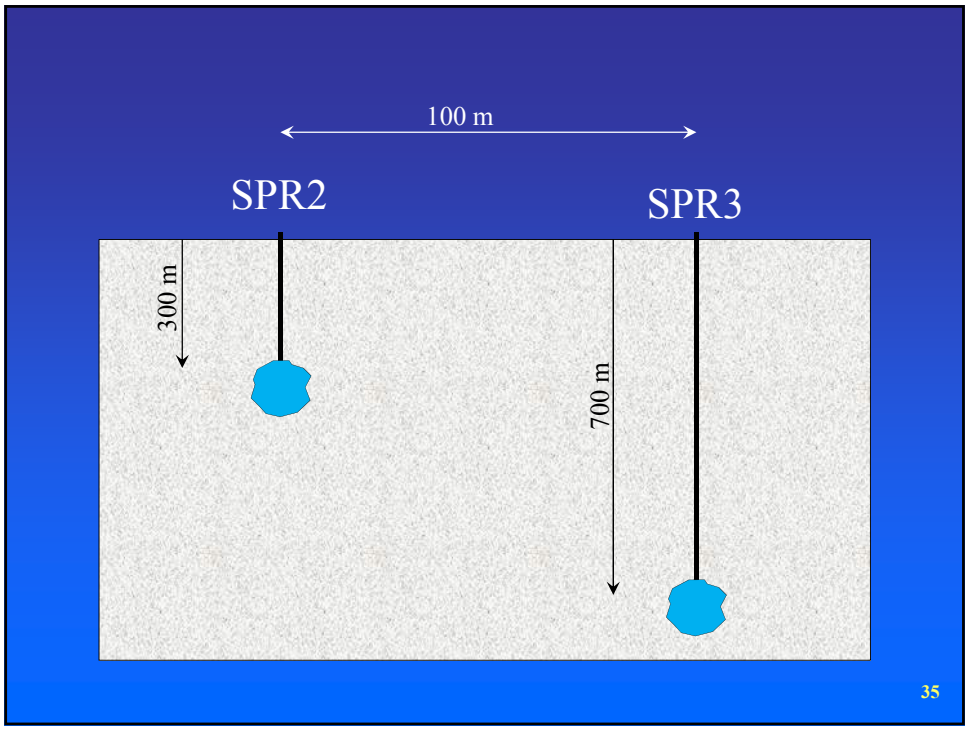
DETERMINATION OF CAVERN TEMPERATURE EVOLUTION

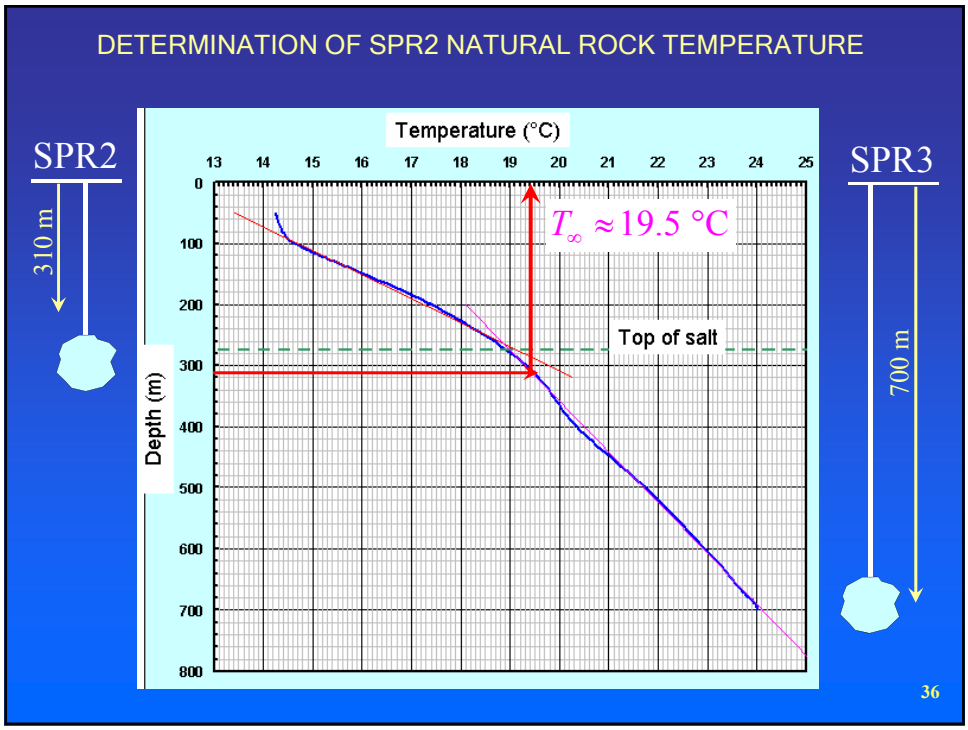
1st task: Determination of natural rock temperature T_∞

2nd task: Fitting of cavern temperature measurement

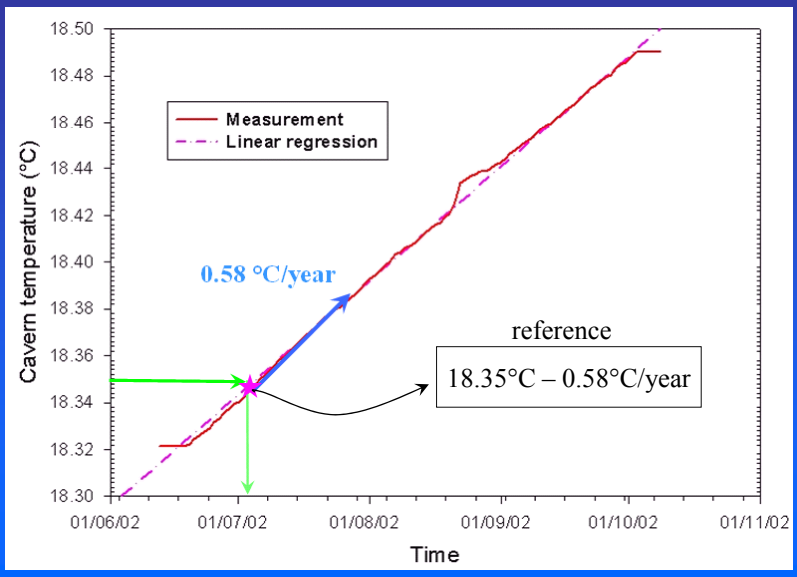
Accurate prediction of brine thermal expansion
during and after the test

34

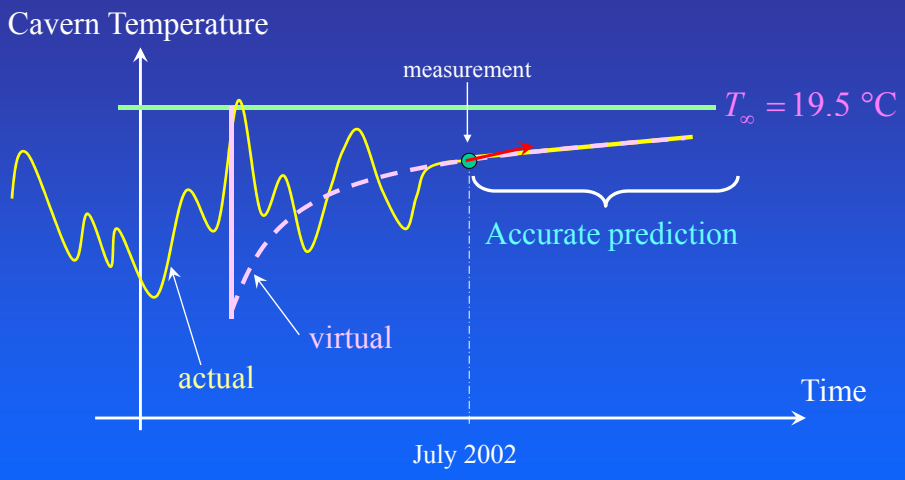

100 m
SPR2
SPR3
300 m
700 m
35


DETERMINATION OF SPR2 NATURAL ROCK TEMPERATURE
SPR2
310 m
Temperature (°C)
13 14 15 16 17 18 19 20 21 22 23 24 25
0 100 200 300 400 500 600 700 800
Depth (m)
$T_\infty \approx 19.5$ °C
Top of salt
SPR3
700 m
36

SPR2 TEMPERATURE MEASUREMENT IN 2002

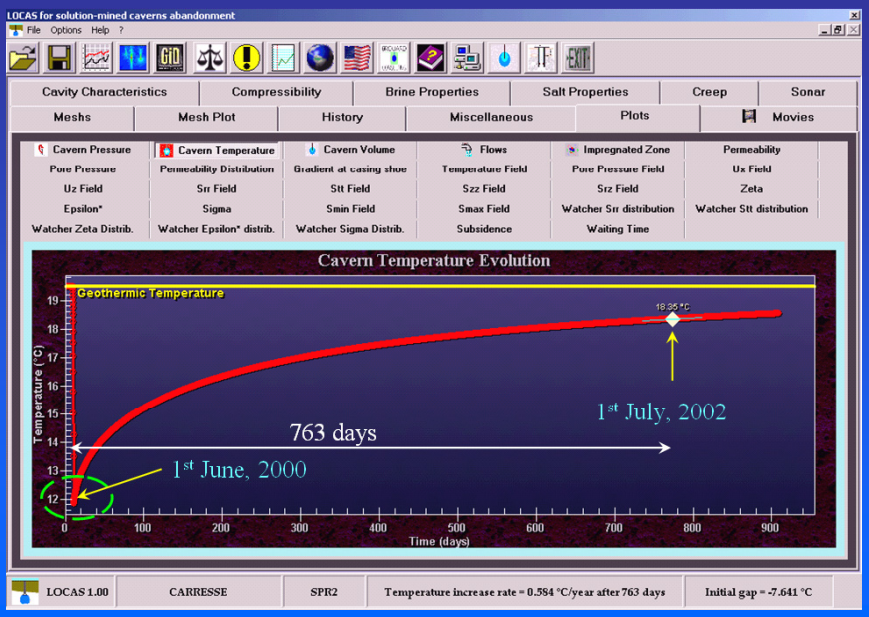


37



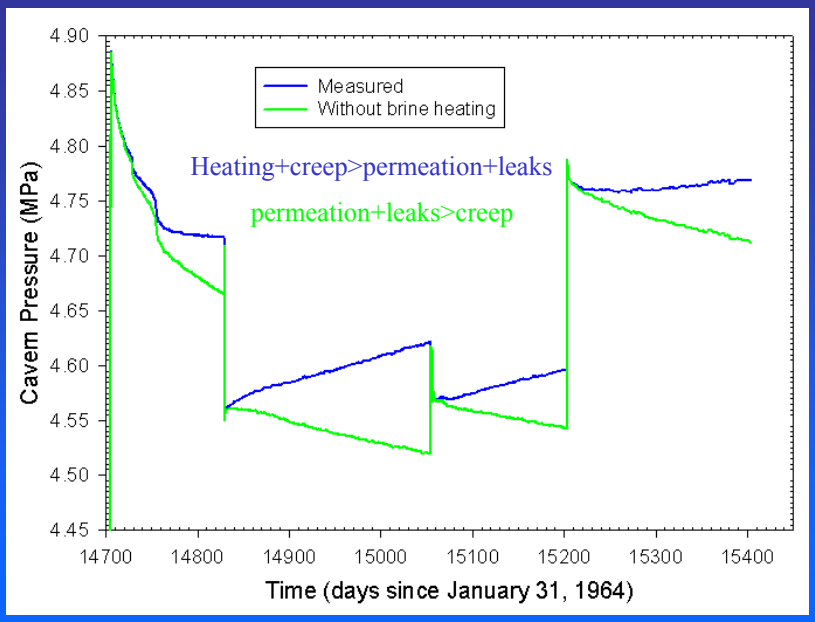
38

CAVERN TEMPERATURE FITTING (FEM computation, LOCAS)



39

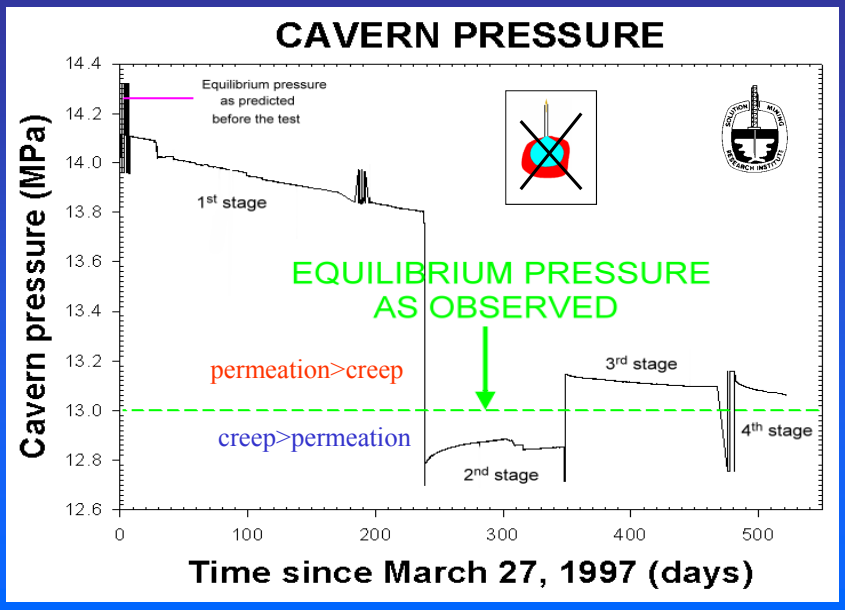
CAVERN PRESSURE EVOLUTION WITH/WITHOUT BRINE HEATING



Brine heating is the main phenomenon leading to cavern pressure increase

40

ETREZ EZ53 TEST (1997-1998) - NO BRINE HEATING



41

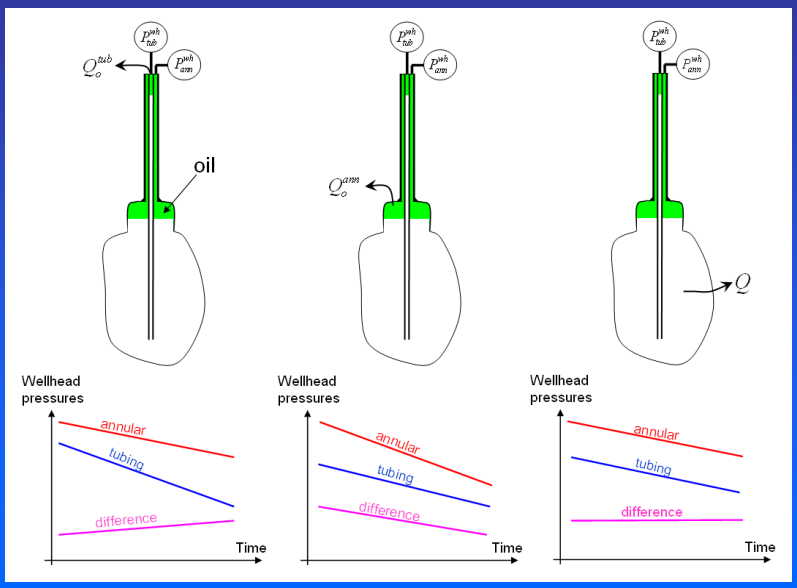
Cavern pressure evolution

WELL KNOWN	NOT WELL KNOWN
Cavern compressibility	Salt creep
Brine thermal expansion	Salt micro-permeation
Leaks	

LONG-TERM FEM COMPUTATIONS

42

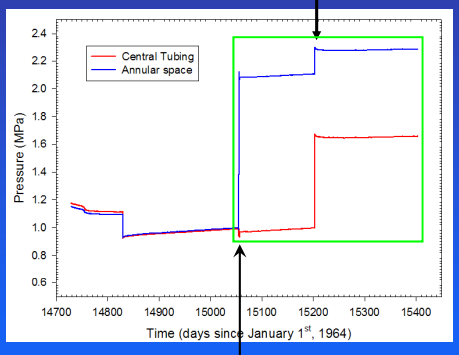
LEAKS DETERMINATION



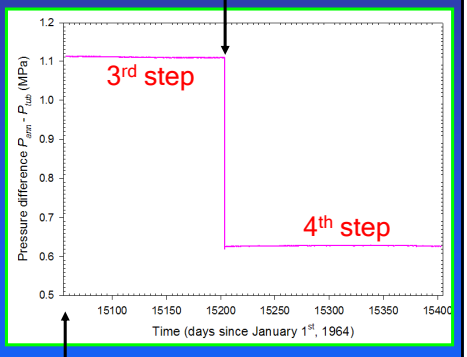
43

oil injection
(Sept. 2005)

Pressures at well head

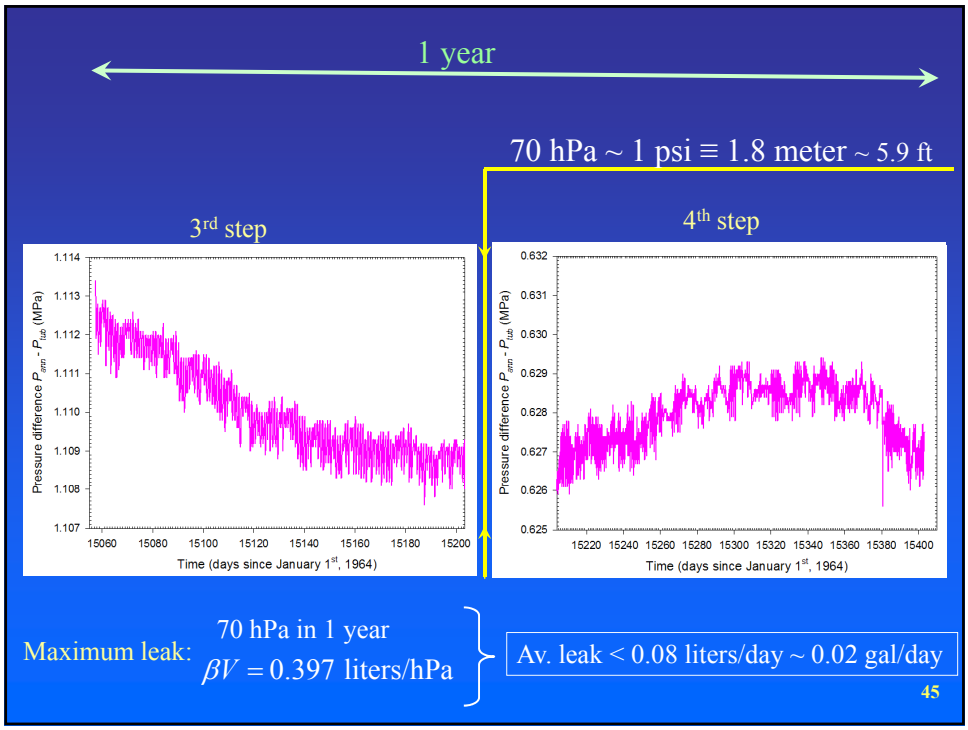


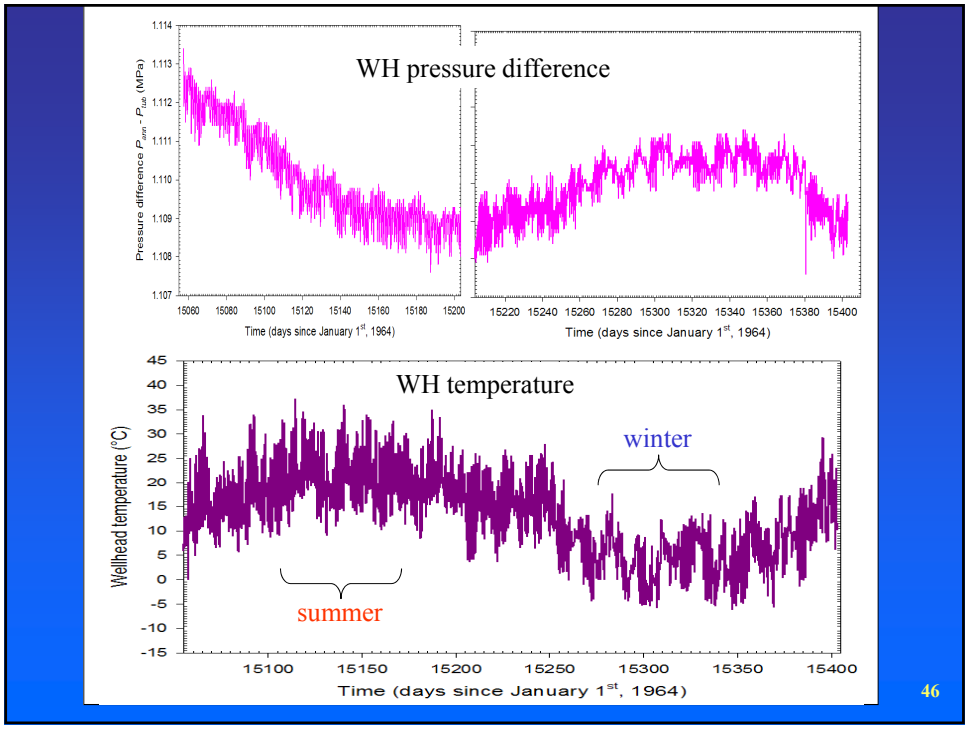
Pressure difference



oil injection
(April 2004)

44


1 year
70 hPa ~ 1 psi ≡ 1.8 meter ~ 5.9 ft
3rd step
4th step
Pressure difference P_{annn} - P_{tub} (MPa)
Time (days since January 1st, 1964)
Maximum leak:
70 hPa in 1 year
$\beta V = 0.397$ liters/hPa
Av. leak < 0.08 liters/day ~ 0.02 gal/day
45


WH pressure difference
Pressure difference P_{annn} - P_{tub} (MPa)
Time (days since January 1st, 1964)
WH temperature
Wellhead temperature (°C)
winter
summer
Time (days since January 1st, 1964)
46

Cavern pressure evolution

WELL KNOWN	NOT WELL KNOWN
Cavern compressibility	Salt creep
Brine thermal expansion	Salt micro-permeation
Leaks	

LONG-TERM FEM COMPUTATIONS

47

SALT PARAMETERS TO BE DETERMINED:

- Salt creep parameters

Stationnary creep	Transient creep
Norton-Hoff parameters	Munson-Dawson parameters
$(A, n, Q/R)$	$(A_1, n_1, m, K_o, \delta, c)$ + reverse creep

- Salt hydraulical parameters (K)

THESE PARAMETERS MUST BE BACK-CALCULATED
AND/OR
A SENSITIVITY STUDY MUST BE PERFORMED

48

Cavern pressure evolution

WELL KNOWN	NOT WELL KNOWN
Cavern compressibility	Salt creep
Brine thermal expansion	Salt micro-permeation
Leaks	

LONG-TERM FEM COMPUTATIONS

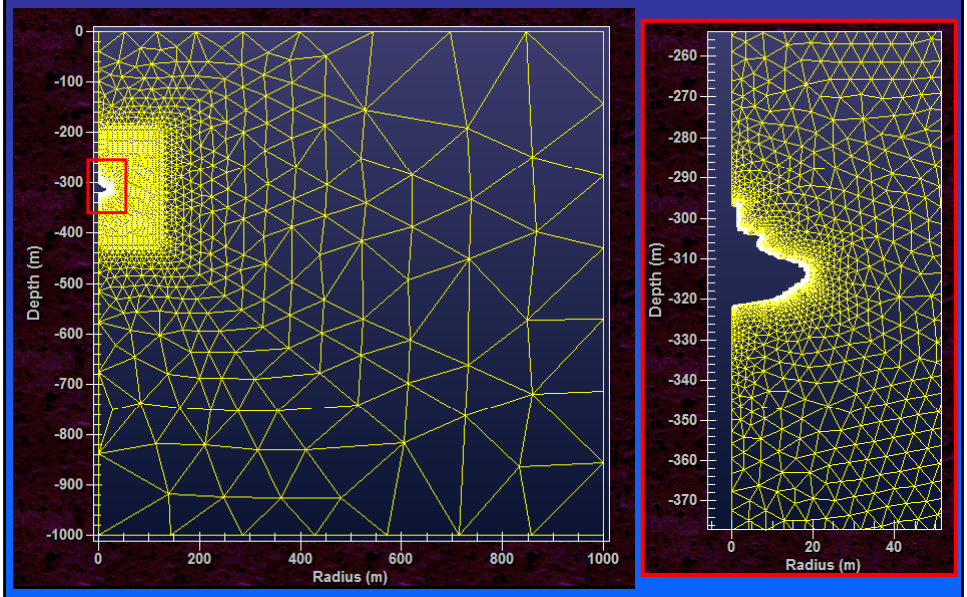
49

Finite Element Computations by LMS & Brouard Consulting

Back-calculation of salt parameters

50

EXAMPLE OF SPR2 MESH



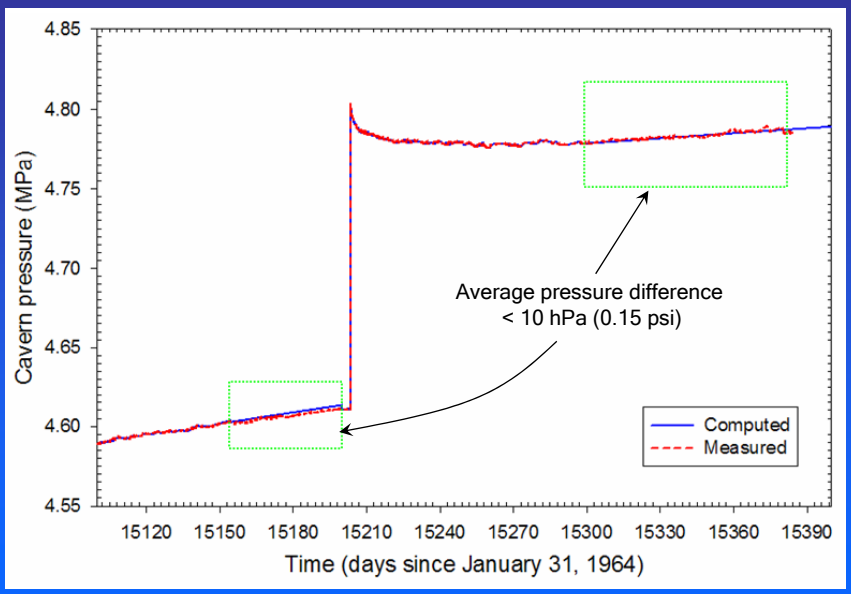
4109 nodes - 7794 elements

51

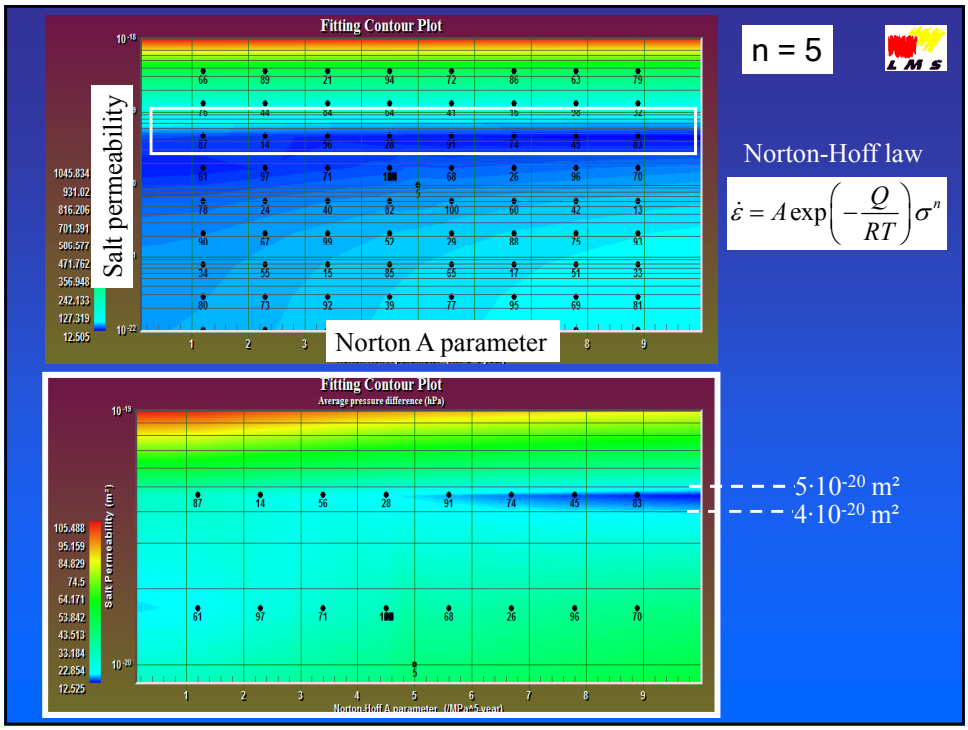
BROUARD CONSULTING

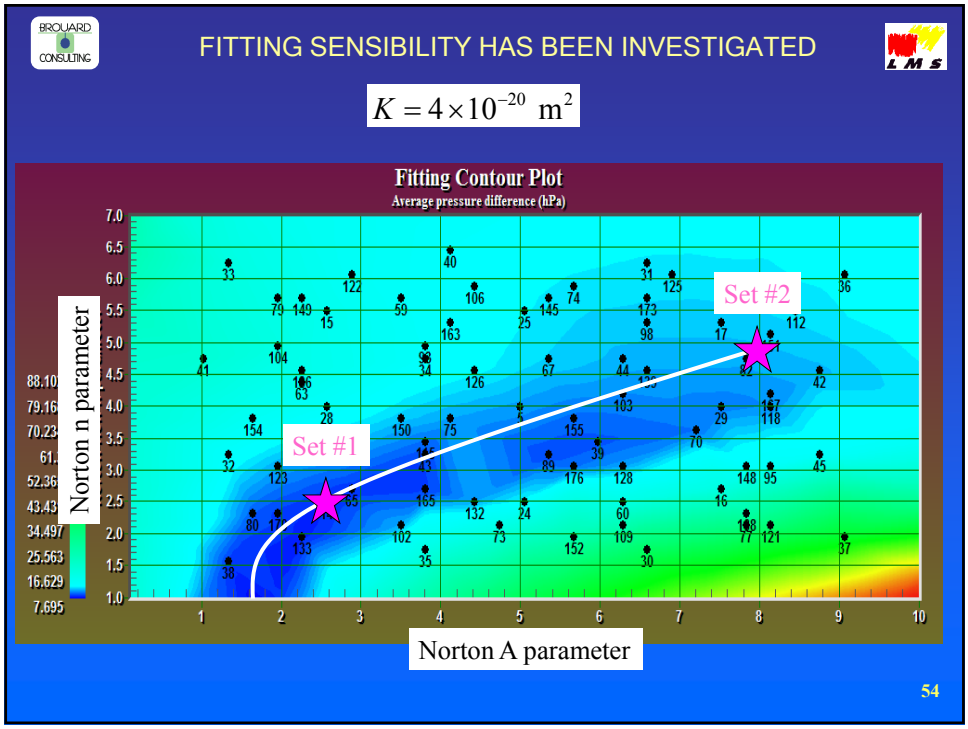
STATIONNARY PARAMETERS FITTED FOR TWO PERIODS

LMS



52


Fitting Contour Plot
Salt permeability
Norton A parameter
n = 5
Norton-Hoff law
$\dot{\varepsilon} = A \exp\left(-\frac{Q}{RT}\right)\sigma^n$
Fitting Contour Plot
Average pressure difference (hPa)
Salt Permeability (m²)
$5 \cdot 10^{-20}$ m²
$4 \cdot 10^{-20}$ m²


BROUARD CONSULTING
FITTING SENSIBILITY HAS BEEN INVESTIGATED
$K = 4 \times 10^{-20}$ m²
Fitting Contour Plot
Average pressure difference (hPa)
Norton n parameter
Norton A parameter
Set #1
Set #2
54

MAIN FITTING RESULTS

- Salt intrinsic permeability: $K \approx 4 - 5 \times 10^{-20}\ \mathrm{m}^2$
- Salt stationnary creep: $\dot{\varepsilon} = A \exp\left(-\frac{Q}{RT}\right)\sigma^n$ (Norton-Hoff law)

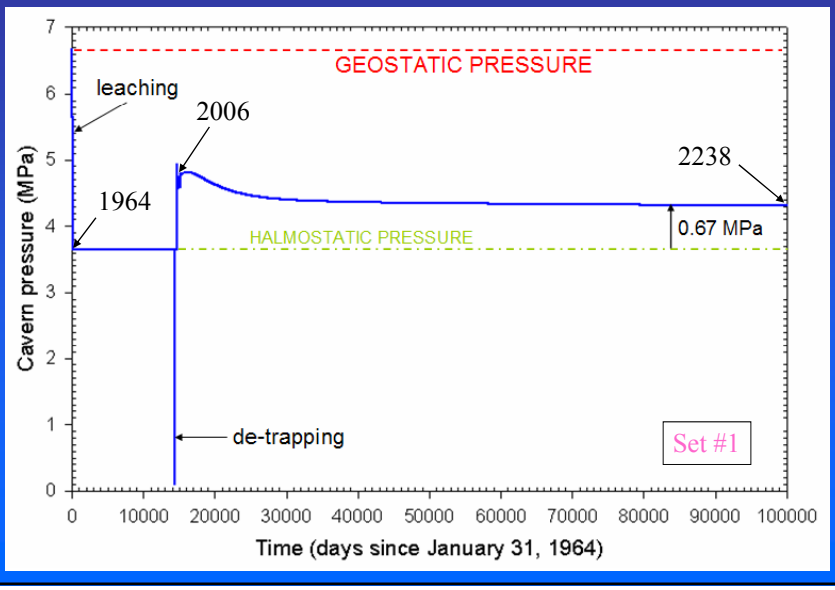
Example of 2 good sets of parameters:

	A (/MPa^n-year)	n	Q/R (K)
Set #1	2.5	2.5	4100
Set #2	7.8	5	4100

55

Norton-Hoff set #1

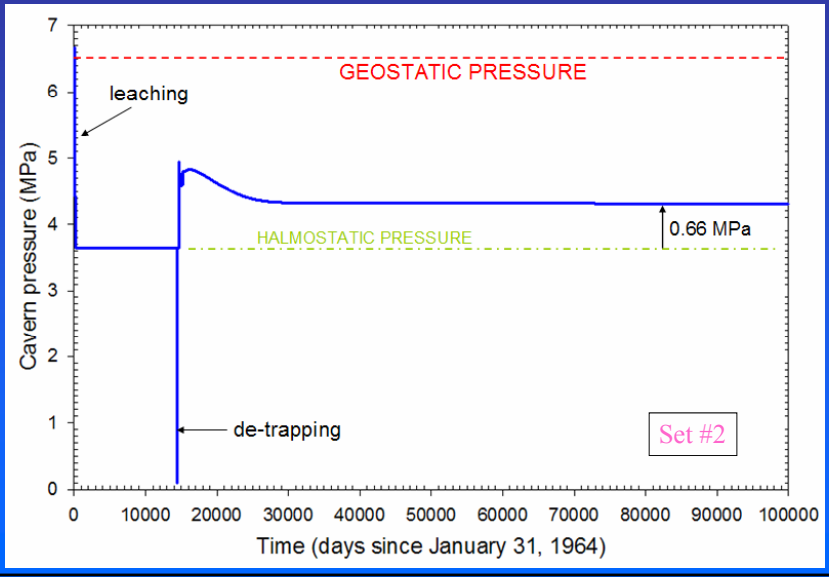
$K_{salt}^{hyd} = 4 \times 10^{-20}\ \mathrm{m}^2$ $n = 2.5$ $A = 2.5$ /MPa$^{2.5}$-year $Q/R = 4100$ K



56

Norton-Hoff set #2

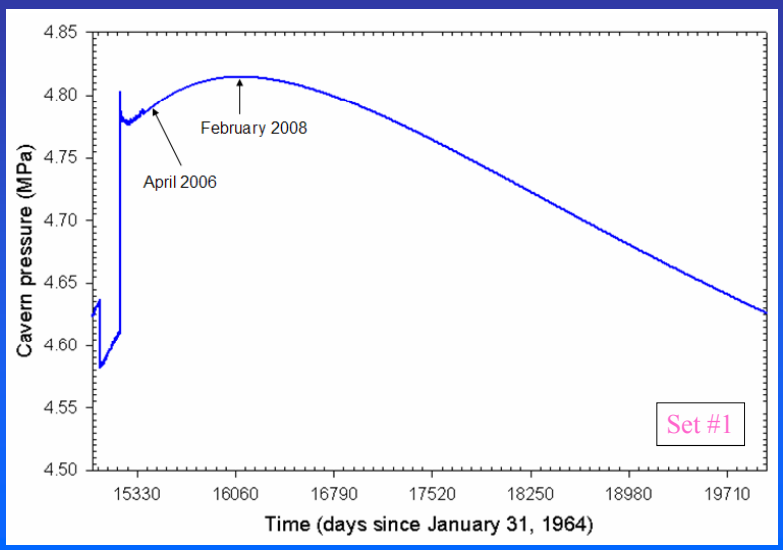
$K_{salt}^{hyd} = 4 \times 10^{-20}$ m^2 $n = 5$ $A = 7.8$ /MPa^5-year $Q/R = 4100$ K



57

Norton-Hoff set #1

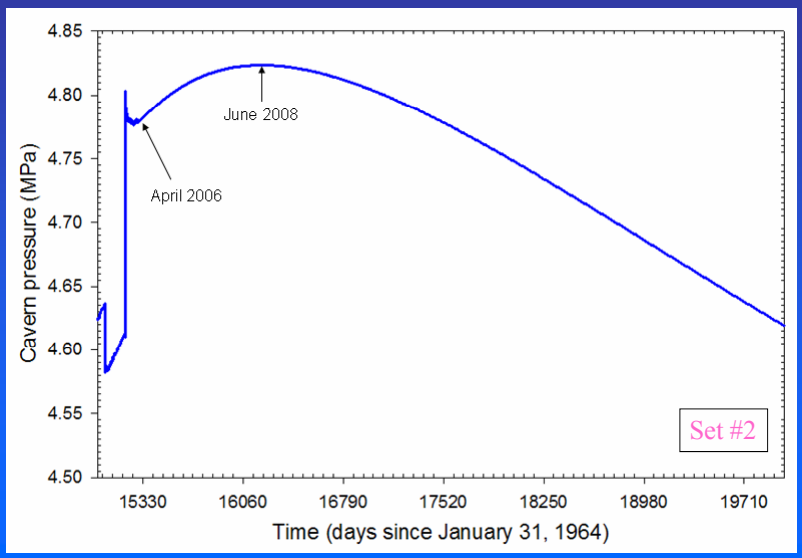
$K_{salt}^{hyd} = 4 \times 10^{-20}$ m^2 $n = 2.5$ $A = 2.5$ /MPa$^{2.5}$-year $Q/R = 4100$ K



58

Norton-Hoff set #2

$K_{salt}^{hyd} = 4 \times 10^{-20}$ m^2 $n = 5$ $A = 7.8$ /MPa^5-year $Q/R = 4100$ K



59

IUB

Finite Element Computations by IUB

Sensitivity study on salt parameters

60

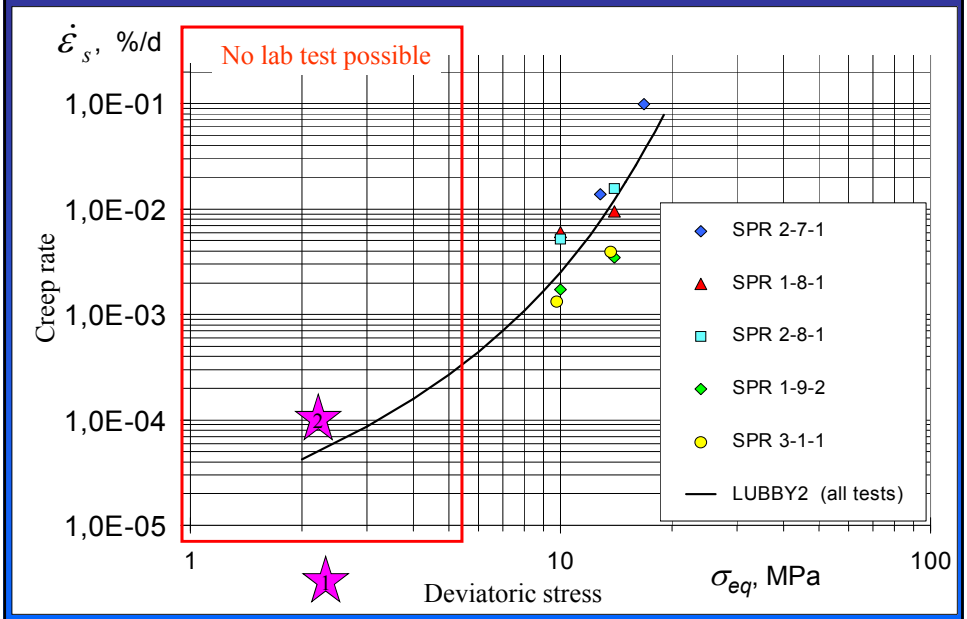
IUB

IUB STUDIES

- data analysis
- calculation of equilibrium pressure after sealing
- determination of the most reliable parameter set
- validation against test observations

61

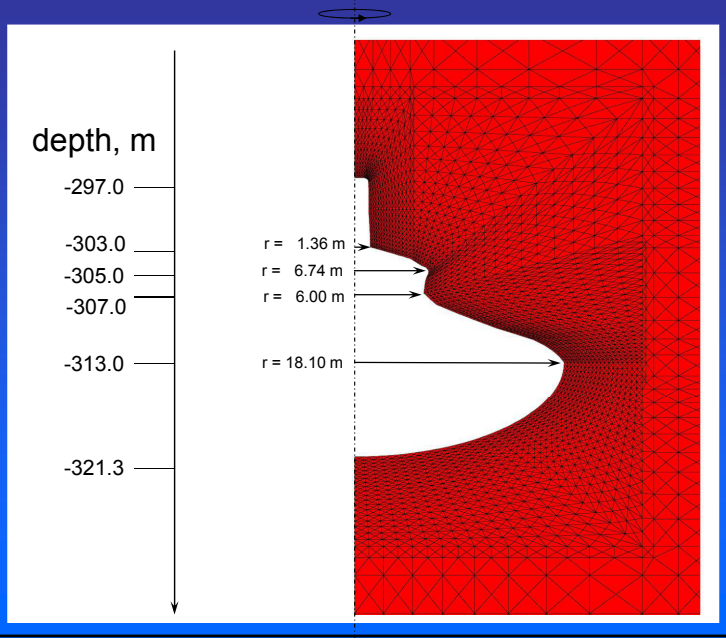
IUB



62

CALCULATION MODEL

IUB



63

Results – Long Term Pressure

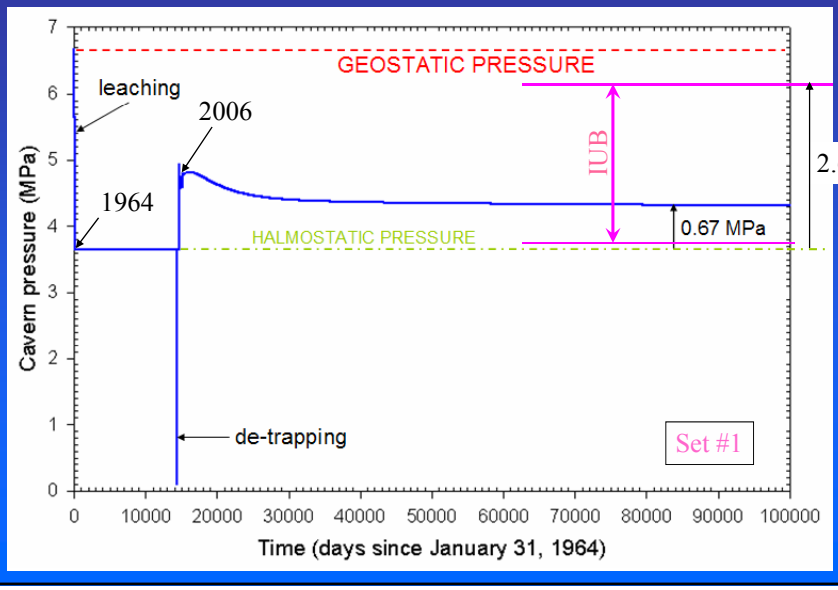
IUB

Assumed Model	Long Term Pressure Increase (MPa)
reference	1.3
higher creep ability	2.6
lower creep ability	0.2
higher permeability	0.9
lower permeability	2.6
hydrostatic far field p_0	0.9
WIPP site far field p_0	1.7

64

Norton-Hoff set #1

$K_{salt}^{hyd} = 4 \times 10^{-20}$ m^2 $n = 2.5$ $A = 2.5$ /MPa$^{2.5}$-year $Q/R = 4100$ K

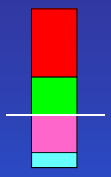


65

PHENOMENA WHICH ARE ACTIVE DURING THE TEST

Pressure increase

Pressure decrease



Brine thermal expansion ≈1 liter/day

Cavern closure (creep) ≈ 0.4 liter/day

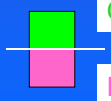
Brine micro-permeation ≈ 0.6 liter/day

Leaks ≈ 0.1 liter/day (MIT: ≈ 400 liters/day)

PHENOMENA WHICH ARE ACTIVE ON THE LONG TERM

Pressure increase

Pressure decrease



Cavern closure (creep) ≈ 0.5 liter/day

Brine micro-permeation ≈ 0.5 liter/day

66

CONCLUSIONS

- ✓ A 2-year long abandonment test on a small and shallow cavern has been performed at Carresse, France.
- ✓ Parameters back-calculation, a sensitivity study, and long-term simulations have been performed.
- ✓ The existence of an equilibrium pressure far below geostatic pressure has been confirmed.
- ✓ It has been proven that this cavern can be safely sealed.
- ✓ Final report is available for members on SMRI Website.

67