Arsenic Trioxide Management

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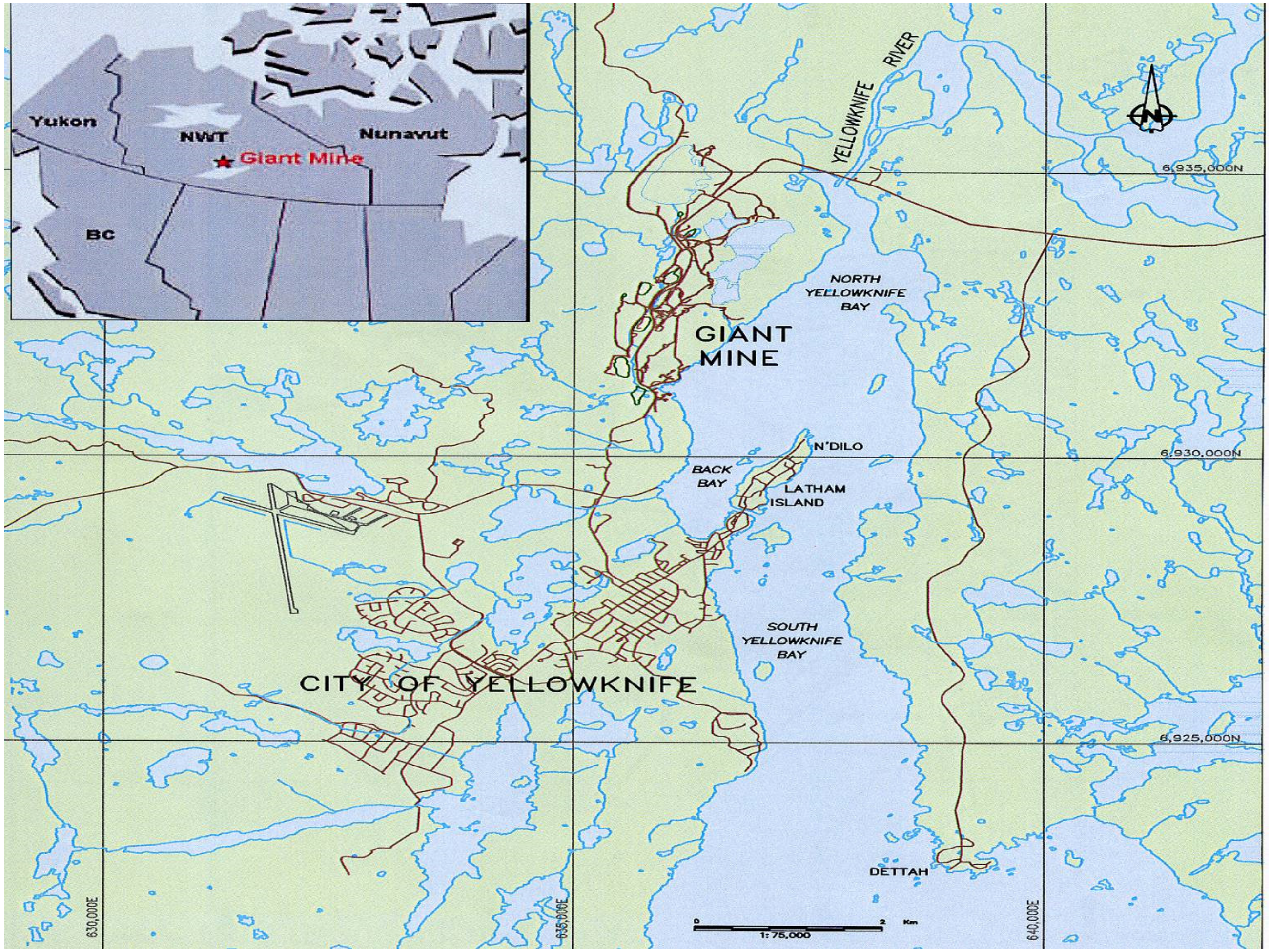
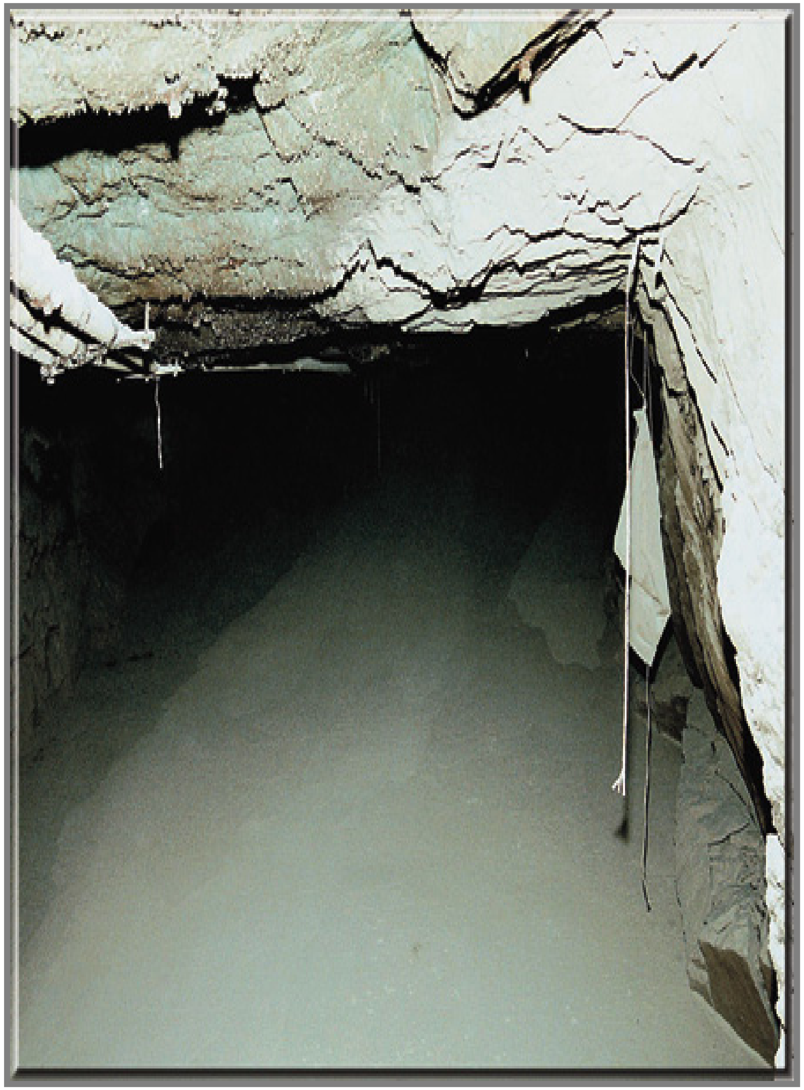
MEND Workshop, December 3-4, 2014

- Overview of presentation
  1. Project Background
  2. Containment of Arsenic Trioxide using Frozen Blocks
  3. Optimization Study
  4. Findings and implications for full-scale design

1. Background



- Arsenic trioxide dust
  - 237,000 tonnes of arsenic trioxide dust
  - 14 underground chambers and stopes
  - Initially a dry powder
  - Like fine flour
  - 60% arsenic
  - Dissolves in water up to 9,000 mg/L



KA1

- Arsenic trioxide dust chambers and stopes

Slide 5

KA1 This slide looks very odd - perhaps something more is coming

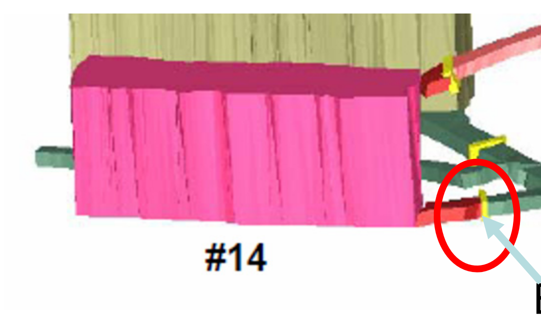
Krista Amey, 8/24/2012

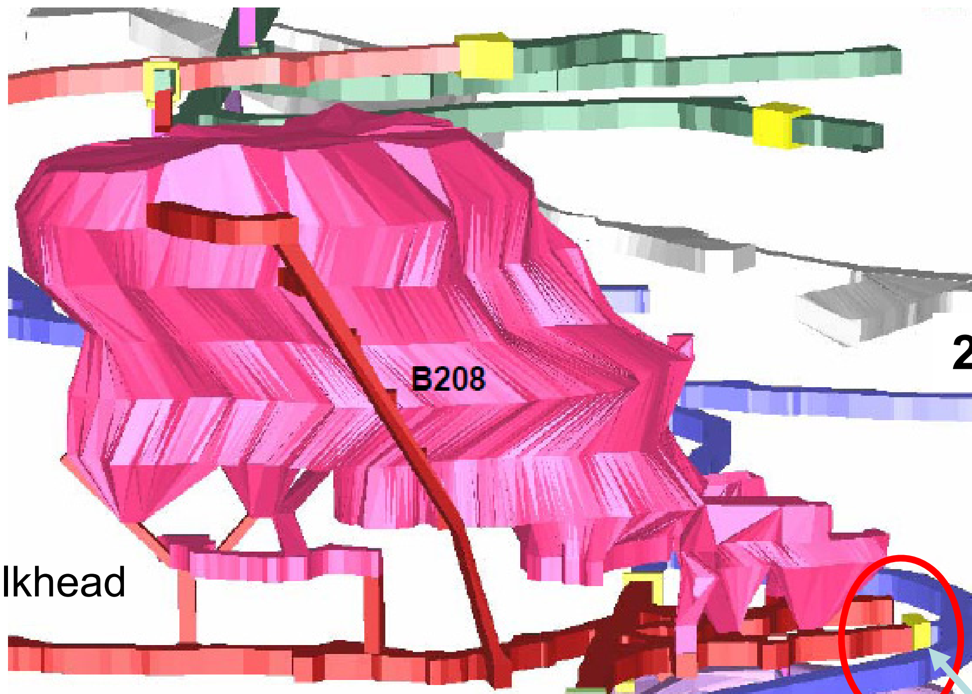
Giant Mine Remediation Project

Northwest Territories

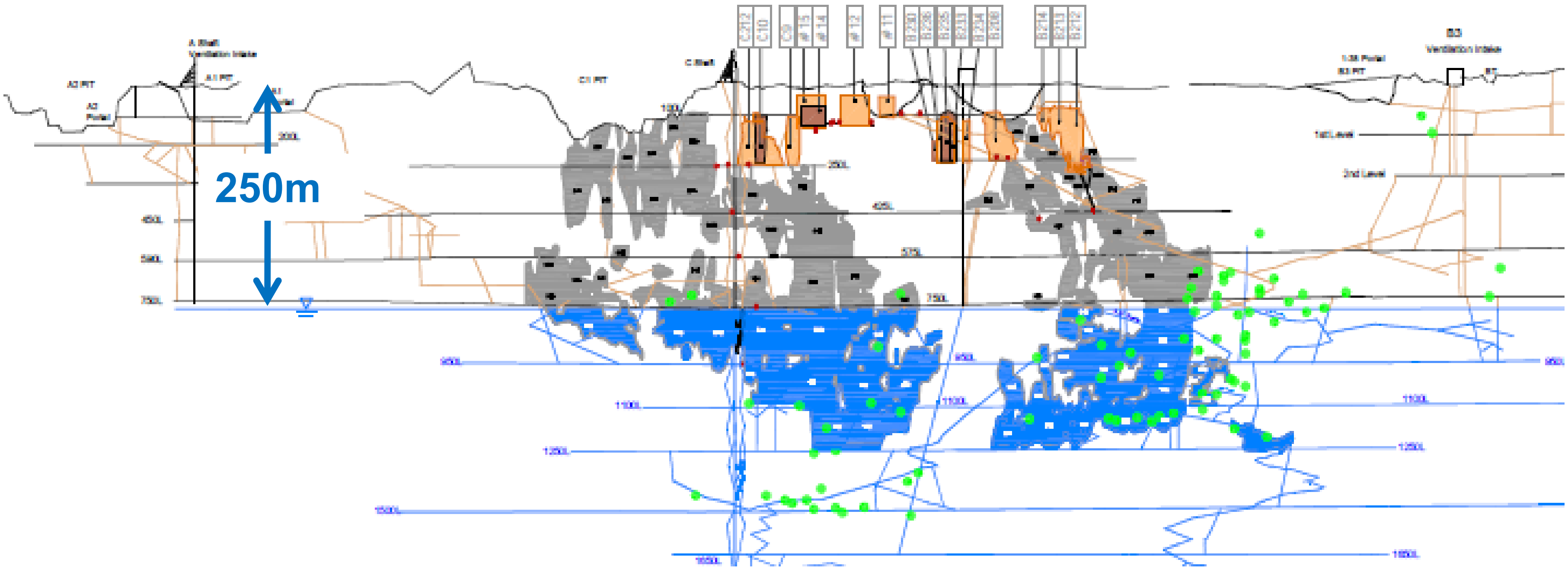
Canada

- Chamber and stope sizes





- Currently completely contained
  - Any water that leaves the mine is treated to remove arsenic



56 Methods → 4 Groups → First Public Workshop

12 Options → 1 Leave-it-UG Option
12 Options → 1 Take-it-Out Option

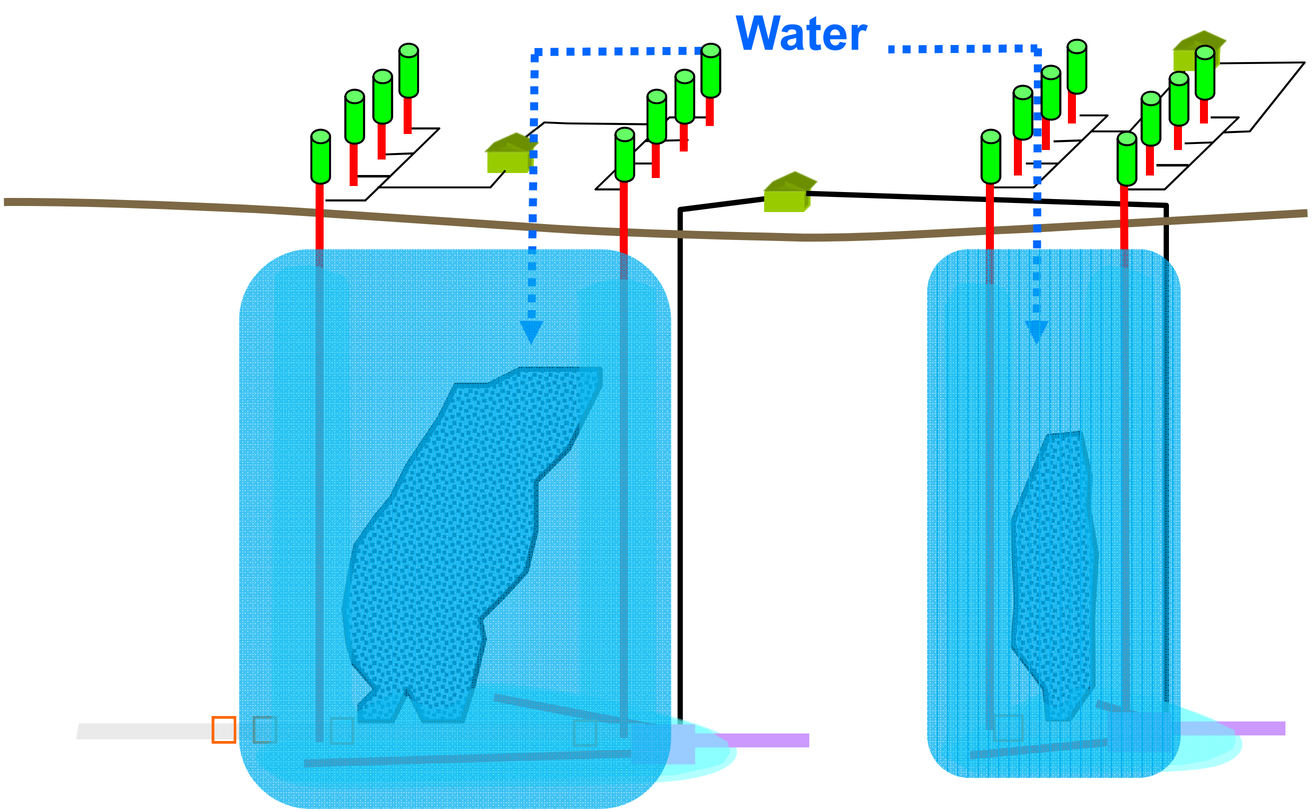
Second Public Workshop

Above plus Combination Option → Third Public Workshop

Draft Option → Independent Peer Review → Recommended Option

Remediation Plan and DAR

2. Frozen Blocks



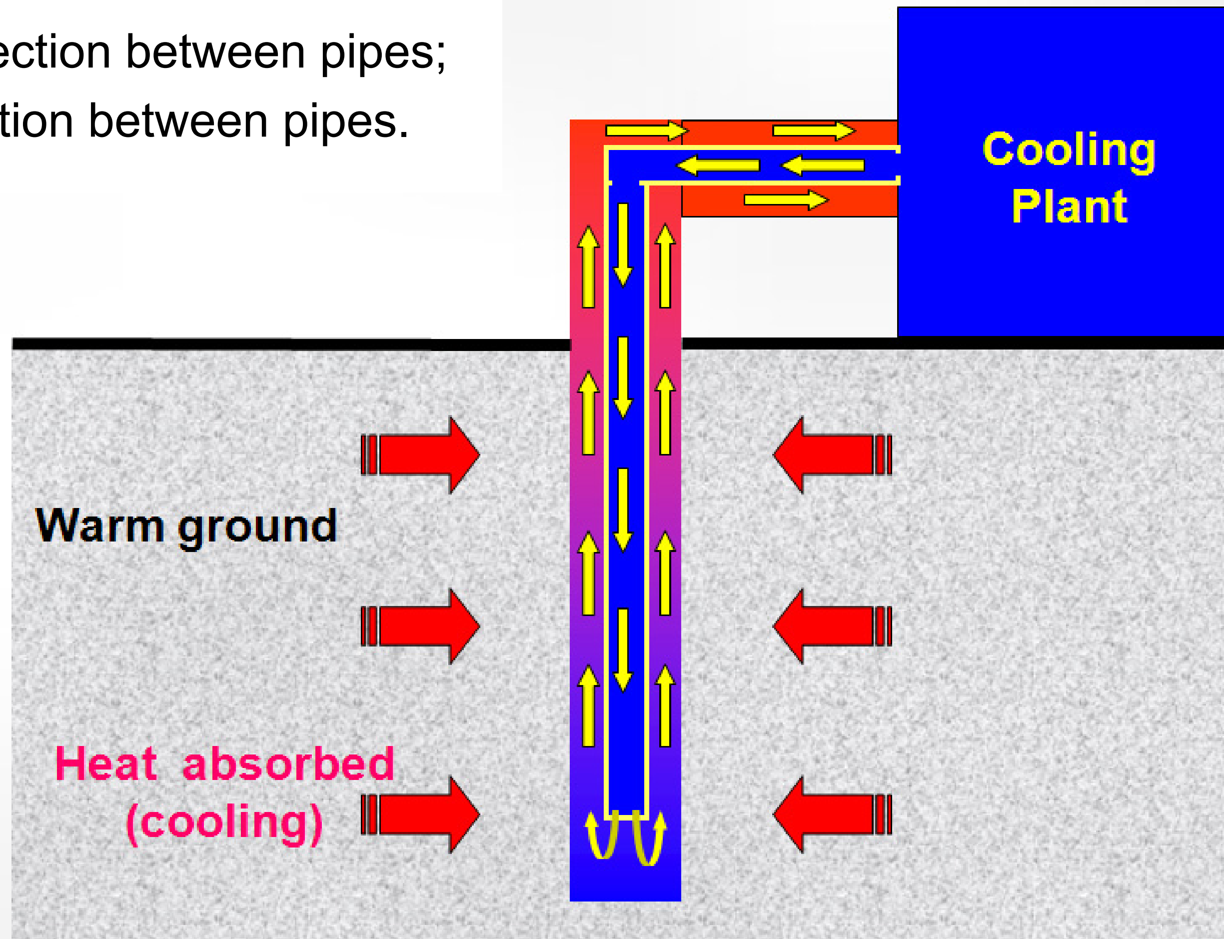
3. Freeze Optimization Study

- Study Objectives
  - Demonstrate to the public that ground freezing works
  - Inform further engineering design
  - Model calibration – Material properties, heat removal rates, etc.
  - Test implementation methods
  - Develop data handling methods
  - Develop insights into project procurement
  - Examine unknown unknowns

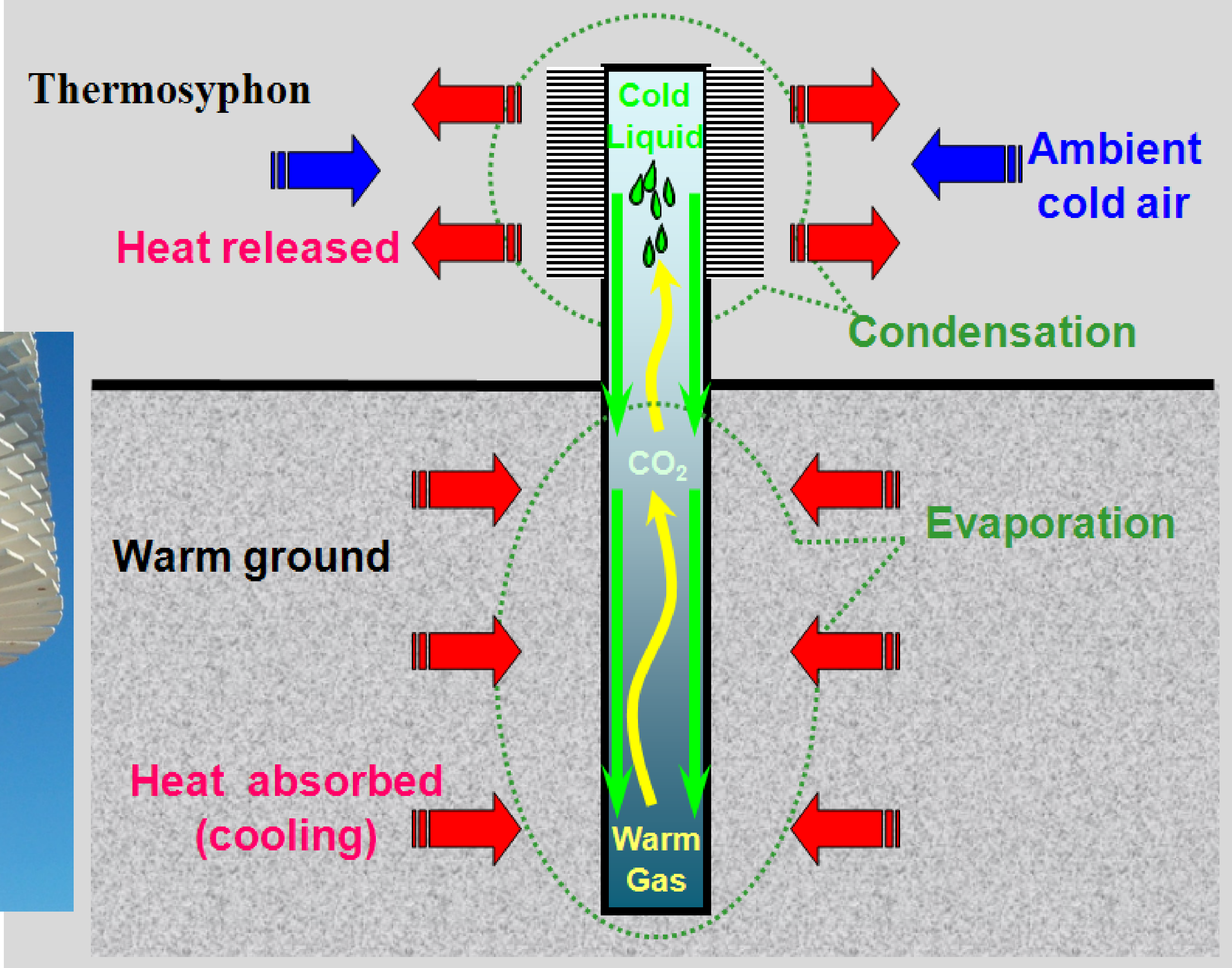
3. Freeze Optimization Study

- Three main freeze technologies:
  - Active Freezing,
  - Passive Freezing (thermosyphons), and
  - Hybrid freezing systems.

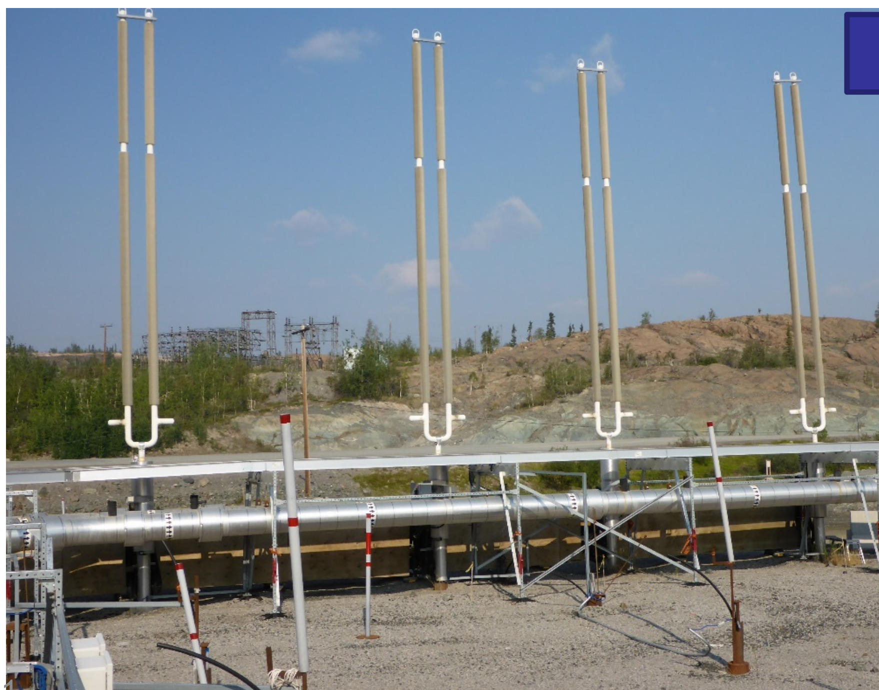
- Active Freezing
  - 4.5” freeze pipe;
  - 3.0” freeze pipe
  - Parallel connection between pipes;
  - Serial connection between pipes.

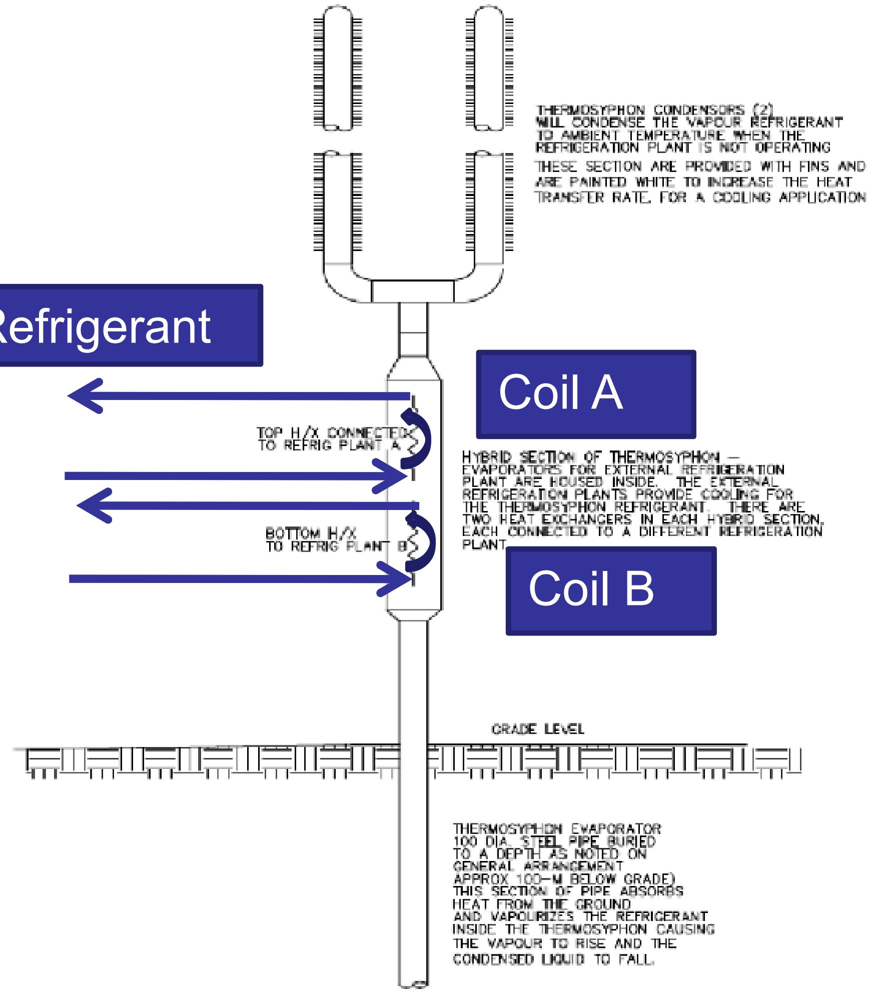


- Passive Thermosyphons
  - 4.0” pipe diameter
  - 3.0” pipe diameter
  - 2.5” pipe diameter



- Hybrid Thermosyphons
  - 4.0” pipe diameter
  - 3.0” pipe diameter
  - 2.5” pipe diameter





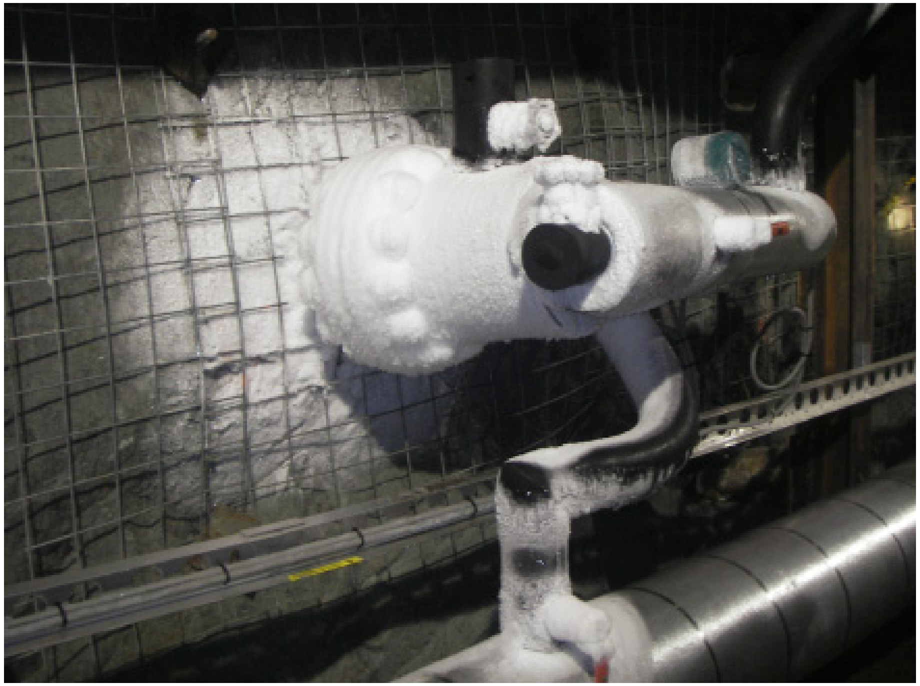
- Drilling freeze holes

- Installing freeze pipes

- Installing thermosyphons

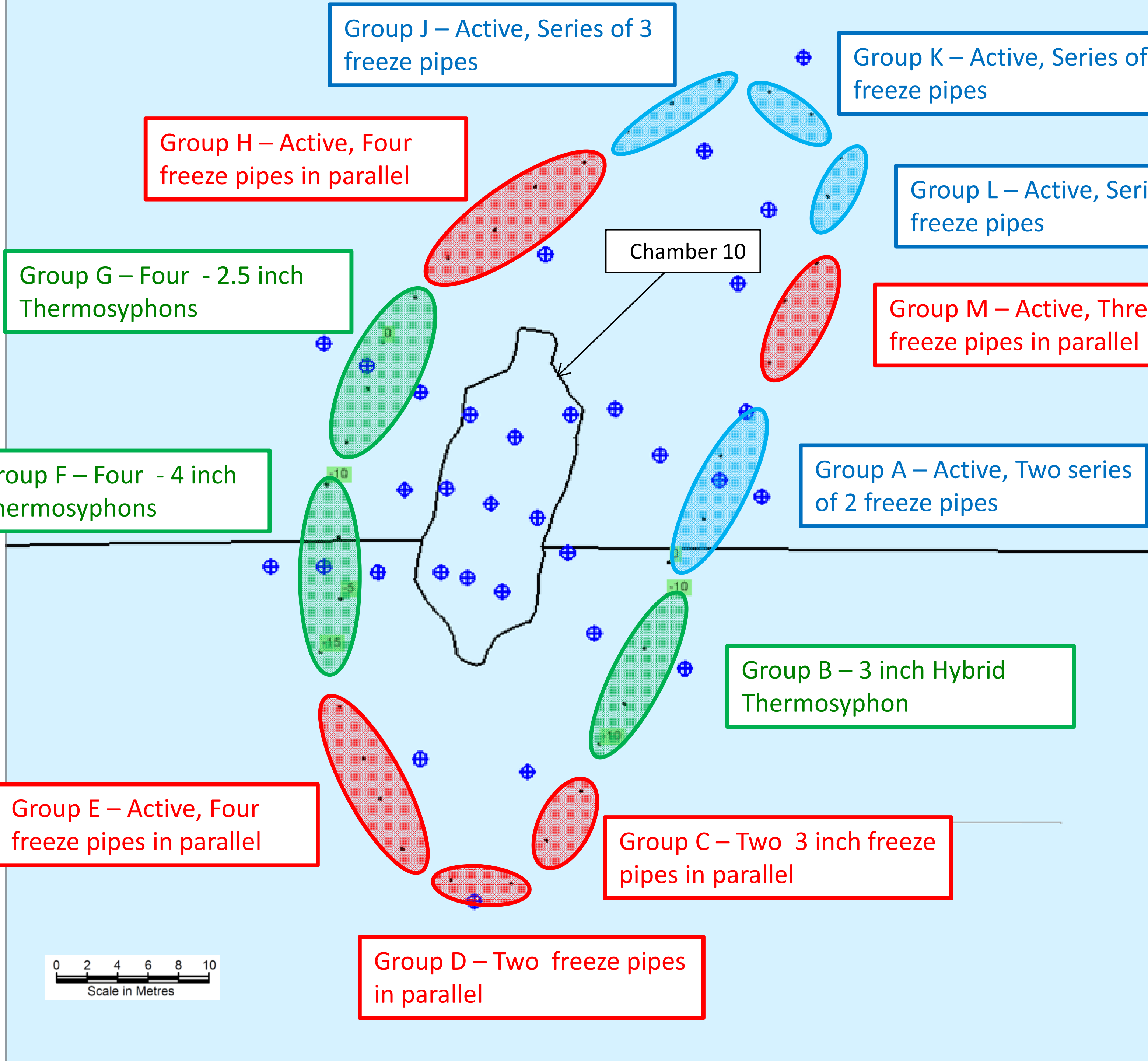
- Freeze plant

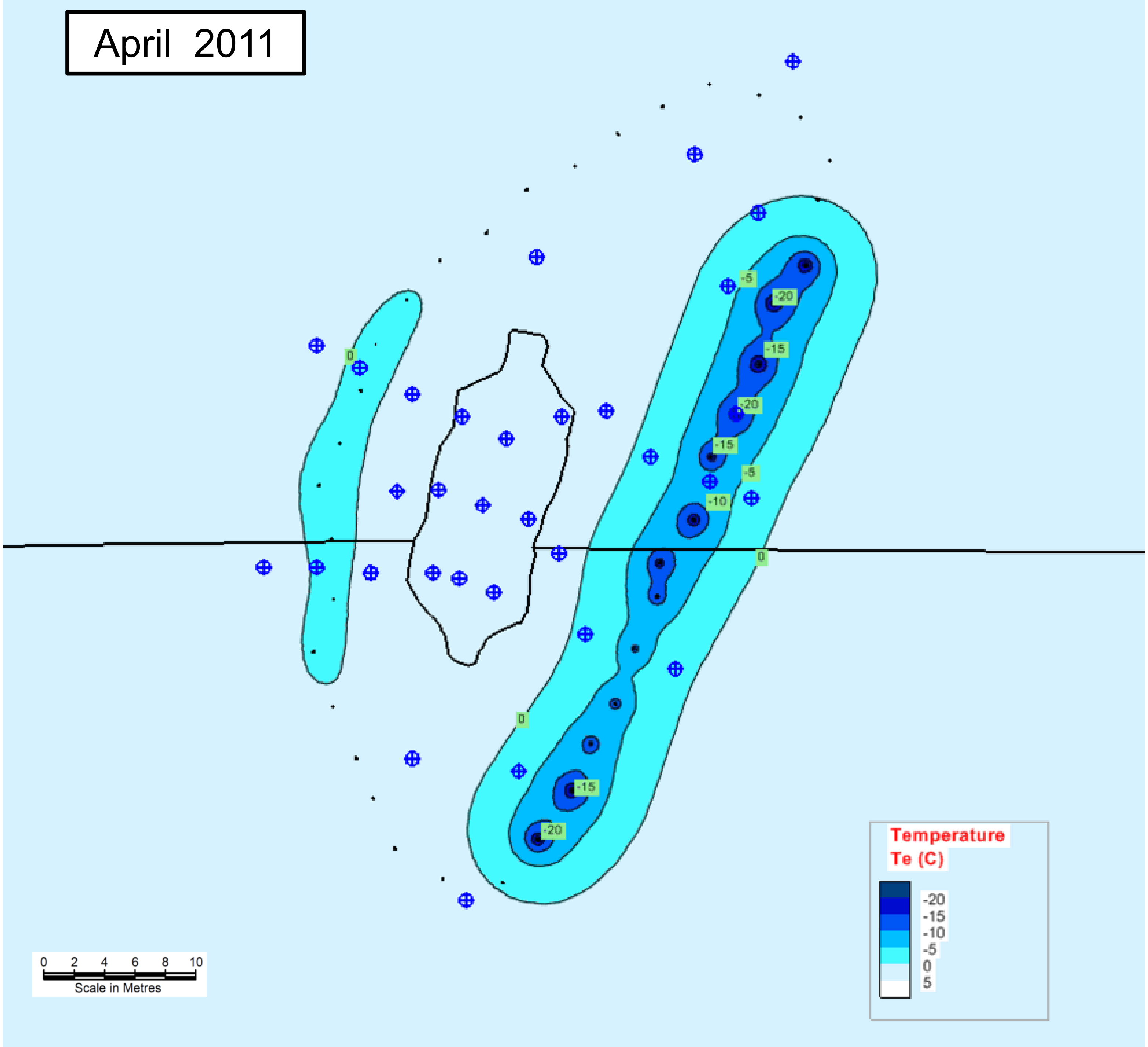
- Coolant distribution piping



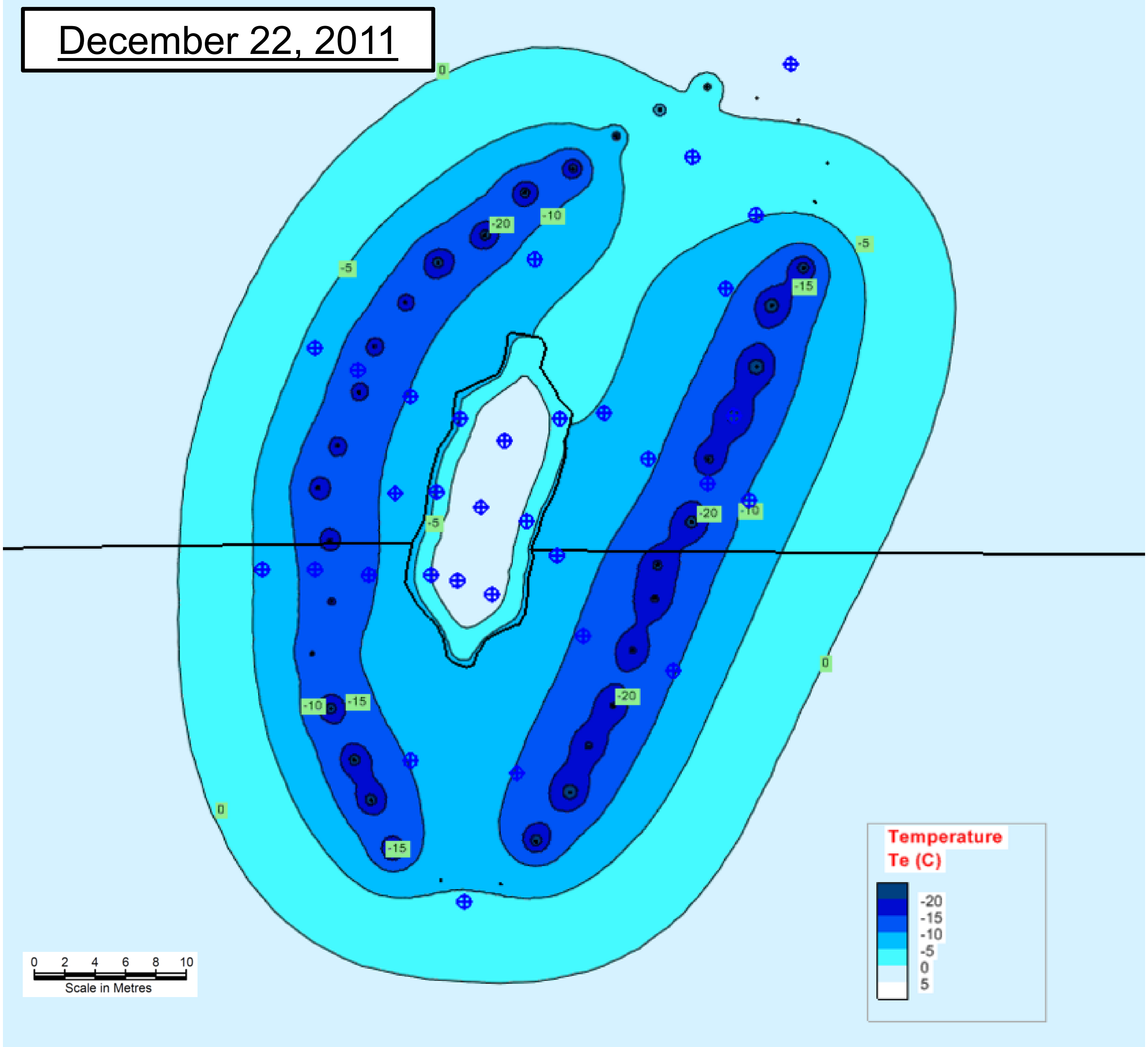
– Underground tunnel below Chamber 10 in March 2011

– Same tunnel in September 2011

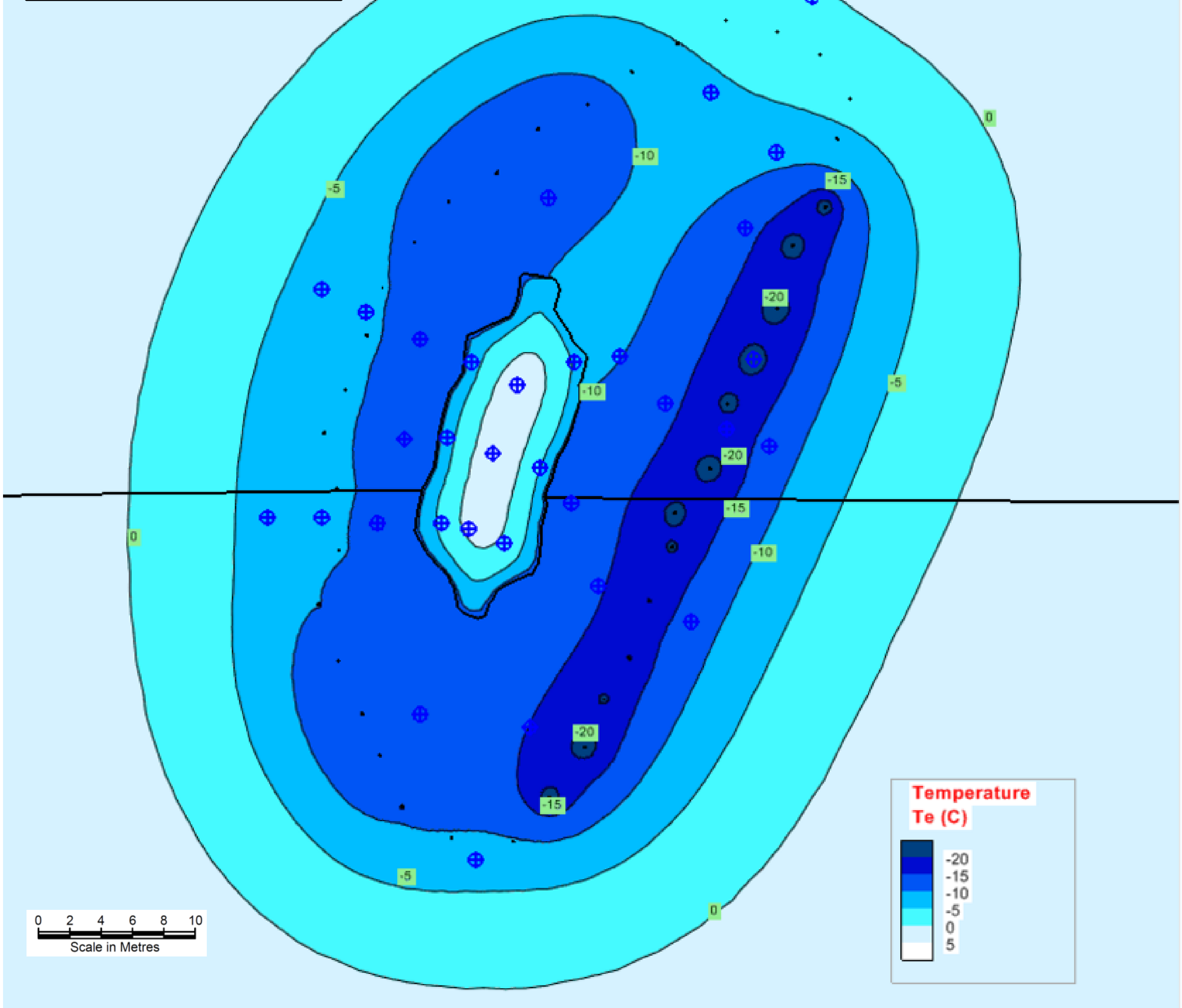

Group J – Active, Series of 3 freeze pipes
Group K – Active, Series of 2 freeze pipes
Group H – Active, Four freeze pipes in parallel
Group L – Active, Series of 2 freeze pipes
Chamber 10
Group G – Four - 2.5 inch Thermosyphons
Group M – Active, Three 3 inch freeze pipes in parallel
Group F – Four - 4 inch Thermosyphons
Group A – Active, Two series of 2 freeze pipes
Group B – 3 inch Hybrid Thermosyphon
Group E – Active, Four freeze pipes in parallel
Group C – Two 3 inch freeze pipes in parallel
Group D – Two freeze pipes in parallel
0 2 4 6 8 10
Scale in Metres


April 2011
Temperature
Te (C)
-20
-15
-10
-5
0
5
0 2 4 6 8 10
Scale in Metres
-5
-20
-15
-20
-15
-5
-10
0
0
0
-15
-20

December 22, 2011

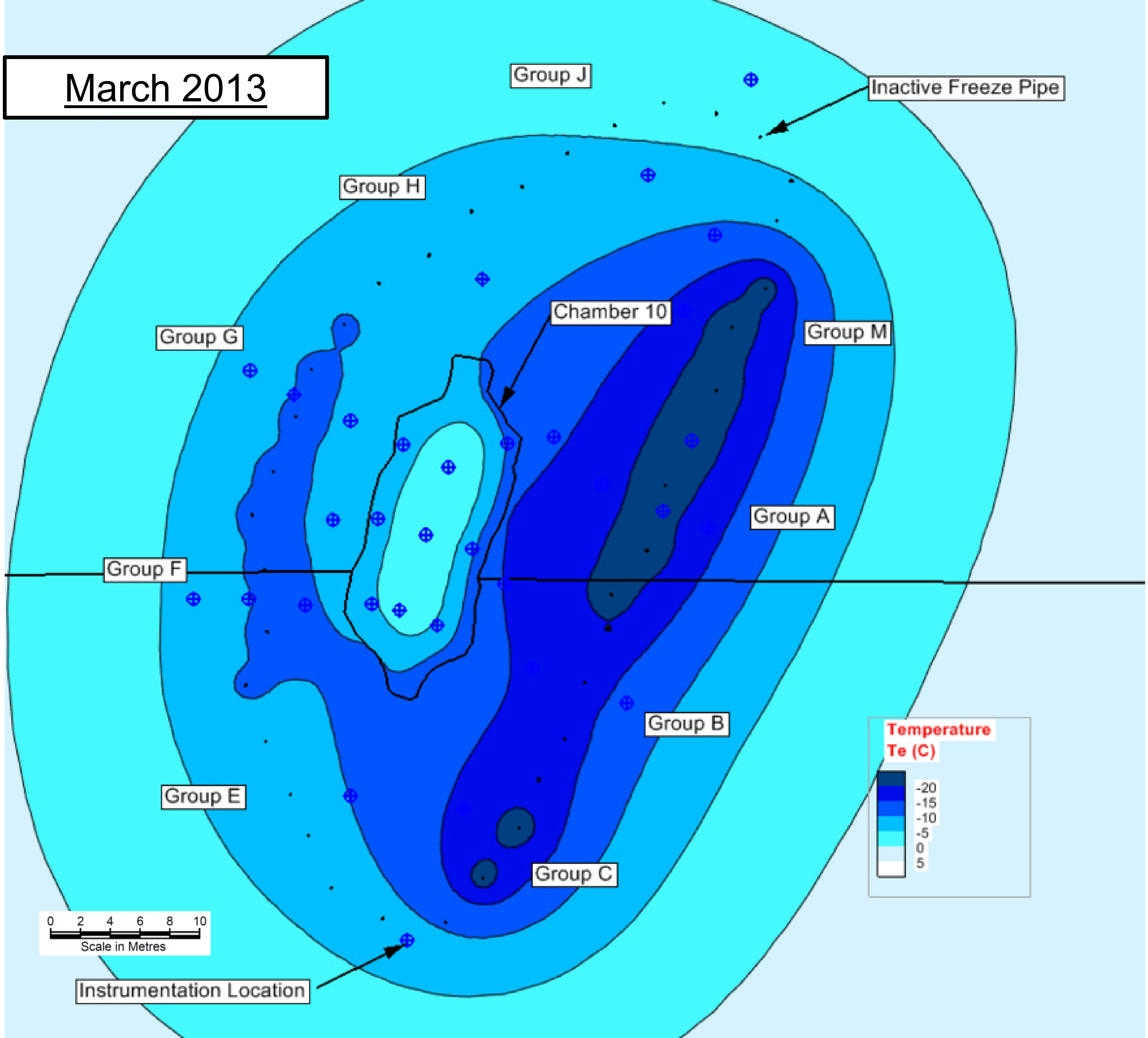


June 2012



0
-5
-10
-15
-20
-20
-10
-5
-15
-20
-15
-10
0
-20
-15
-5
0
0 2 4 6 8 10
Scale in Metres
Temperature
Te (C)
-20
-15
-10
-5
0
5

March 2013



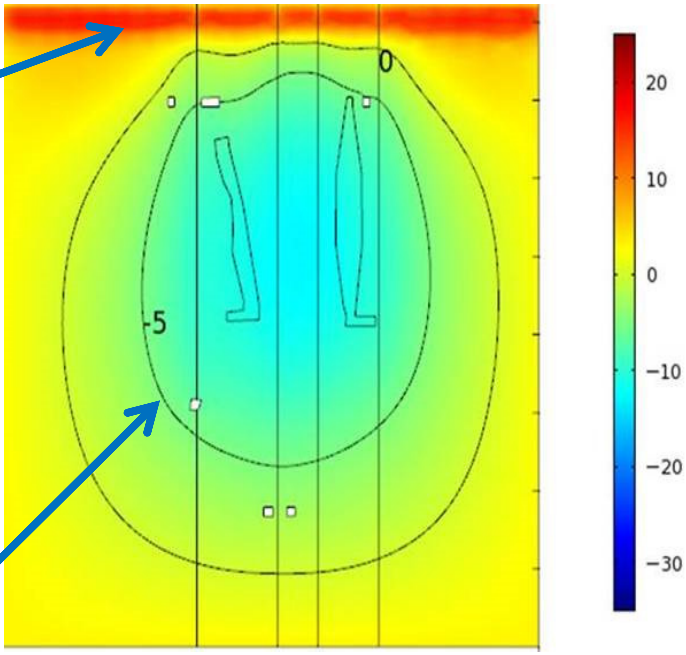
Group J
Inactive Freeze Pipe
Group H
Chamber 10
Group G
Group M
Group A
Group F
Group B
Group E
Group C
Instrumentation Location
Temperature
Te (C)
-20
-15
-10
-5
0
5
0 2 4 6 8 10
Scale in Metres

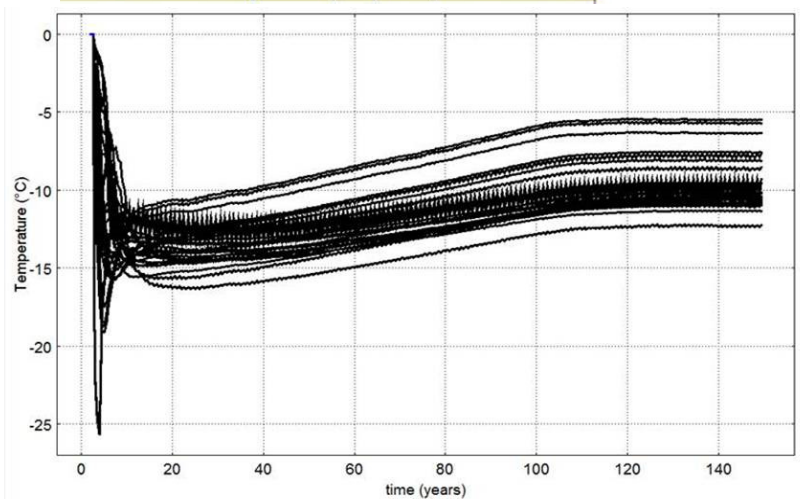
4. FOS Findings

- Calibration of thermal model parameters
  - Bedrock and dust thermal properties
  - Boundary conditions (climate, ground surface geothermal gradient)
  - Efficiencies of the freeze systems
    - Heat transfer efficiency
    - Plant and instrumentation reliability
- Design optimizations (drilling method, pipe diameters, and pipe layout)
- Trade-off studies

- **Severe climate warming (+6⁰C increase to the mean air temperature)**
- **Passive freezing (thermosyphons) only**
- **Thermosyphons maintain the frozen block**

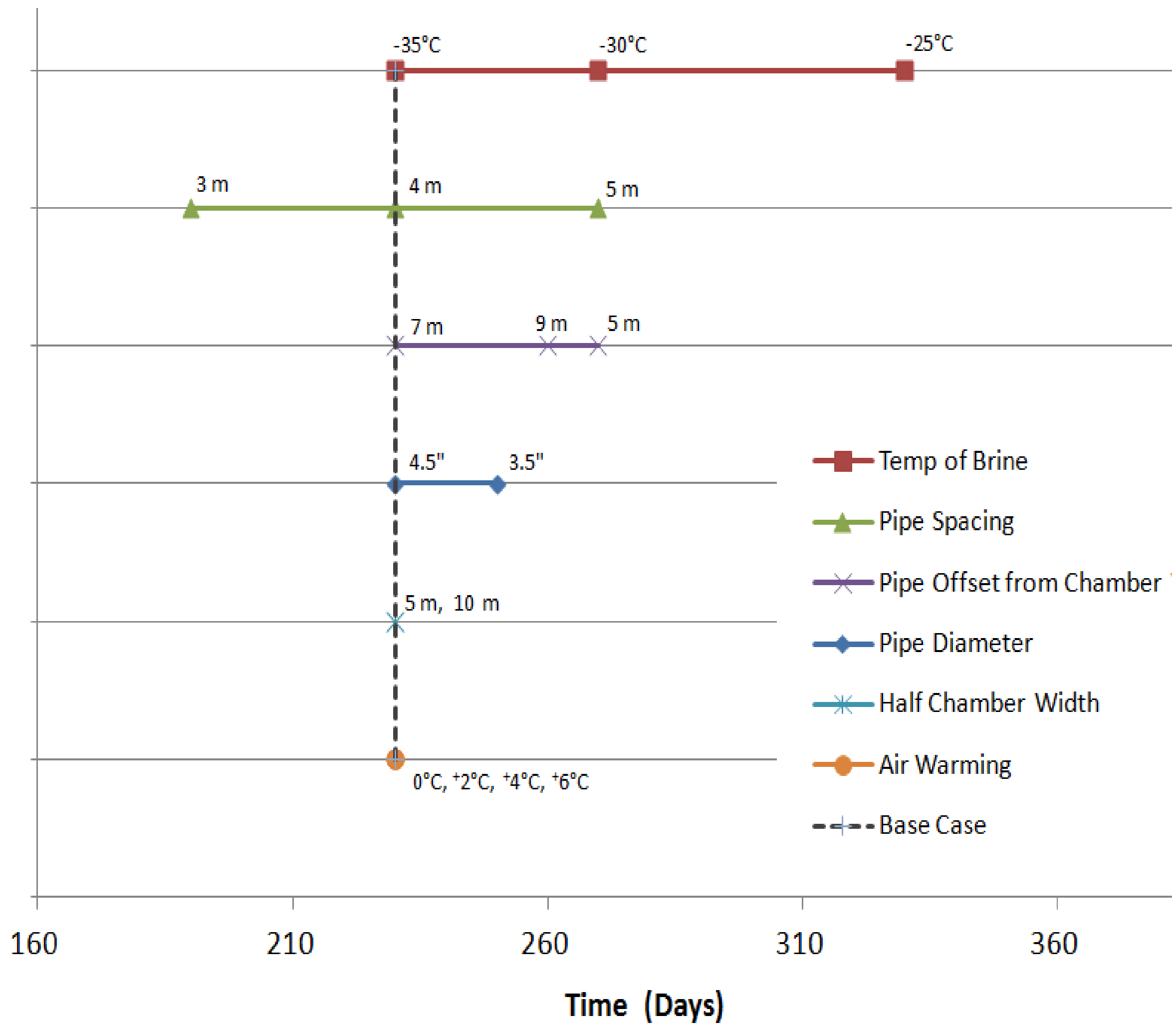
- **Ground surface gets quite warm in summer**
- **Dust remains at -5C**





Sensitivity of initial freezing times to design choices

- Time to complete frozen wall
- -10ºC or colder
- 10 m wide



Trade-off Studies

- Evaluations of significant design choices
  - Wet vs. dry frozen blocks
  - Freezing from surface & underground vs. surface only
  - Freezing rate
  - Methods of active to passive conversion
  - Active vs. hybrid vs. passive
  - Surface amendments/treatments

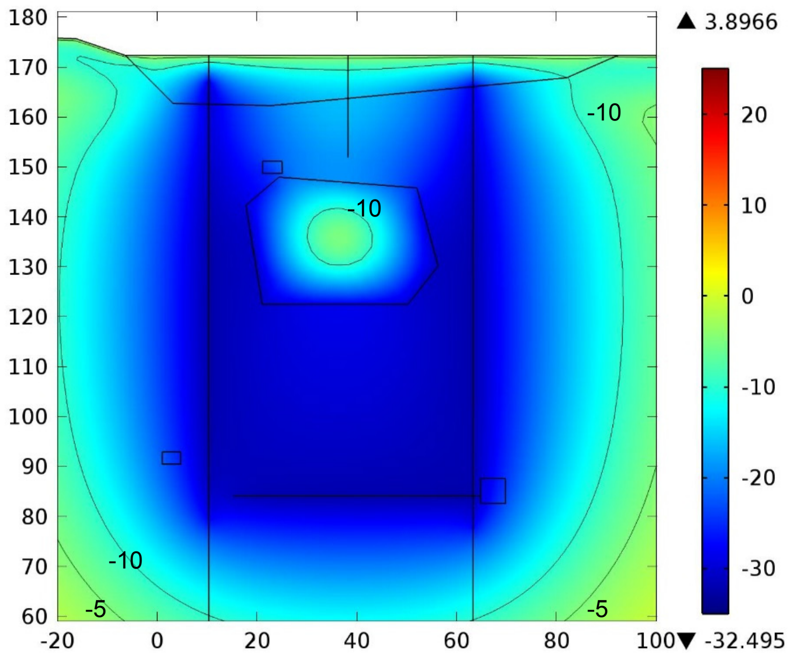
Trade-Off Study #1 - Wet vs Dry Frozen Blocks

- Wet Frozen Block Method:
  - Ground around each chamber is cooled until a -10°C 10m thick freeze wall is established
  - Arsenic dust is wetted
  - Active freezing continues until the dust reaches -5°C
  - Freeze pipes are converted to passive thermosyphons
- Dry Frozen Block Method:
  - Same as above except the wetting step is omitted

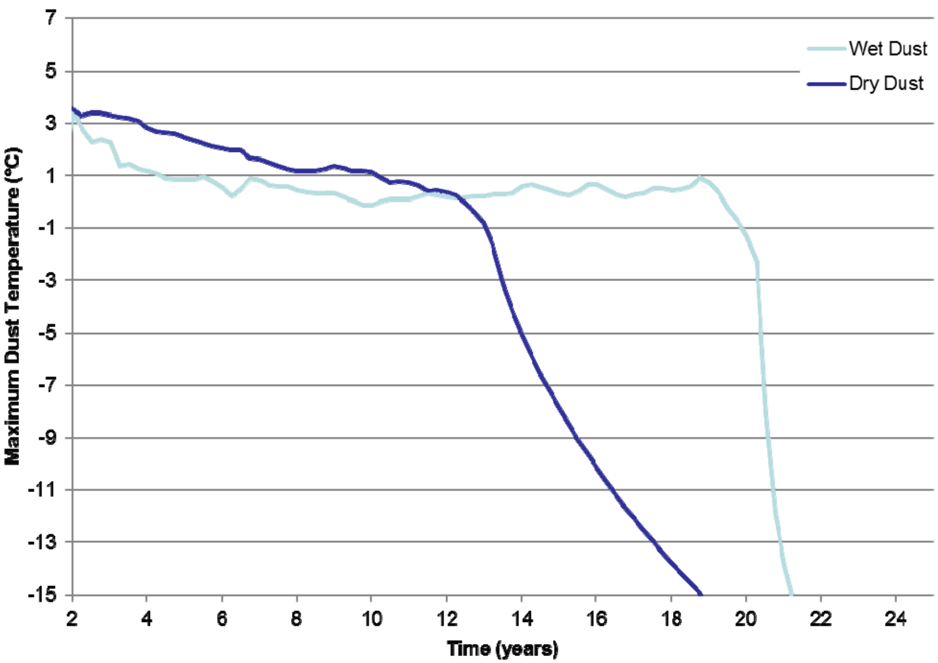
Trade-Off Study #1 - Wet vs Dry Frozen Blocks

– Dry frozen block freezes 3-7 years faster

– Dry cost $23.1 million less than wet



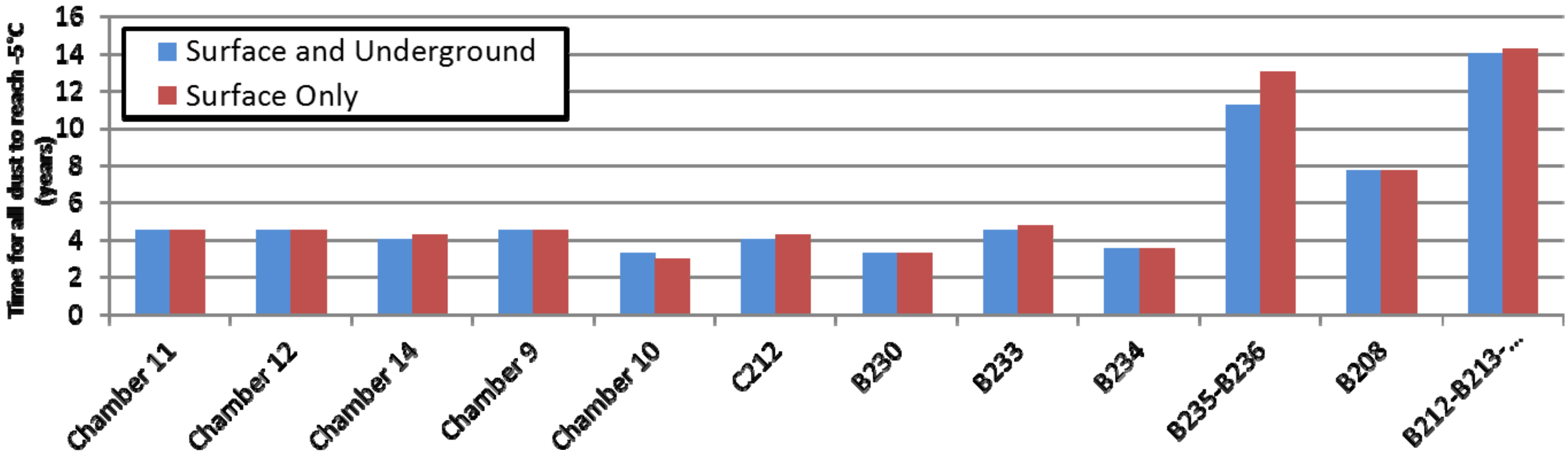
Dry frozen block after 14 years of active freezing, when all areas of the dust have reached -5°C (completion of active freeze period)

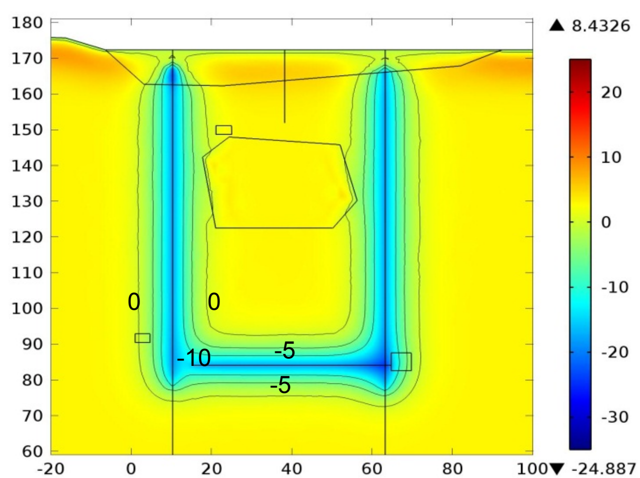


Trade-Off Study #2 – Surface & Underground Freezing Vs. Surface Freezing Only

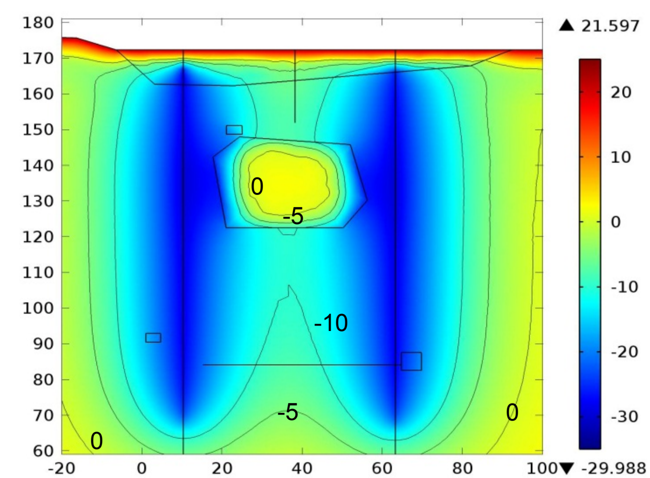
- Surface and Underground Freezing:
  - Vertical freeze pipes extend 10 m beyond dust
  - Horizontal freeze pipes below chambers
    - Requires underground development
- Surface Only Freezing:
  - Vertical freeze pipes extend 20 m beyond dust
  - No horizontal freeze pipes

Trade-Off Study #2 Surface Vs. Underground Freezing





Surface and underground method at 0.5 years, when a -10°C freeze wall has been established.



Surface only method at 5.25 years when a -10°C freeze wall has been established.

Northwest Territories Canada

Other Trade-Off Study Results

Study Name	Description / Outcome
Method of conversion from active freezing to passive freezing	1. Insert a new thermosyphon pipe inside each freeze pipe. 2. Clean each freeze pipe and attach a thermosyphon radiator on top of each pipe. • Option 1 is less complex, proven, and less costly.
Hybrid freezing rate of cooling	• Study compared life cycle costs for two types of hybrid thermosyphon units • No significant difference
Active freezing vs. hybrid thermosyphon vs. freezing vs. passive thermosyphon freezing	• Full scale design will use a combination of freeze technologies. • Larger chambers will require active freezing to minimize the overall freeze durations. • Some of the smaller chambers can be frozen passively in the same time as the larger chambers are frozen actively.
Surface Amendments	• Evaluated potential for fill or additional thermosyphons to be placed at surface in order to reduce the amount of pipes around the perimeter of the dust. • Shallow thermosyphons installed directly over the dust found to be most effective.

Current Design

- Dry frozen blocks
- Freezing from surface only
- Larger chambers and stopes actively frozen
- Smaller chambers passively frozen

Thank-you for your attention