Physics in Mining
A Career Perspective

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Where do physicists come in?

Both of my grandfathers were miners for INCO and they would be proud to see where I stand in this industry today.

We were asked to discuss our career paths involving physics in the mining industry.

Mining is a complex undertaking, the projects involve discovery, usually by geologists/prospectors, verification by geologists and engineers, financing by engineers, lawyers, investors and accountants and the construction of the mine engineers, MBAs, technicians, technologists and a host of contractors with specialised talents.

After that, the mine must be operated for the predicted LOM, but often new discoveries will revise the LOM.

Where do physicists come in?

Thermal Stress!!

There are two areas in mining where physics is obviously at the root of the knowledge

Firstly Mine Thermodynamics, which is the assessment and abatement of heat and providing of ventilation to remove particulate matter, various contaminants and heat to create an acceptable working environment.

The second is geotechnical, this includes the determination of stress and redistribution of stress in the rock and the measures referred to as ‘Ground Control’ to keep openings stable. This involves tensor analysis and the solutions are similar to those in electromagnetic theory.

There are numerous other aspects of physics in mining.

Syed Naeem Ahmed

Naeem started his career in his home country of Pakistan as a theoretical physicist. During Naeem’s Masters project, he worked on modelling the human brain by looking at calculating the change in EEG natural frequencies in space. This was done by building a background Lorentz transformation matrix using Einstein's weak field approximation.

The basic idea was to write coupled harmonic oscillator equations in the co-moving frame of the signal, through neurons, and then transform those in the lab using the Lorentz transformation.

Syed Naeem Ahmed

Following that project, as many theoretical physicists do, he struggled to get a position in an academic environment. He eventually decided to join the Centre for Nuclear Studies, which was a premiere institute in Pakistan. He graduated with a Masters Degree in Nuclear Engineering degree and was awarded gold medal for the highest achievement. While there, he learned quite a great deal about Radiation Physics and had the opportunity to work on the Physics of transient behaviour of the nuclear core. It was rewarding and interesting work.

Syed Naeem Ahmed

He then got a scholarship to do his PhD in Germany and joined Siegen University. By that time, his interest with Nuclear Engineering had waned, for various reasons, and he wanted to continue to work in Physics.

He decided to work in high energy physics. For his PhD he developed a high precision ionization chamber to determine the limit of quantum fluctuations.

It was a very exciting and demanding work.

Syed Naeem Ahmed

Right after completing his PhD, he was offered a position at the Max-Planck-Institute for Physics in Munich to work on the Hera-B experiment at Deutsches Electronen-Synchrotron, Hamburg and he worked there for about a year until he was offered a position at Fermilab. While there, he worked on the DZero experiment. During both of these engagements, he worked heavily on silicon detector Physics and the physical development of said detectors, he was also involved in radiation and particle Physics.

Syed Naeem Ahmed

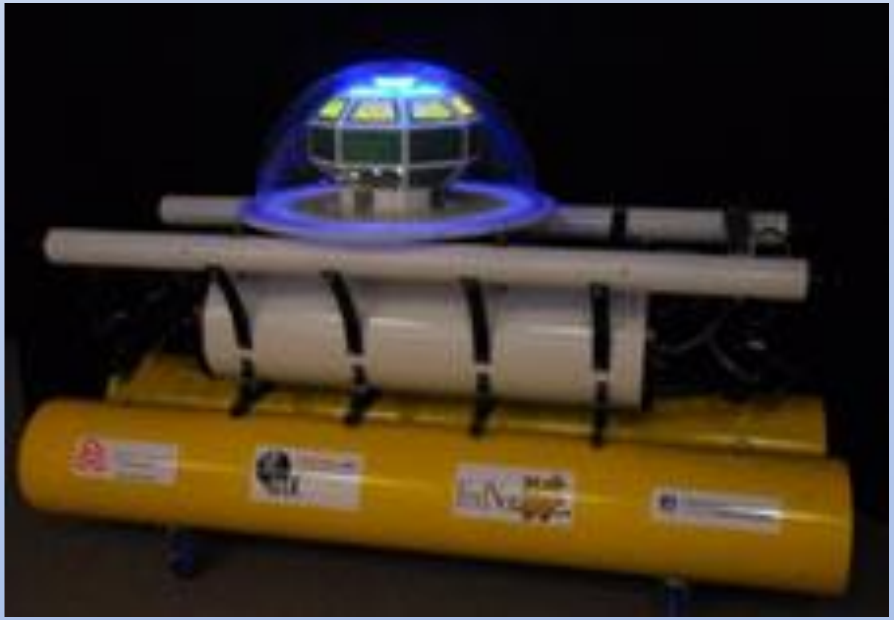
In early 2003, he joined the SNOLab in Sudbury. He worked there for about 5 years looking after the main detector. This was his first experience working in an active mine. He was fascinated and challenged by the work. Looking after a 10k channel detector with complicated electronics was very challenging. He was always on call and would sometimes get called in the middle of the night to solve a problem. The work itself was very exciting with challenging tasks such as figuring out from where noise was getting into the system and understanding asymmetries in Cherenkov light cone.

An Unexpected Sleep Over:

Once we had to stay underground overnight due to sudden seismic activity triggered by controlled blasts underground.

Syed Naeem Ahmed

When the SNOLab experiment was over, he joined a private company in Sudbury and worked on developing cutting edge technologies, such as light modem for underwater communication.



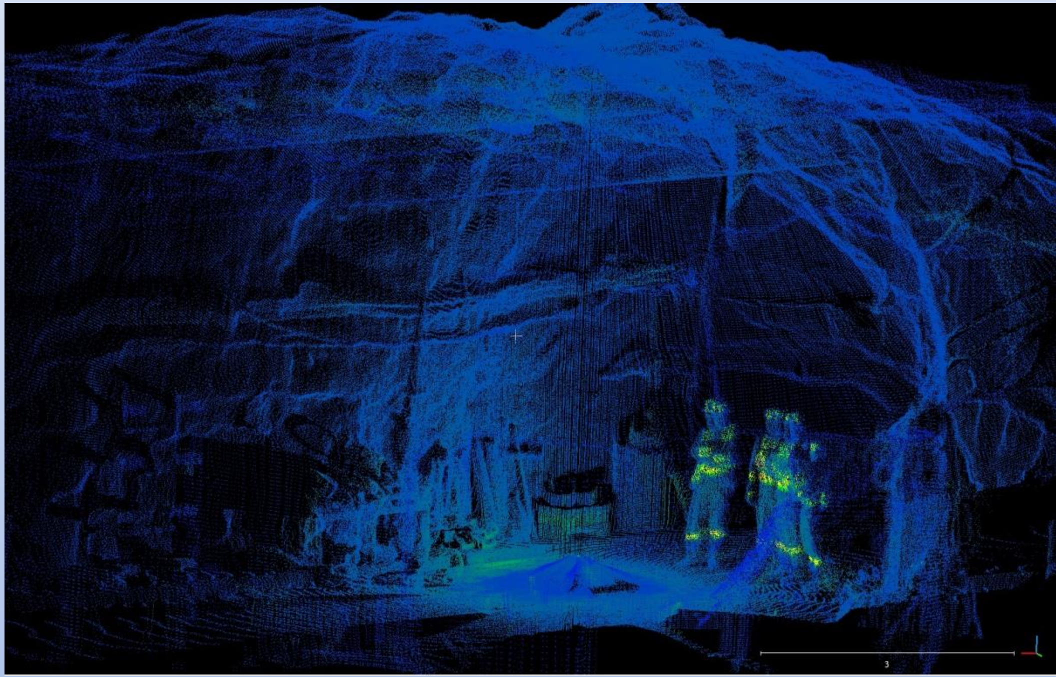
Syed Naeem Ahmed

After about 3 years working there, he joined a larger company in Sudbury as the head of their automation department. They worked on several innovative projects including a collision avoidance system using RFID technology and development of a fully automated 9-axis drill boom jumbo for underground mines. This involved development of mathematics for inverse kinematics calculations, simulations and control algorithms.

Syed Naeem Ahmed

In late 2013, he established Clickmox Solutions in Sudbury with the main objective to develop disruptive technologies for the mining industry. They are now known as pioneers in bringing forward drone-based 3D laser scanning and mapping solutions to the industry. We have developed a number of other products as well, most of which are related to stationary and mobile 3D laser scanning and mapping underground mine openings.

Syed Naeem Ahmed



Physics is still at the foundations of his work and he utilizes the principles and methodologies he learned in Physics for the development of these technologies and methods. With the digital mine concept now being aggressively pursued by the mining industry, more and more Physicists will be needed to develop cutting edge technologies, process massive amounts of data and create safer and more productive mines.

Steffon Luoma

Steffon's first exposure to mining was as an undergrad summer student at BESTech a private engineering company in Sudbury. He was responsible for programming programmable logic controllers (PLC) and human machine interfaces (HMI). This was mainly using digital logic and a little bit of electronics. He also authored some data acquisition software to populate a database with drilling data for analysis to help with process improvements.

Steffon Luoma

Later during his time as an undergraduate he was fortunate to get a student job at SNO. During that time he worked on refinements of the control monitoring and alarm (CMA) system that monitored the lab's environmental state – things like temperature and humidity. He continued his career by earning a Masters degree in Physics from Laurentian University.

Steffon Luoma

During Steffon’s degree work he investigated methods of identifying electron anti-neutrino's from a modelled supernova in SNO during the salt phase. The charged current interaction between the electron anti-neutrino and the deuterium nuclei results in a signal that can be distinguished from other signals
(2 neutrons and 1 positron).

Steffon Luoma

This unique signal makes it possible to identify and count the number of electron anti-neutrinos. Monte Carlo models were used to simulate the numbers of neutrinos arriving at the detector as well as how the detector would respond. The results of these simulations were used to develop an event-by-event method that classified and counted the number of electron anti-neutrinos.

Steffon Luoma

After graduation he spent a short time designing a system and procedure to decommission BF_3 neutron counters, the task was to design a system to safely neutralize and dispose of the gas.

In 2008 he began a position with at a private engineering company that designs solutions for the mining industry. During the next 7 years he developed a suite of software for the tele-operation of mobile robotic mining equipment. This included sensor, control, and communications software and hardware. He managed a team of engineers, computer scientists and mathematicians.

Steffon Luoma

Because the location of the remote machine is as important as the information the sensors are feeding back to the operator and since GPS signals don't reach underground a big part of his work focused on inertial navigation systems using ring laser gyroscopes to locate the position of the mobile equipment in 3D sub-surface space and to a lesser extent SLAM (simultaneous location and mapping algorithms) to aid in the underground navigation.

Steffon Luoma

Steffon helped design vision systems to assist the operator increase their perception and improve the operation of the machine. He experimented with neural network and fuzzy logic for semi-autonomous operation of the machine – this would allow the operator to offload some of the more mundane and repetition heavy tasks to the robot. There was work in radio communications and laser scanning systems.

Currently Steffon is developing systems to help manage heat stress for miners working in the hot environment ultra-deep mines. One of these systems is a non-invasive heat strain estimation algorithm. He and his colleagues wirelessly operated the robots at a distance of ~2km away from the control station, to keep the operator out of harms way. This was mostly system integration work but involved an understanding of RF propagation.

Steffon Luoma

The output from this can be used simply to warn the miner, so that they might alter behaviour or, more interestingly, it can be used to control a personally worn cooling system. Another system he is designing is an active cooling vest that is untethered and automatic. If you let the miners control the system, there is a real risk of them setting it to max and overcooling. This could end up being worse than having no system at all. This has resulted in a collaboration with scientists, engineers and specialists from a wide range of fields, from physiologists, electrical engineers and all the way down to fashion designers.

The SNO Man

My first real job in physics was working on SNO, just as I was completing my Masters in Physics, I graduated about 6 months after starting. Prior to that I had worked for various government ministries.

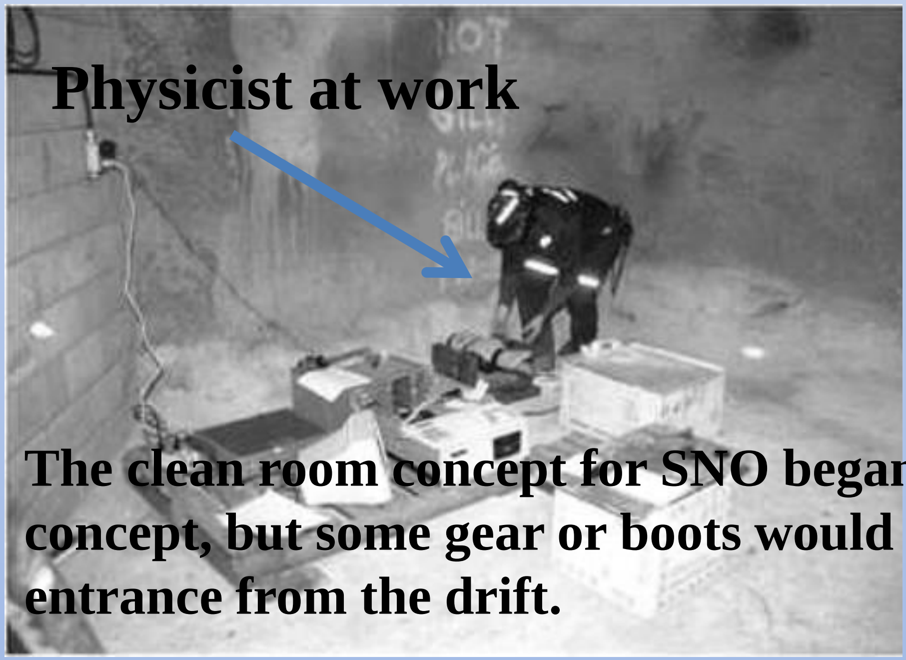
It was at SNO that began my physics in mining journey.

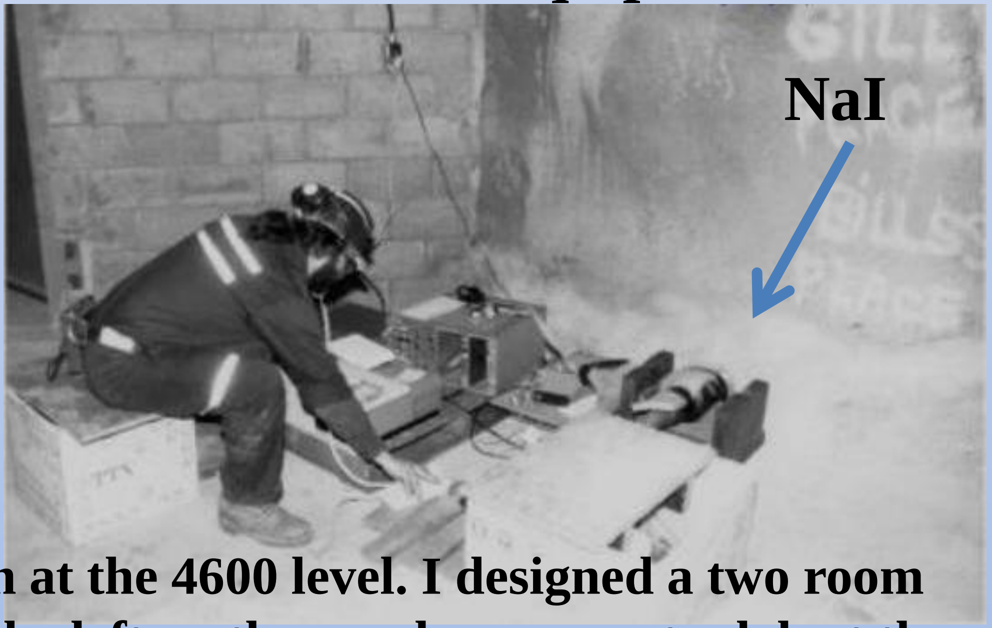
The construction phase of SNO was essentially a mining project with the added bonus of collaborators from the world over conduct numerous verification exercises, experiments or even develop new technologies or materials.

At LU I would use all of the science labs – they called me ….

4600 L Lab

One of the interesting things I did at SNO was build the clean room at the 4600 level of Creighton Mine. It was my responsibility to supervise the daily operations and commission the equipment.

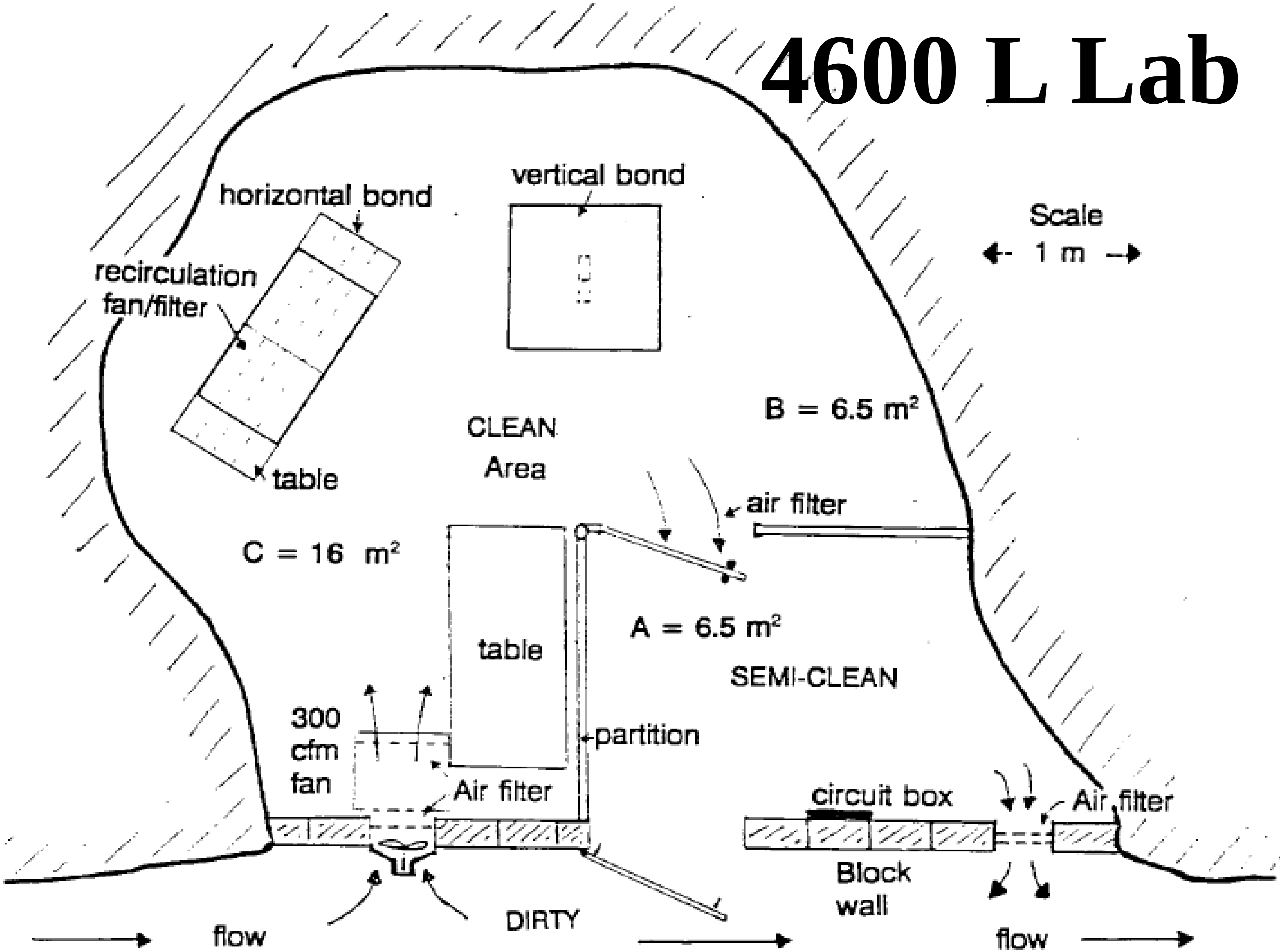




The clean room concept for SNO began at the 4600 level. I designed a two room concept, but some gear or boots would be left on the porch, a concrete slab at the entrance from the drift.

The entrance was the ante room, where we changed from mine clothes to cleanroom garments like running shoes and funny hats, second room was the cleanroom proper. It was there that the verification trials took place.

4600 L Lab



vertical bond
horizontal bond
Scale
1 m
recirculation
fan/filter
B = 6.5 m²
CLEAN
Area
table
air filter
C = 16 m²
A = 6.5 m²
table
SEMI-CLEAN
300
cfm
fan
partition
Air filter
circuit box
Air filter
Block
wall
DIRTY
flow
flow

4600 L Lab, Acrylic Bonding Trials

The clean room concept for SNO began at the 4600 level. I designed a two room concept. Some gear or boots would be left on the porch, a concrete slab at the entrance from the drift.

The entrance was the ante room, where we changed from mine clothes to cleanroom garments like running shoes and funny hats, second room was the cleanroom proper. It was there that the verification trials took place.

SNO Surface Building

Sometimes you have to stand around and look at things like the cool new rail cars for delivering the PMT and PMTSUP

Apart from supervising the operations of the Lab.

My other responsibilities involved liaising with partner institutions who would visit to test or otherwise evaluate their particular part of the overall scheme.

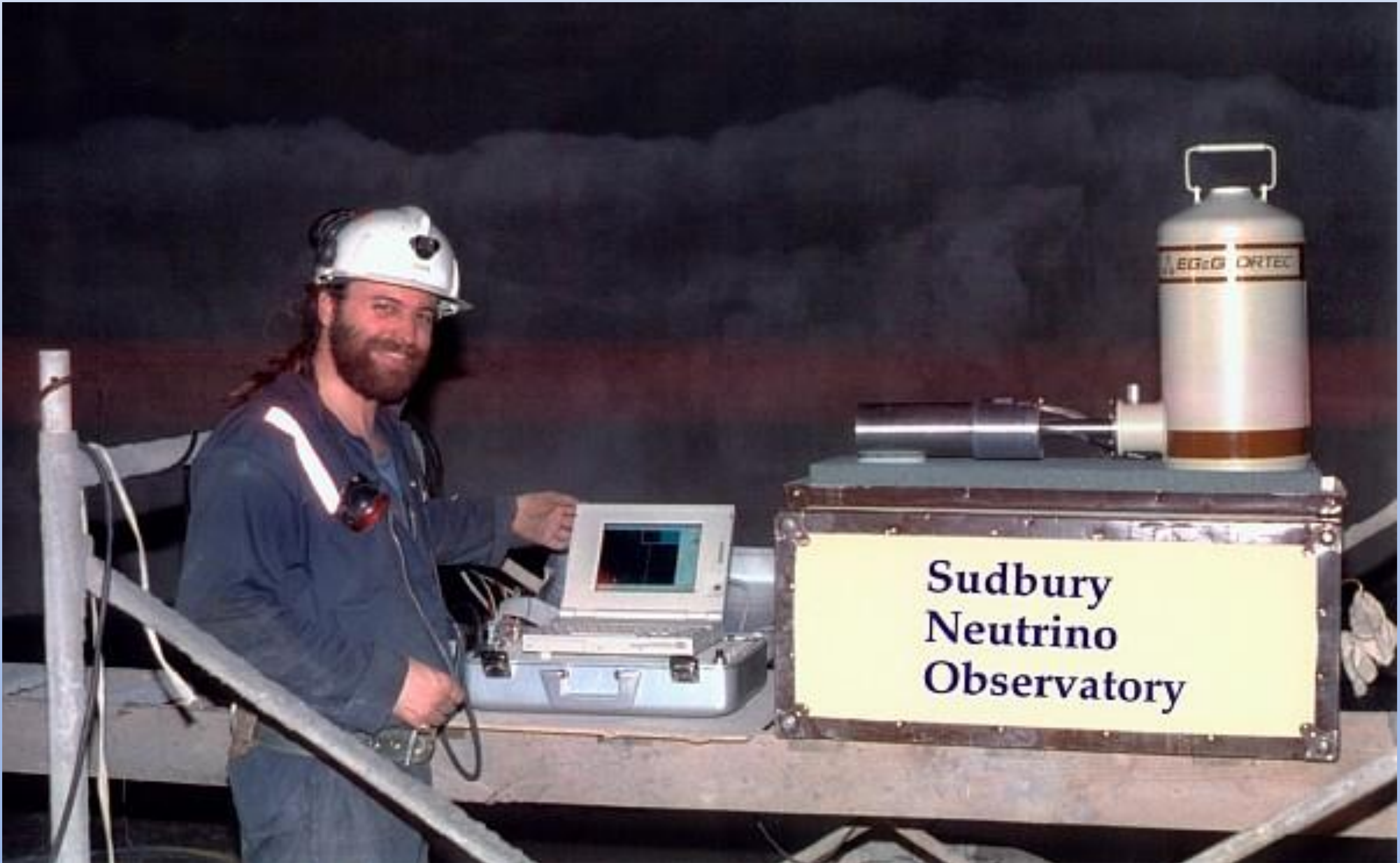
I was the person in Sudbury qualified to go underground unaccompanied by INCO personnel.

Or we might push a rail car.

Some Other Notable Projects

1. determination of Radon present in the mine. A small amount of radon can lead to large problems with regards to the sensitivity of the detector.
2. Several measurements using the typical radon cell and filter basically the same way you would determine the radon in your basement, were performed.
3. In a more sophisticated approach, a number of partners collaborated to develop a means by which we could directly count the radon emanating from the surface of the rock.
    - Secured a stainless steel box to the wall and sealed it with a liquid plastic and epoxy.
    - Purging of the 'radon box' using liquid nitrogen
    - The flow from the so called 'radon-box' was passed through a liquid nitrogen U tube, which collected the radon for transport to Queens University for analysis.
    - Various other measurements relevant to the detector, dust, magnetic fields
    - Invention of a neutron absorbing glass – 1 tonne of glass and tonnes of bricks

Neutron Measurements and Gamma Spectroscopy in the Centre of the Detector Cavity



And now for Something Completely Different

A Frozen Backfill Project.

Can we create frozen backfill for use in permafrost without using cement as a binder?

What’s Backfill – you ask?

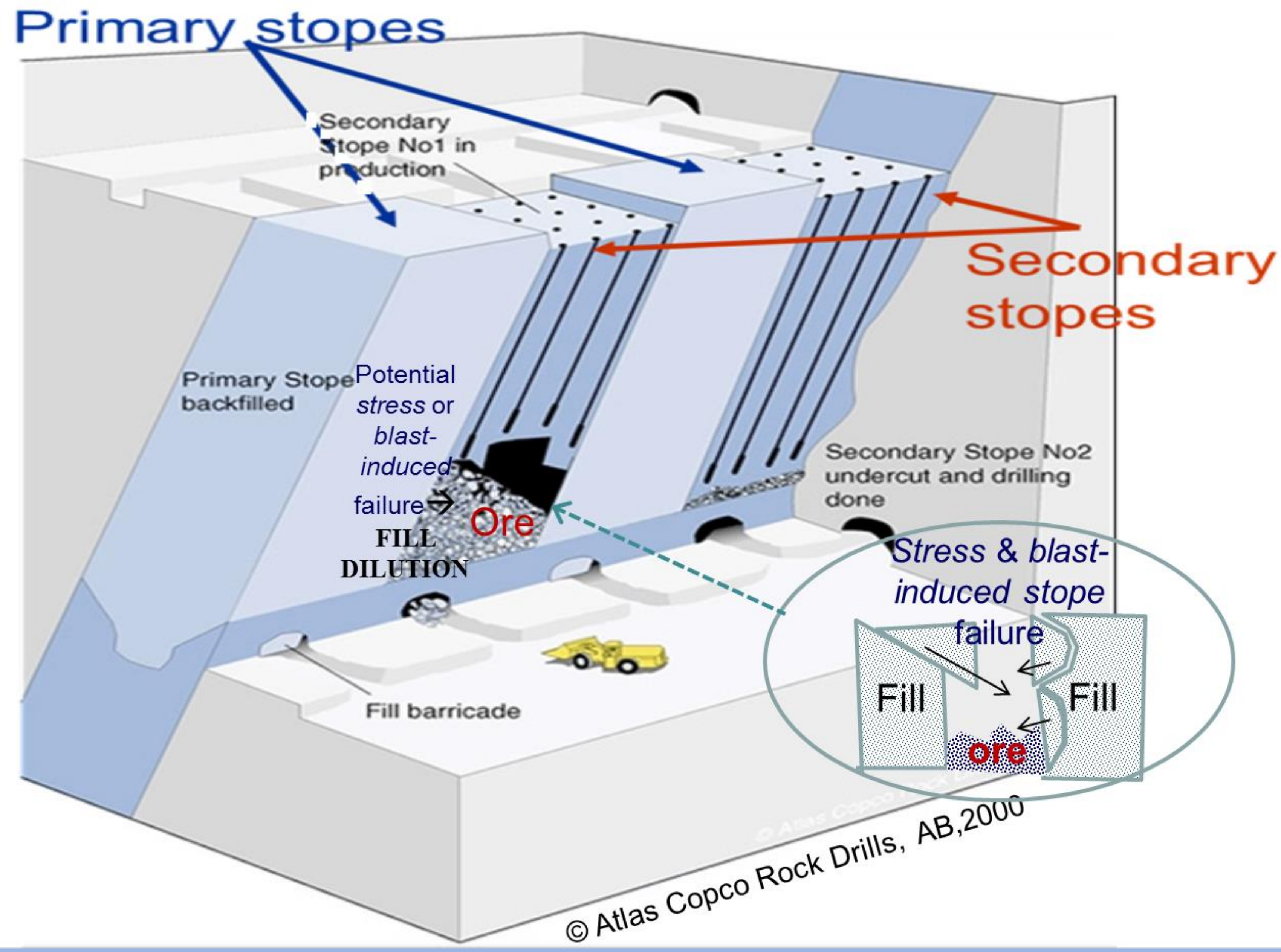
Backfill is the material used to fill a stope in a mine after the extraction of ore.

Frozen Backfill would be used for mines which operate in the permafrost.

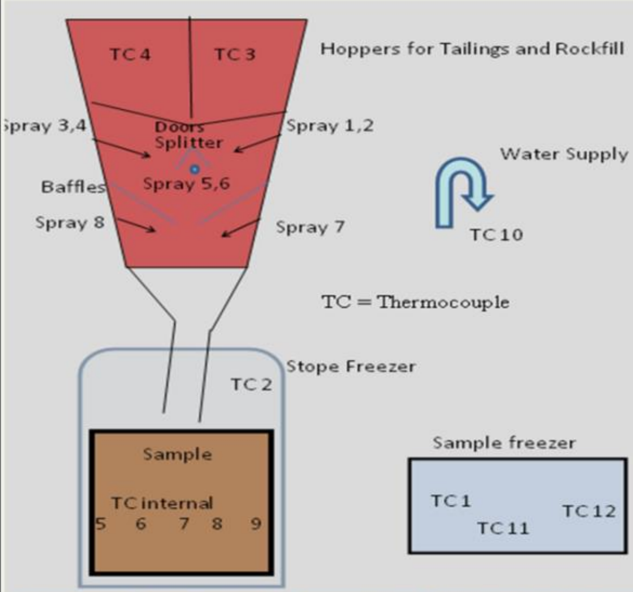
You may have seen on a program called Ice Road Truckers, if we do not have to truck loads of cement to an arctic mining project, the overall benefit to all parties is substantial

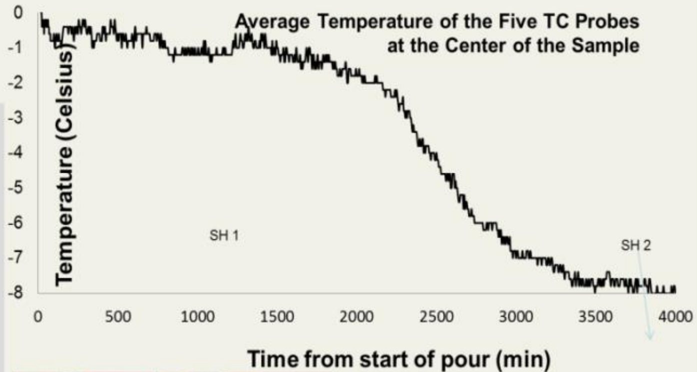
- Cement is an expensive, carbon intensive material
- Removal from the trucking route would open up truckloads for other purposes.

Stopes are BIG!

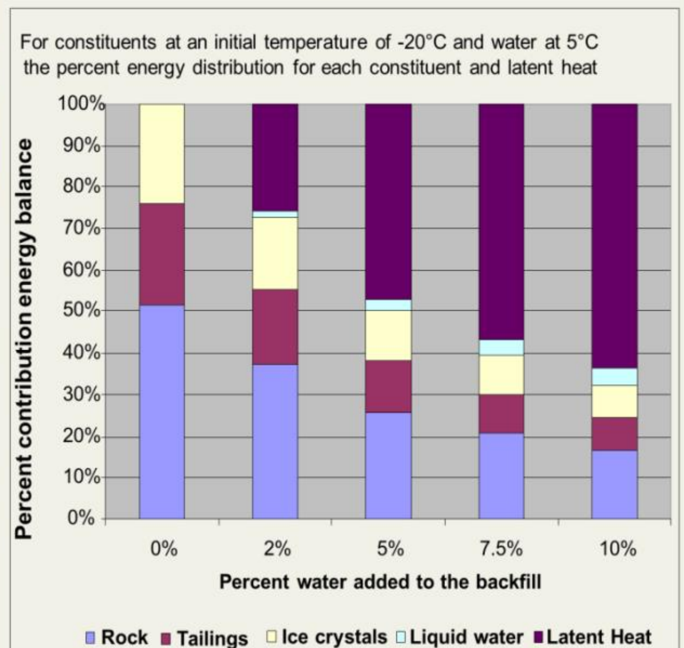


LAB TESTING
Laurentian University Testing Laboratory





Sept 26/08 (60% rockfill/40% tailings) 6% - 7% water



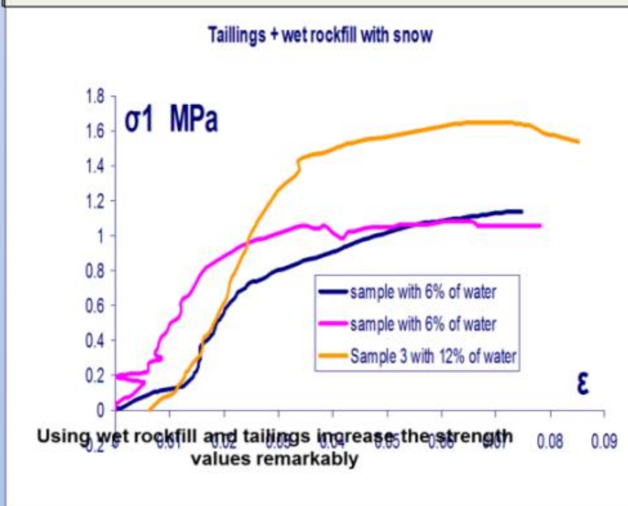
METHODOLOGY - NORCAT TESTING

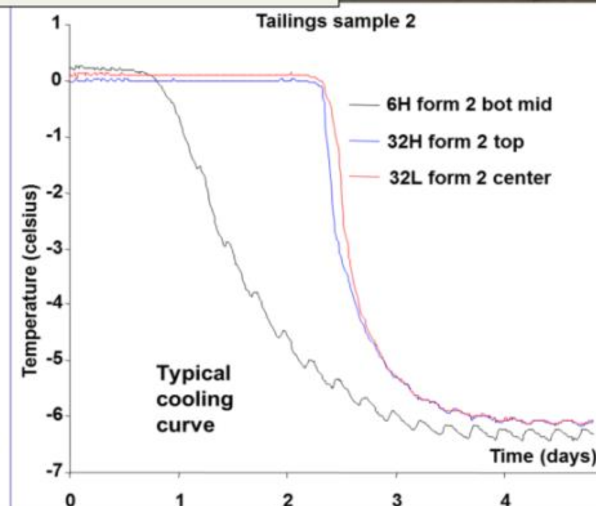
The tests were performed by using cylinder steel forms to make samples 2 ft in diameter and 4 ft high.

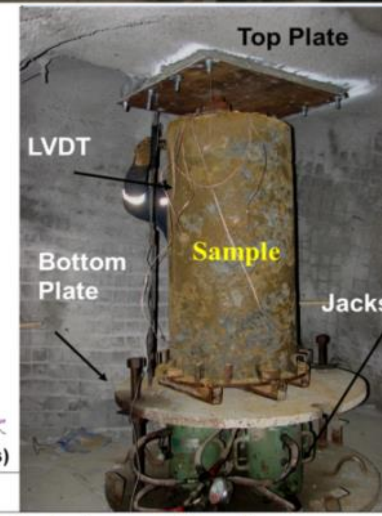
The work included:

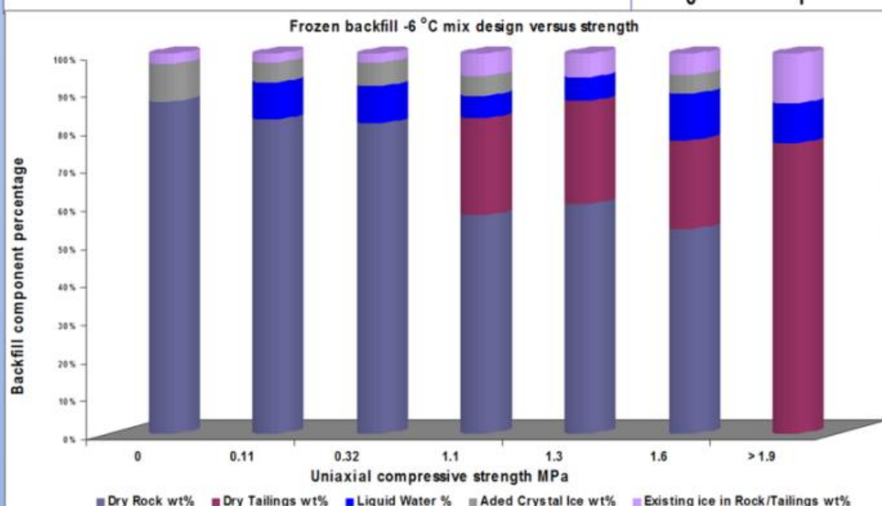
- Use of different mix designs;
- Control of the mixing process;
- Measurement of temperature, cooling times and thermal properties of the samples;
- Uniaxial Compressive Strength tests.

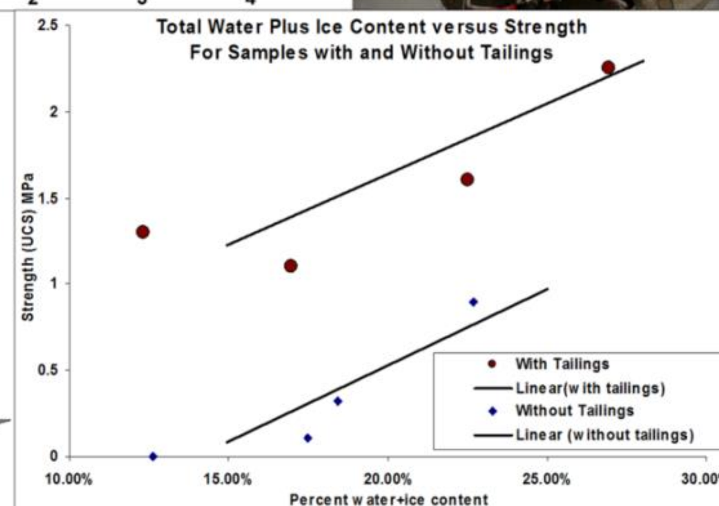
Results





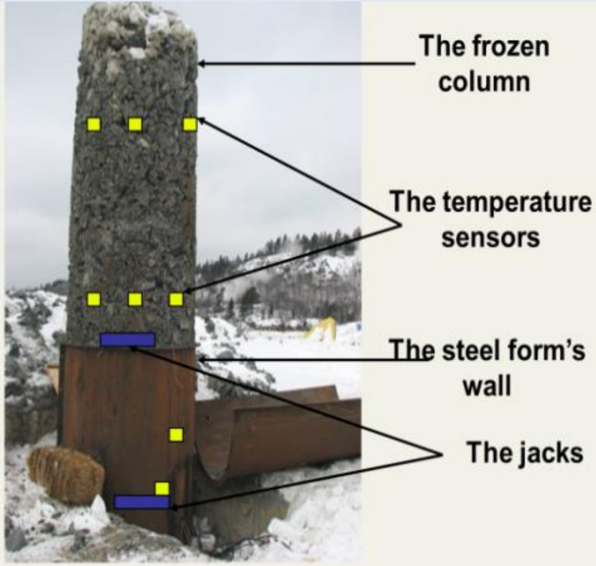






LARGE FORM TESTING AT NORCAT

The frozen backfill mixture of rock, ice and water dumped into the large form

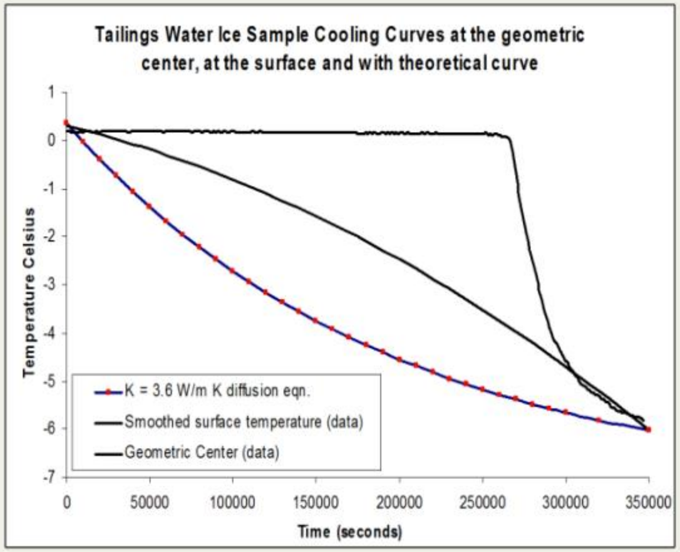


6 ft X 20 ft large form

Field Testing at NORCAT: One 20 ft large form was built to examine:

- Mix design of the best strength;
- Control of the mixing process;
- Measurement of in–situ stiffness by placing two jacks inside the rockfill;
- Measurement of temperature around and inside the form.

Constituents	weight %	Initial T(˚C)	Final T(˚C)
Rock	~85	-5 to -10	
Ice Crystals	~5	0	-6
Water Added	8~10	+5	

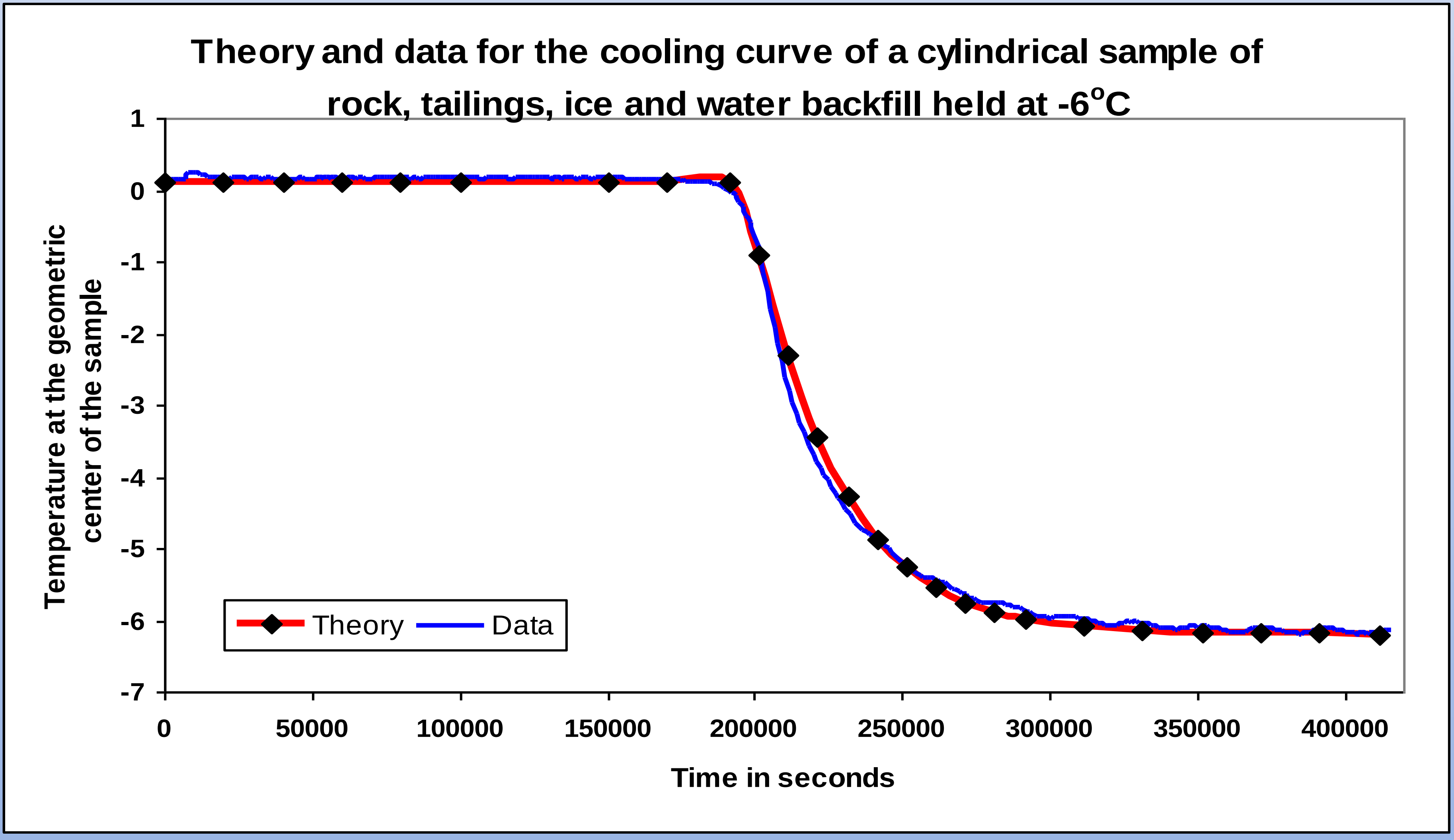


Using a scooptram to knockdown the frozen column

The complex cooling curve due to the latent heat effect and the diffusion equation model for a total cooling time of 97 hours with specific heat capacity of 3.89 J/g°C, density of 2250 Kg/m3 and thermal conductivity of 3.6 W/m K.

An Equation !!!

U(n,k)(ρ, φ, z, t) = -Σ nΣ kA(n, k)Uie-(τ/σμ)λ(n,k)λ(n,k)t Jo((ρ/a)ζn)sin(kπz/L



LOWCARB

Another project I worked recently was called LOWCARB.

Not to be mistaken with the diet fad.

The overall goal of LOWCARB was to reduce methane emissions from coal mining.

I considered the combustion dynamics of the very low concentration methane in ventilation air, commonly referred to as VAM.

I determined that the combustion of such low concentrations of methane will only occur when the temperature of the mixture is sufficiently raised to the point that an emission spark will create what is known as ‘flameless combustion”.

Combustion Theory Equations

$$H(T_1) = \sum_1^n \nu_k' \left(\Delta H_{f,k}^{0,m} + \int_{T^0}^{T_1} C_{pk}^m dT\right) = H(T_2) = \sum_1^n \nu_k'' \left(\Delta H_{f,k}^{0,m} + \int_{T^0}^{T_2} C_{pk}^m dT\right)$$

Includes the enthalpy of formation

$$T_2 = T_0 + \frac{\left(\phi C_p^m(CH_4) + 2C_p^m(O_2) + 2aC_p^m(N_2)\right)(T_1 - T_0) + \phi Q^m}{\left(2\phi C_p^m(H_2O) + \phi C_p^m(CO_2) + 2aC_p^m(N_2) + 2(1-\phi)C_p^m(O_2)\right)}$$

Adiabatic flame temperature calculated for the global reaction (single step assumption)

$$C_nH_{2n} + {}^{n}/_{2}\,O_2 \rightleftharpoons nCO + (n+1)H_2 \quad \longrightarrow \quad CH_4 + {}^{1}/_{2}\,O_2 \rightleftharpoons CO + 2H_2$$

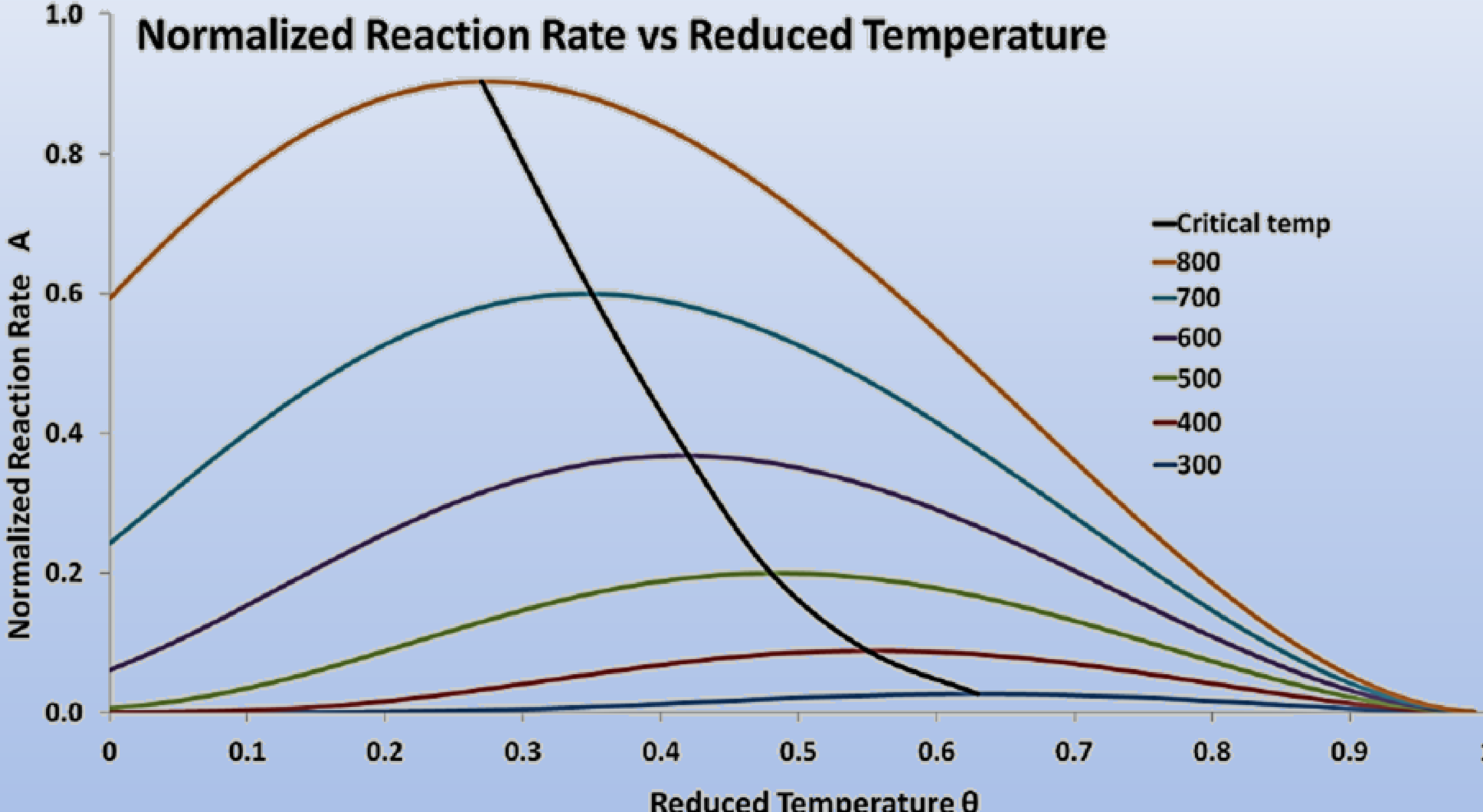
$$C_nH_{2n} + nH_2O \rightleftharpoons nCO + (2n+1)H_2 \quad \longrightarrow \quad CH_4 + H_2O \rightleftharpoons CO + 3H_2$$

$$H_2 + {}^{1}/_{2}\,O_2 \rightleftharpoons H_2O$$

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

The four step reaction used for our model, plus three equations for species momentum (velocity), one equation for the continuity of species and one equation for species energy
4 + 3 + 1 + 1 = 9 equations with variations in parameters as the combustion sequence evolves.

This is why we need a supercomputer!!



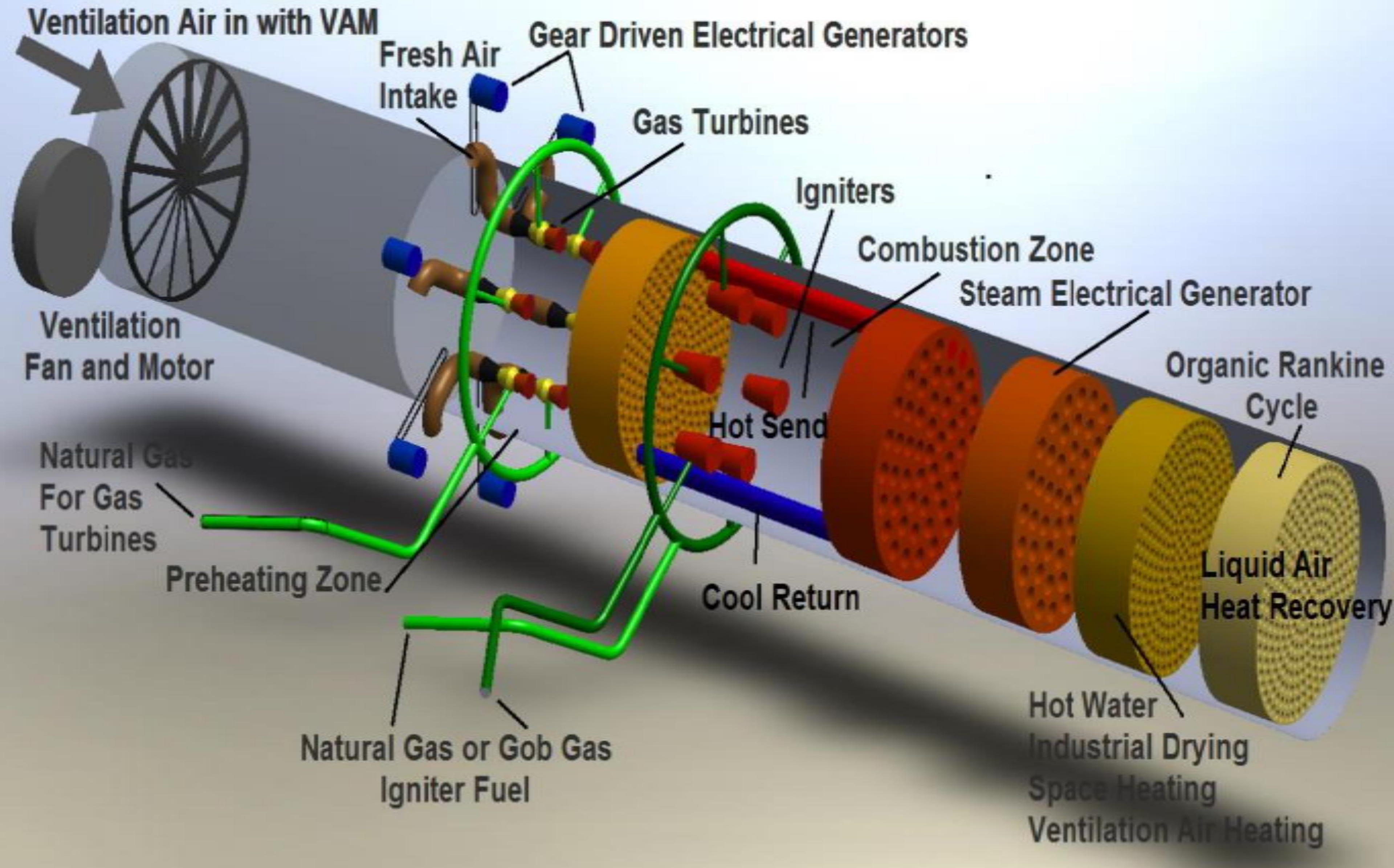
Analytically on a spreadsheet

$$A\rho(1-\theta)e^{\left(-\frac{\beta}{\alpha}\right)}\frac{e^{\left(-\beta\frac{1-\theta}{1-\alpha(1-\theta)}\right)}}{1+\alpha\frac{\theta}{1-\theta}}$$

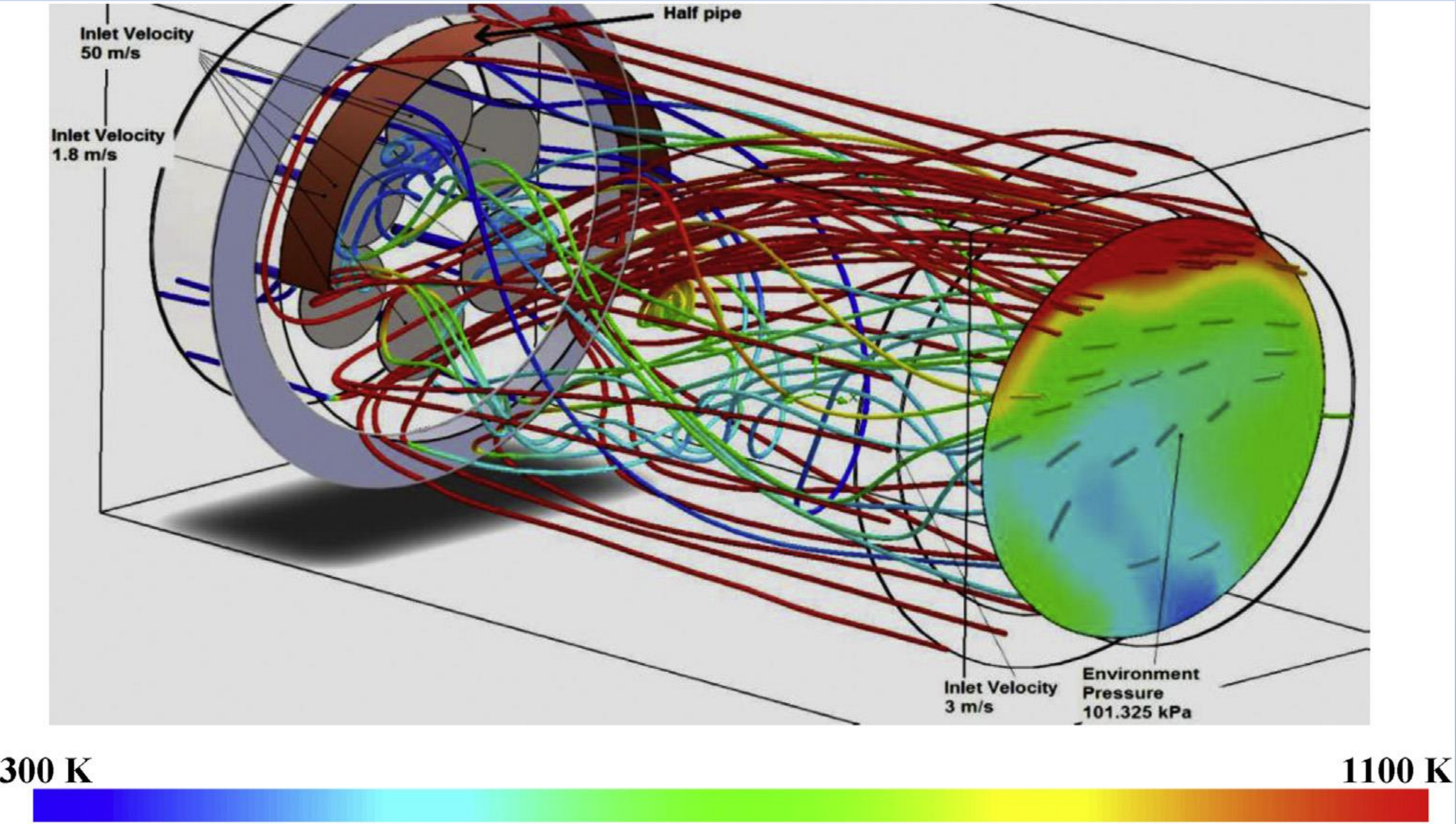
$$\theta = {}^{(T-T_1)}\big/_{(T_2-T_1)} \quad and \ \mathbb{Y} = {}^{Y_F}\big/_{Y_F^1}$$

$$\rho_1 S_L \frac{d\theta}{dx} = \frac{d}{dx}\left(\rho D\frac{d\theta}{dx}\right) + A\rho(1-\theta)e^{-{}^{T_a}/_{T}}$$

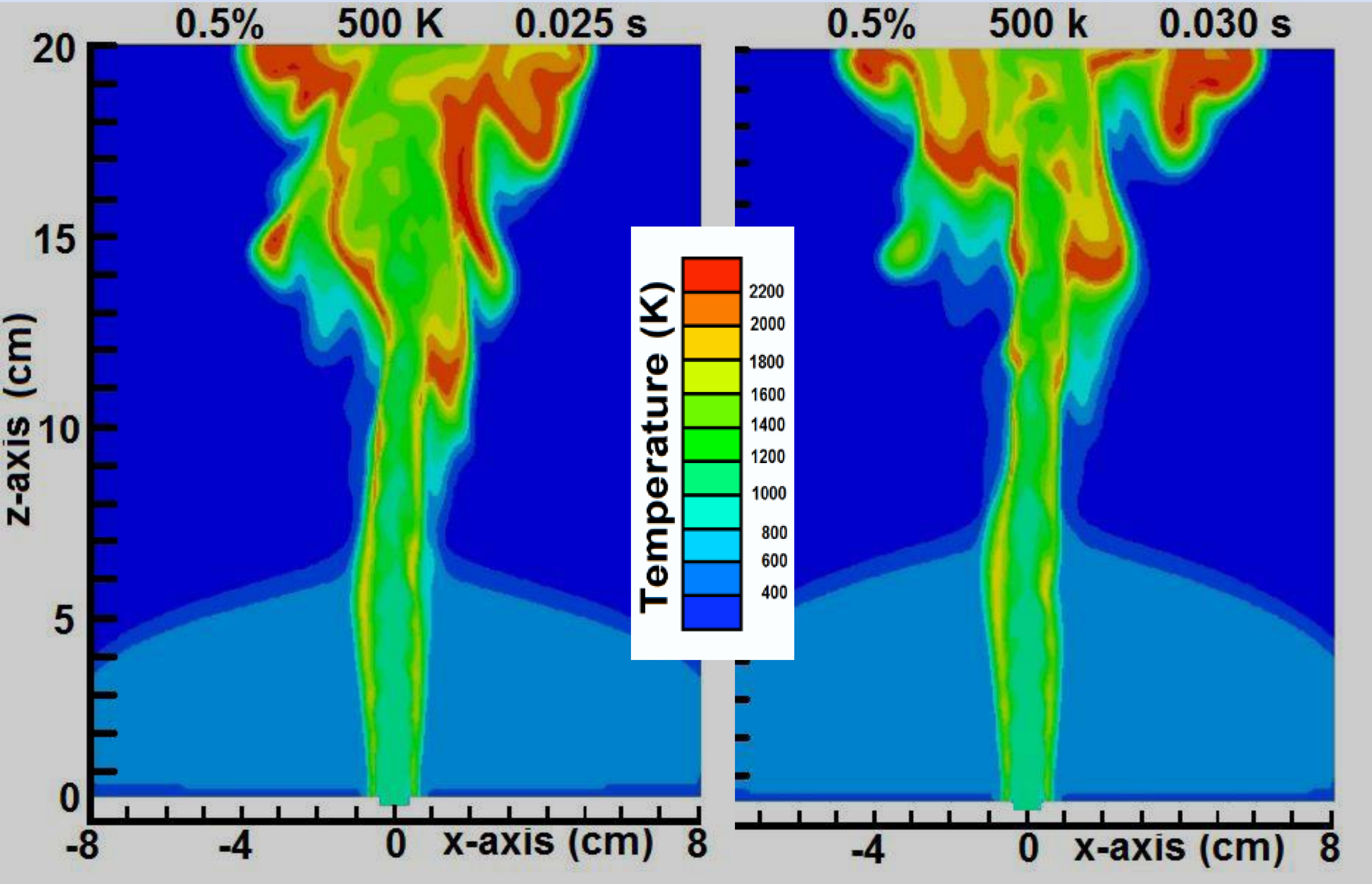
The VamTurBurner©



Computational Fluid Dynamics



Super Computer Large Eddy Simulation
0.5% Methane, 500 K



Thank You