

3rd International Mine Rescue Conference

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Pittsburgh Safety & Health Technology Center**





Evaluation of Lightning Coupling into the Sago Mine

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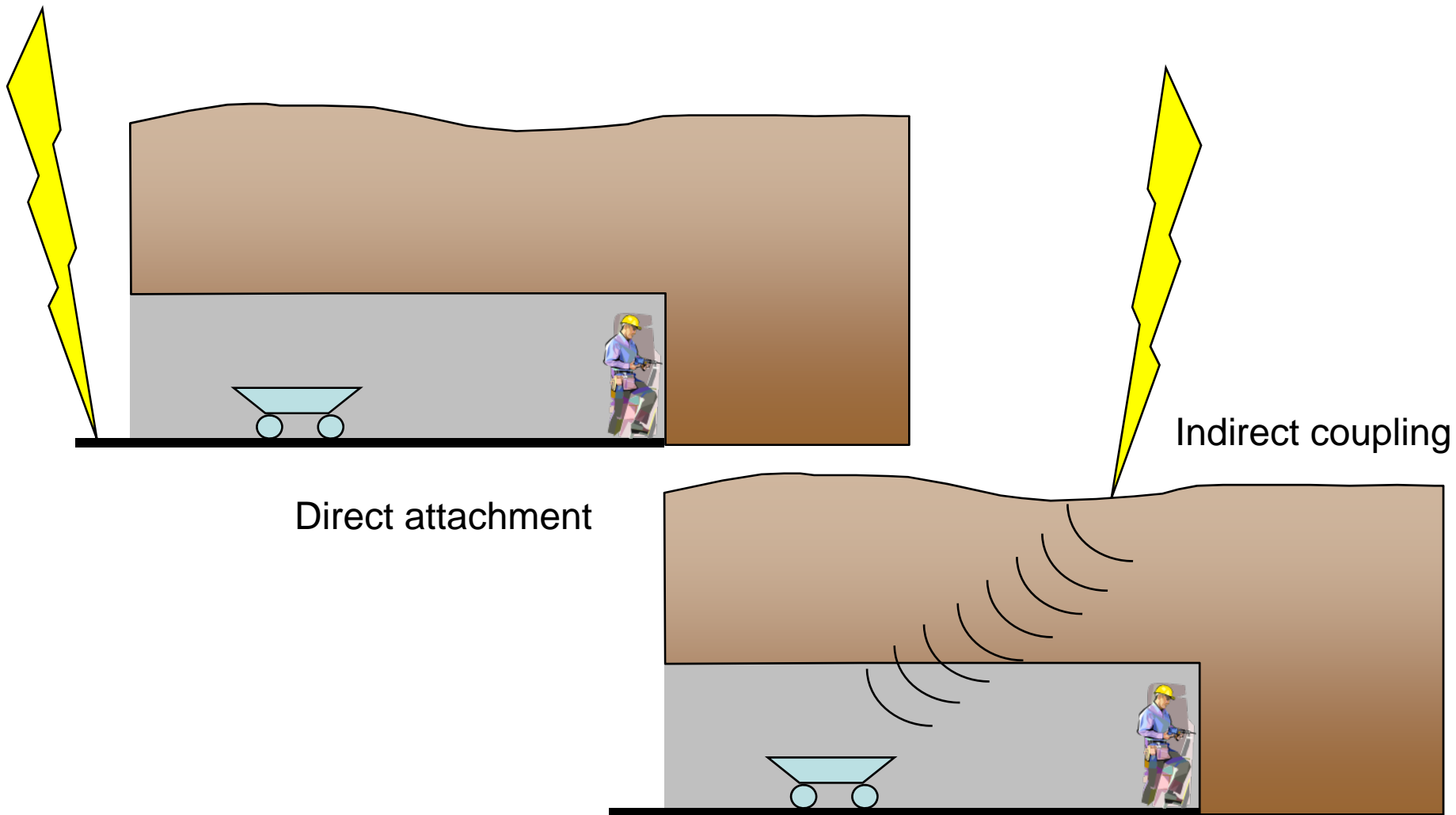
Sandia's role was to determine if lightning was a plausible cause

Could lightning have created an electrical arc in the sealed area at Sago?



Photo 1. An upward, ground-to-cloud lightning flash in Rapid City, SD, on 26 March 2004. [Photo © 2004 by Tom Warner]

Lightning can propagate by direct attachment or electromagnetic (indirect) coupling



Direct attachment

Indirect coupling

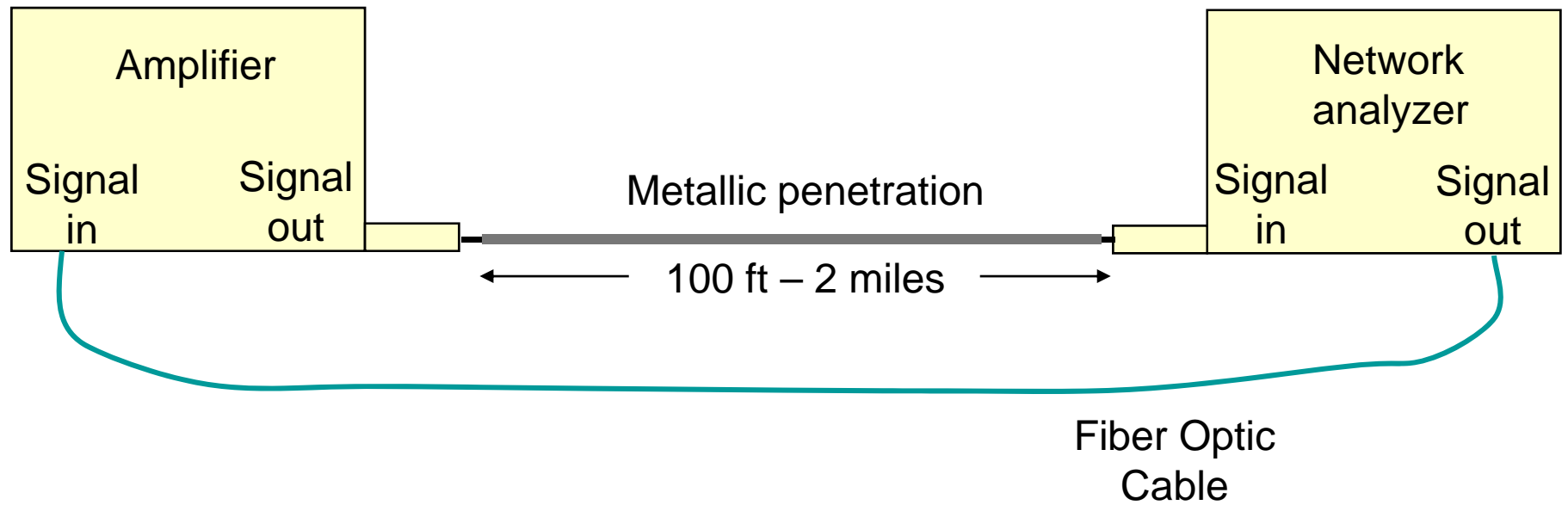


Direct-attachment lightning effects on mine penetrations were determined

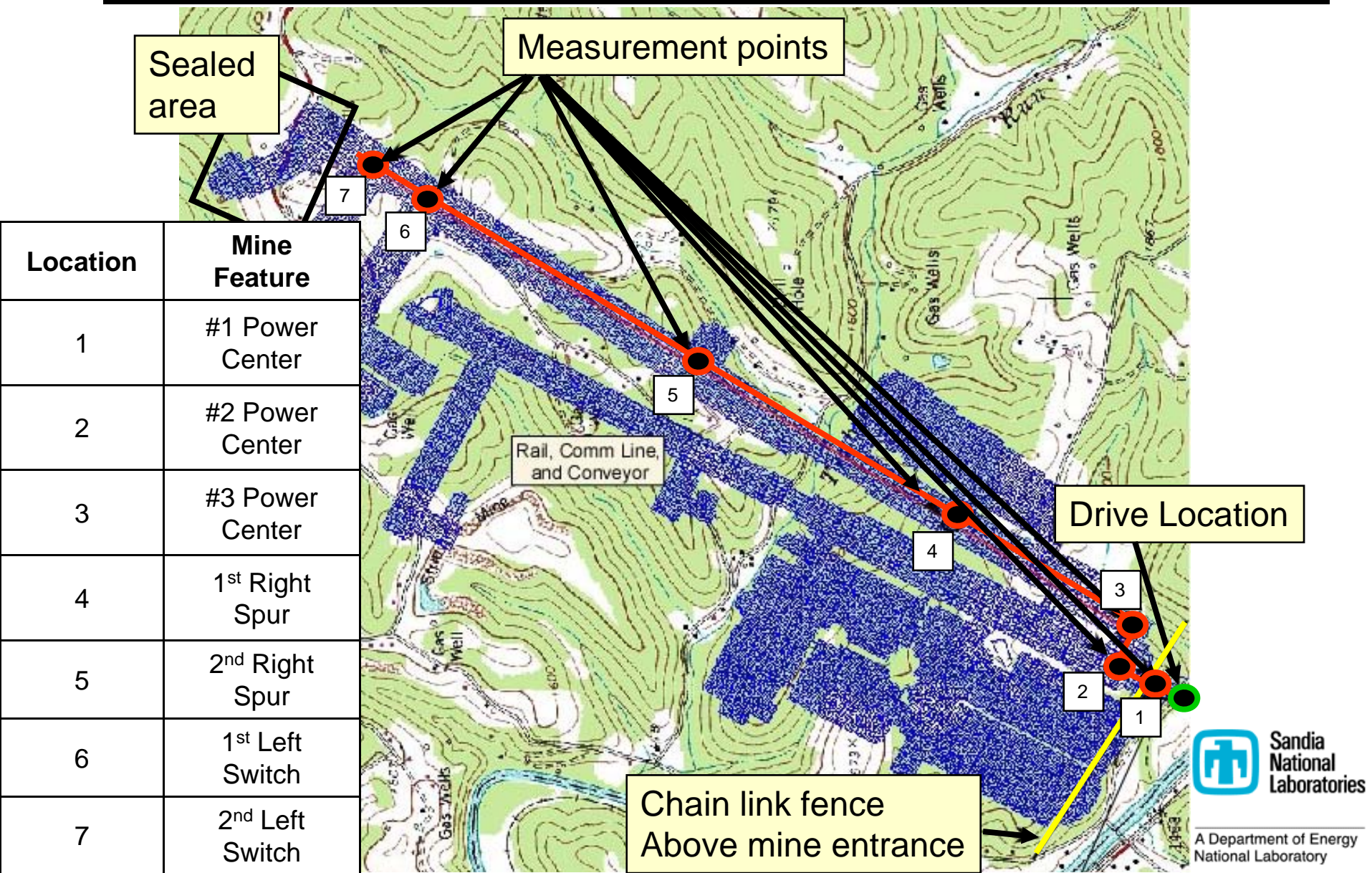
- Measured transfer functions of direct coupling paths
 - Rails
 - Conveyor
 - Power shield
 - Trolley communication line

- Applied a mathematical representation of a lightning stroke to the transfer function
 - to calculate realistic voltages and currents on conductors inside the mine
 - Assumed worst-case scenario of lightning attachment at the mine entrance

Direct-drive measurement technique



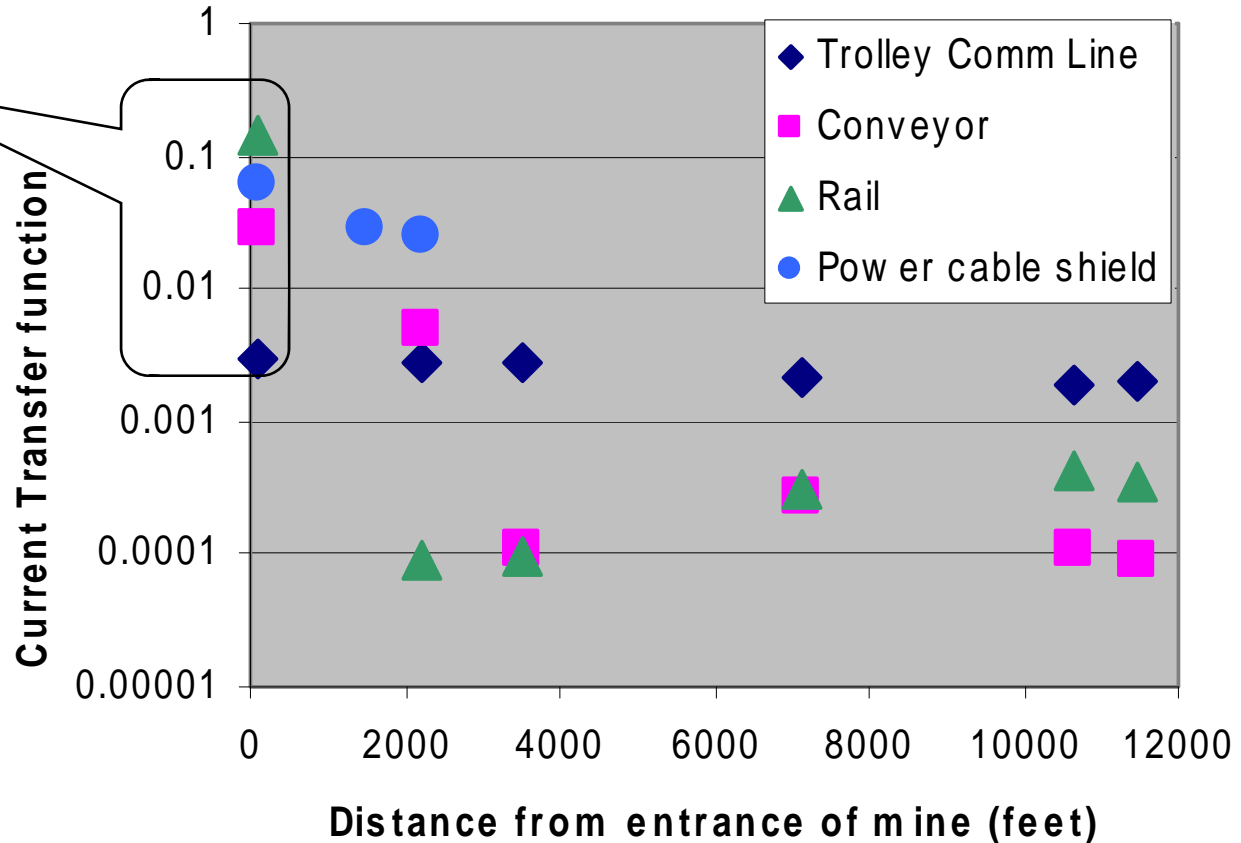
Direct-drive measurement locations



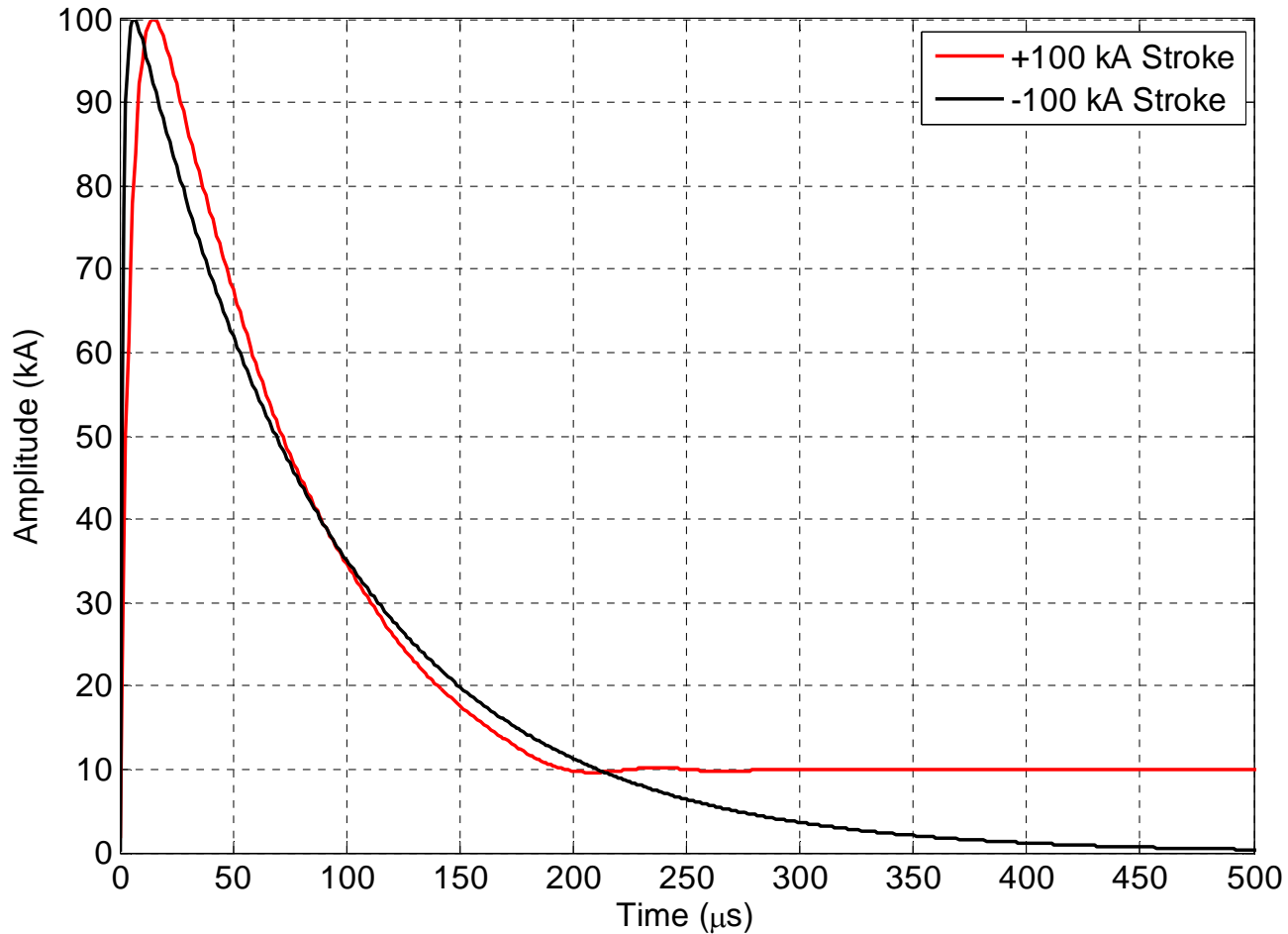
Direct-drive transfer functions

$$\text{Transfer function} = \frac{\text{Output current (A)}}{\text{Input current (A)}} \text{ or } \frac{\text{Output voltage (V)}}{\text{Input voltage (V)}}$$

Results at Power Center #1, 100 ft into mine



Mathematical representation of lightning stroke



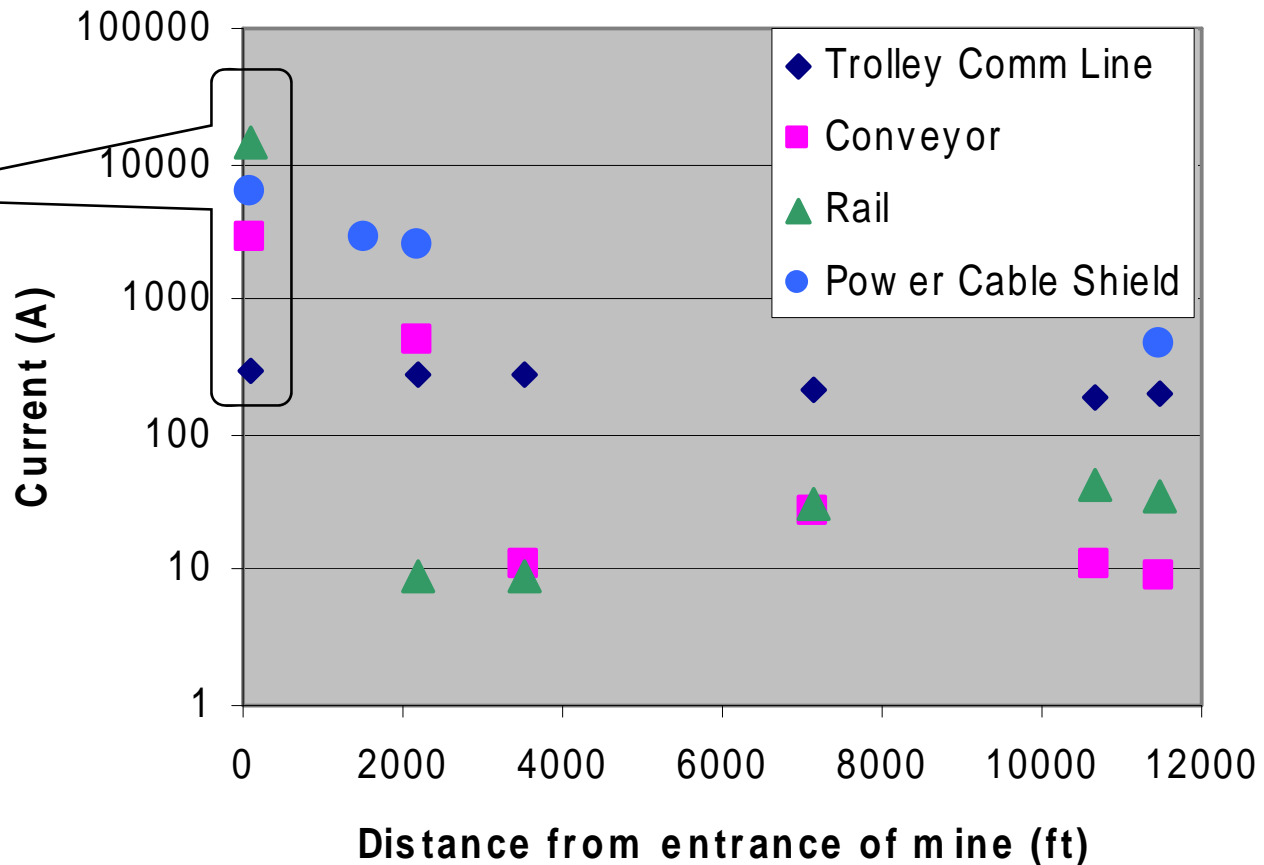
References for lightning waveforms:

Cianos, N., and Pierce, E. T., *A Ground-Lightning Environment for Engineering Usage*, Technical Report 1, SRI Project 1834, August 1972.
Rakov, Vladimir A., and Martin A. Uman, *Lightning, Lightning Physics and Effects*, Cambridge University Press, New York, NY, 2003.

Direct-drive results given lightning attachment at the mine entrance

Results = Transfer function x Mathematical Representation of Lightning Strike

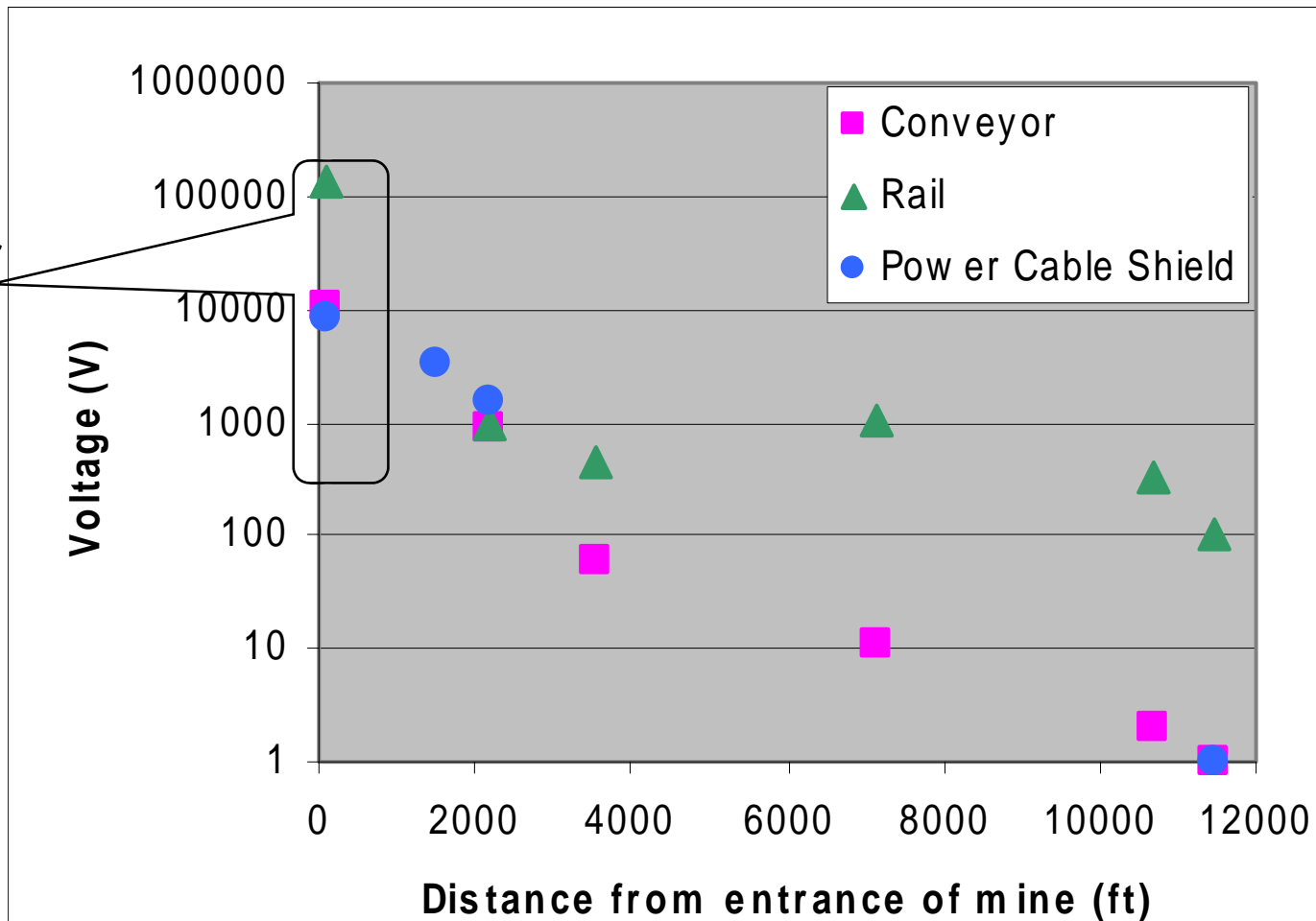
Results at Power Center #1, 100 ft into mine



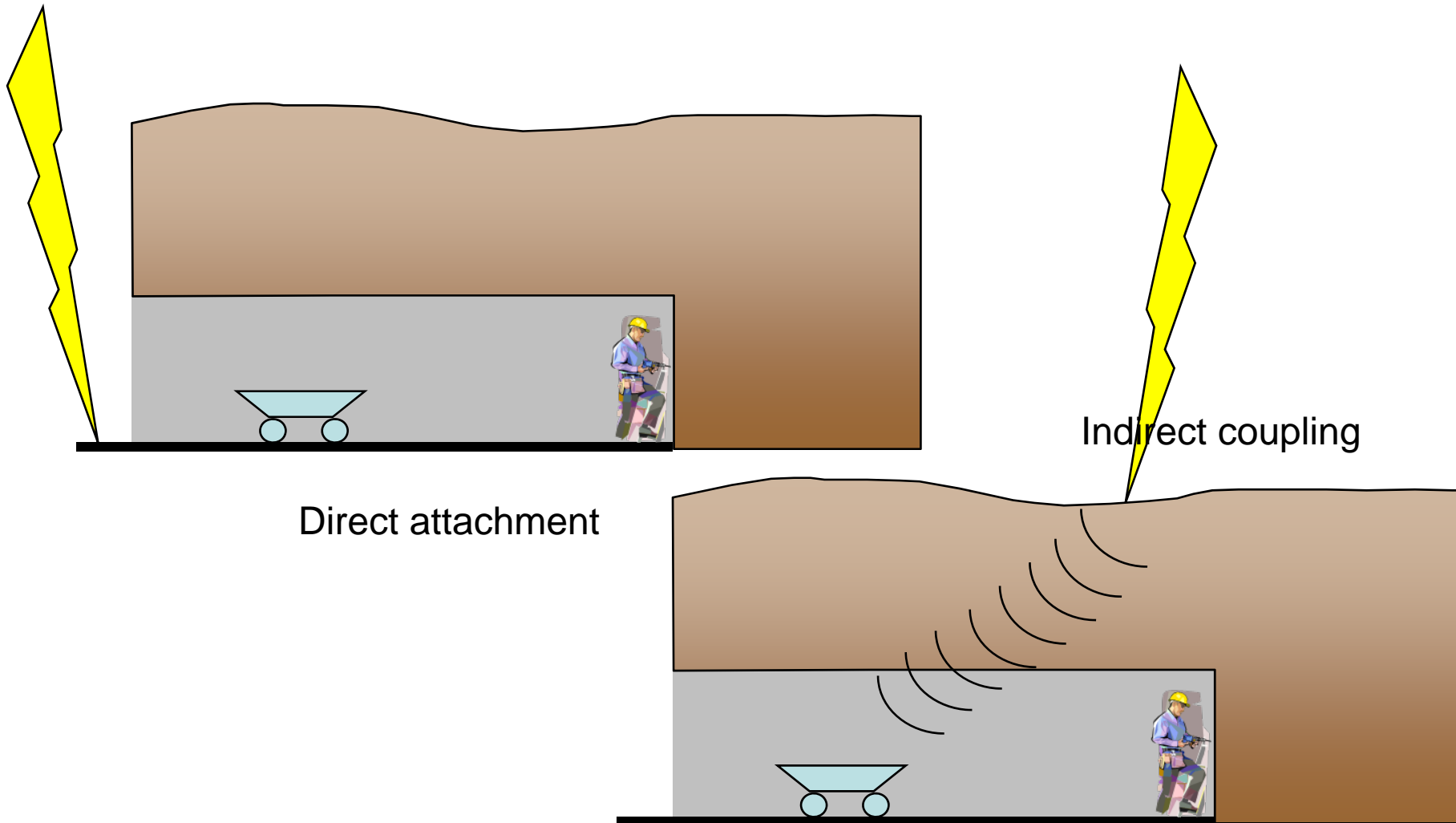
Direct-drive results given lightning attachment at the mine entrance

Results = Transfer function x Mathematical Representation of Lightning Strike

Results at
Power Center
#1, 100 ft into
mine



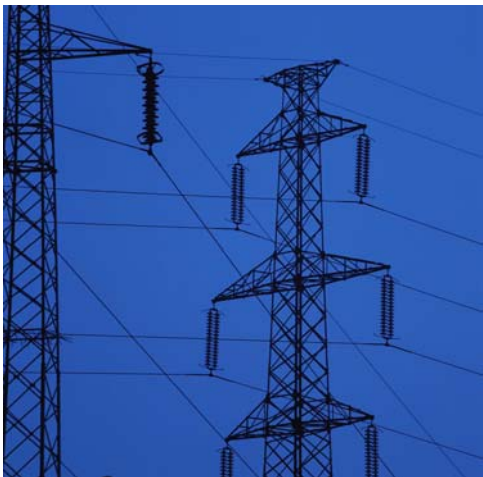
Lightning can propagate by direct attachment or electromagnetic (indirect) coupling



Direct attachment

Indirect coupling

Common examples of electromagnetic propagation



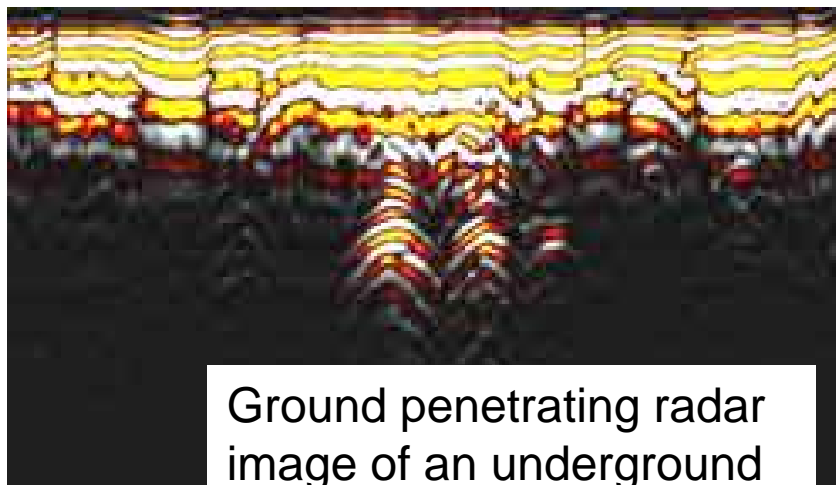
Radiation from power lines



communications

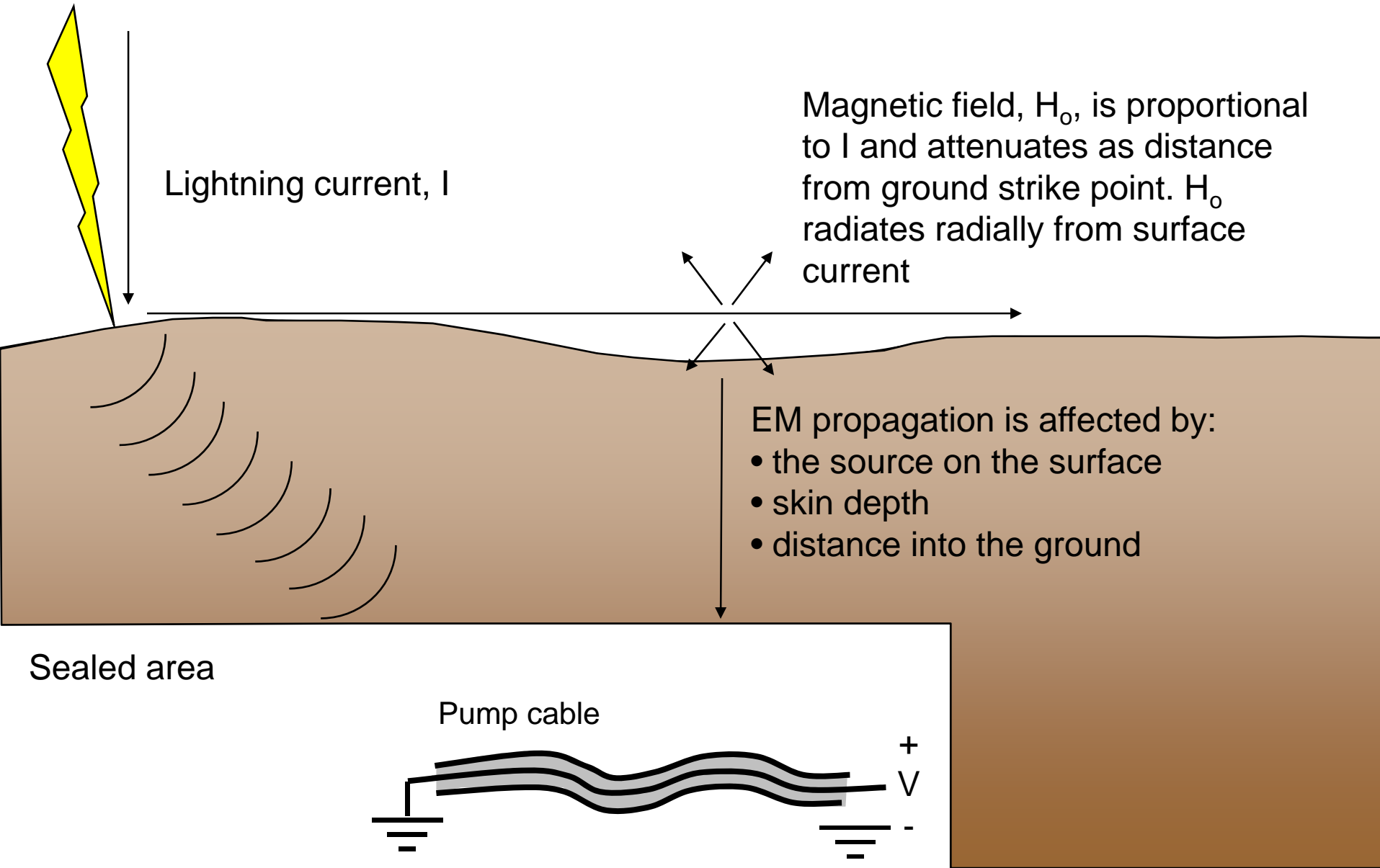


Extremely low frequency communications for submerged submarines



Ground penetrating radar image of an underground cavern

Lightning energy penetrates the earth through electromagnetic waves

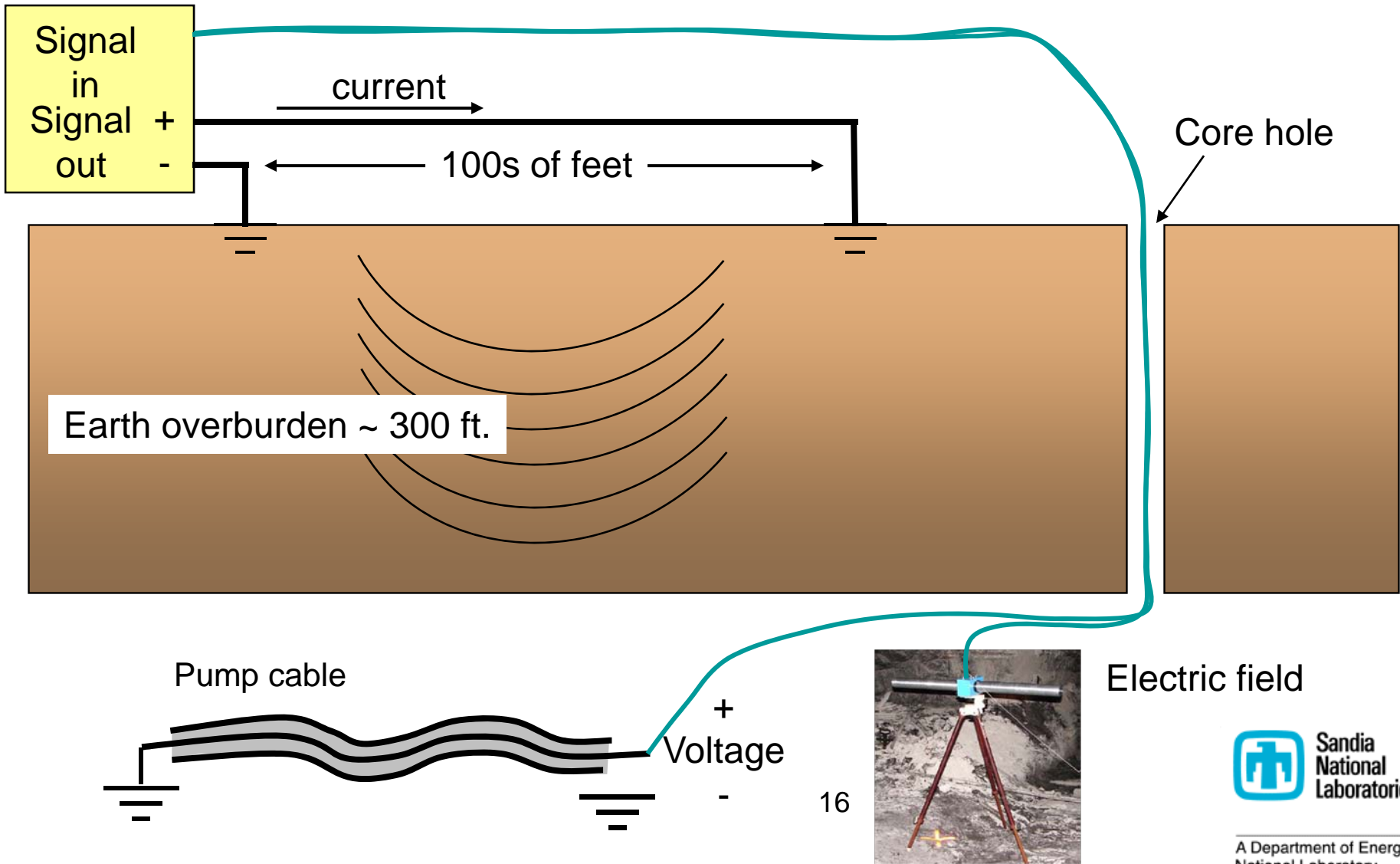




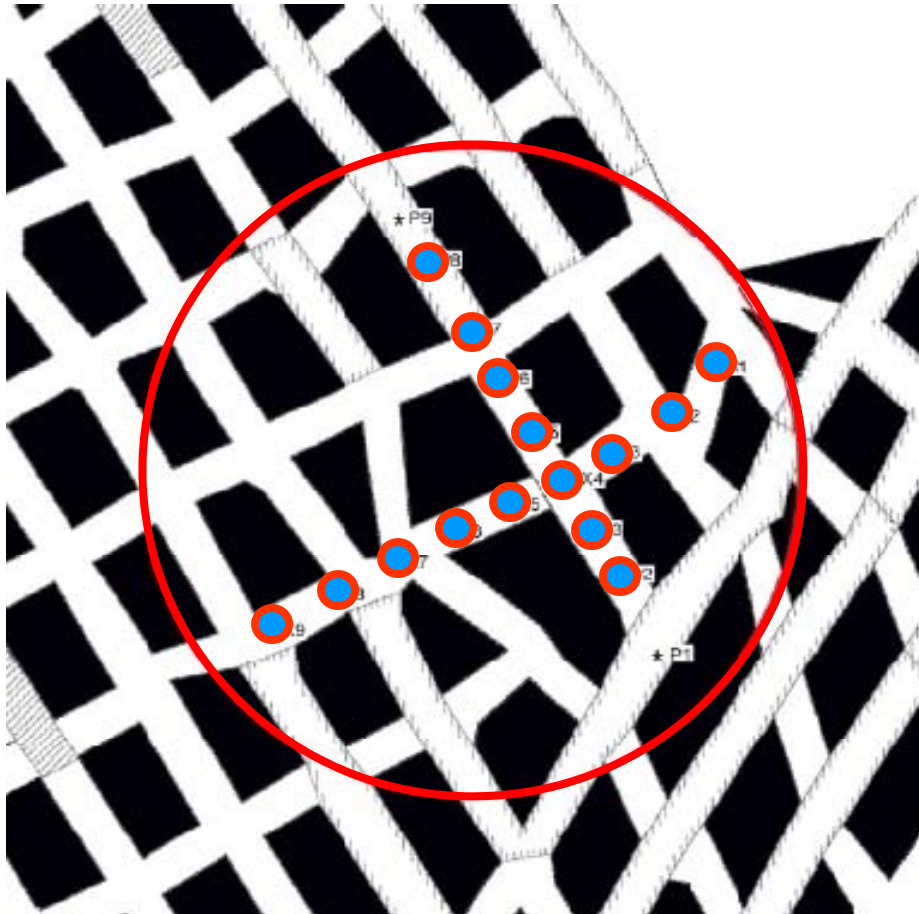
Indirect coupling of lightning effects in the sealed area were determined

- Measured transfer functions of indirect coupling paths
 - Electric field mapping in sealed area
 - Voltage measurements on pump cable in sealed area
- Applied a mathematical representation of a lightning stroke to the transfer functions
 - to calculate realistic electric fields in the sealed area and voltage on pump cable
 - Used recorded lightning strokes and related cases
- Compared measured results with a simplified analytical model of electromagnetic propagation through the earth

Indirect-drive measurement technique



Indirect-drive electric field measurement locations

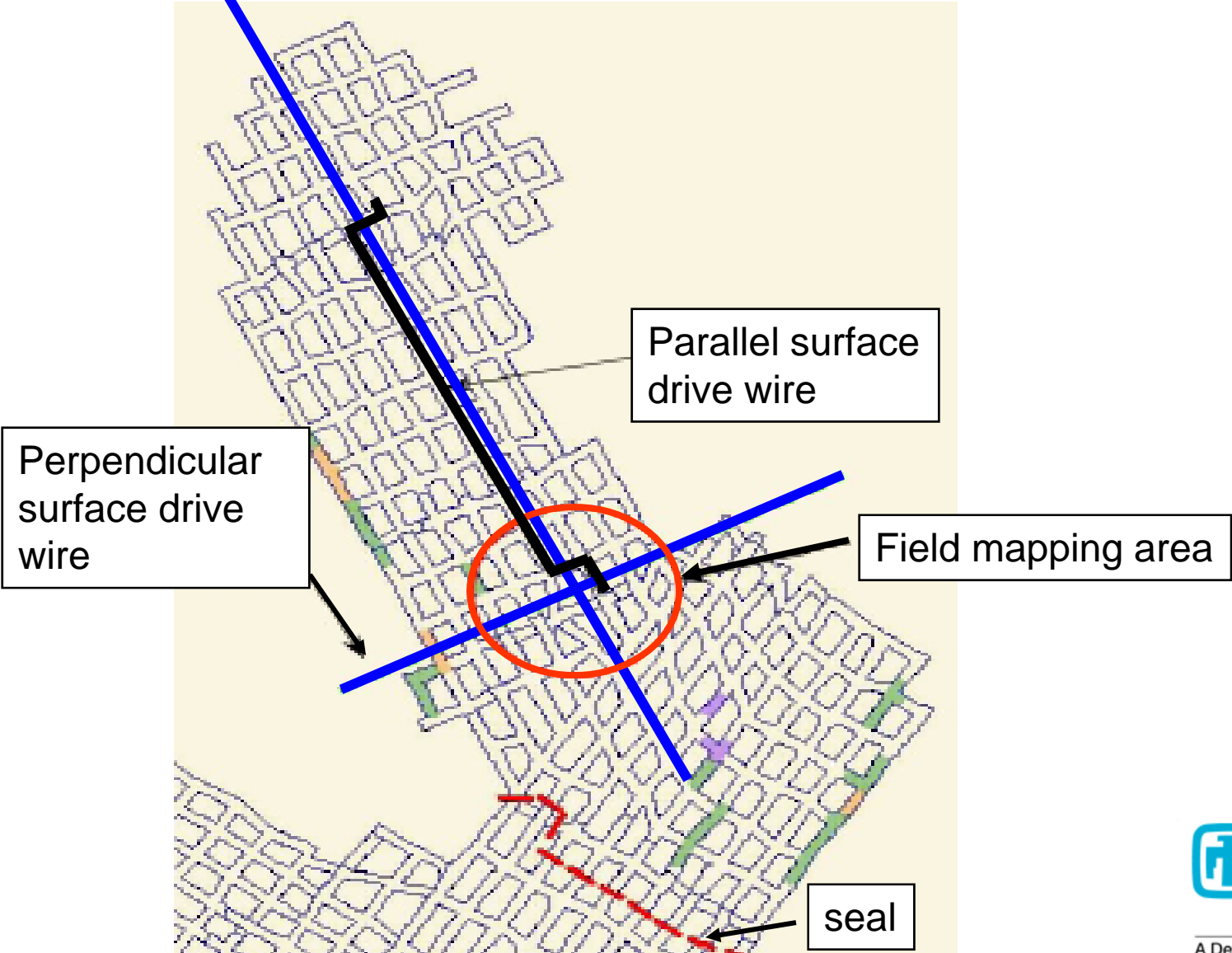


Measurement locations in sealed area

Custom antenna used in sealed area was developed to evaluate DOE facilities

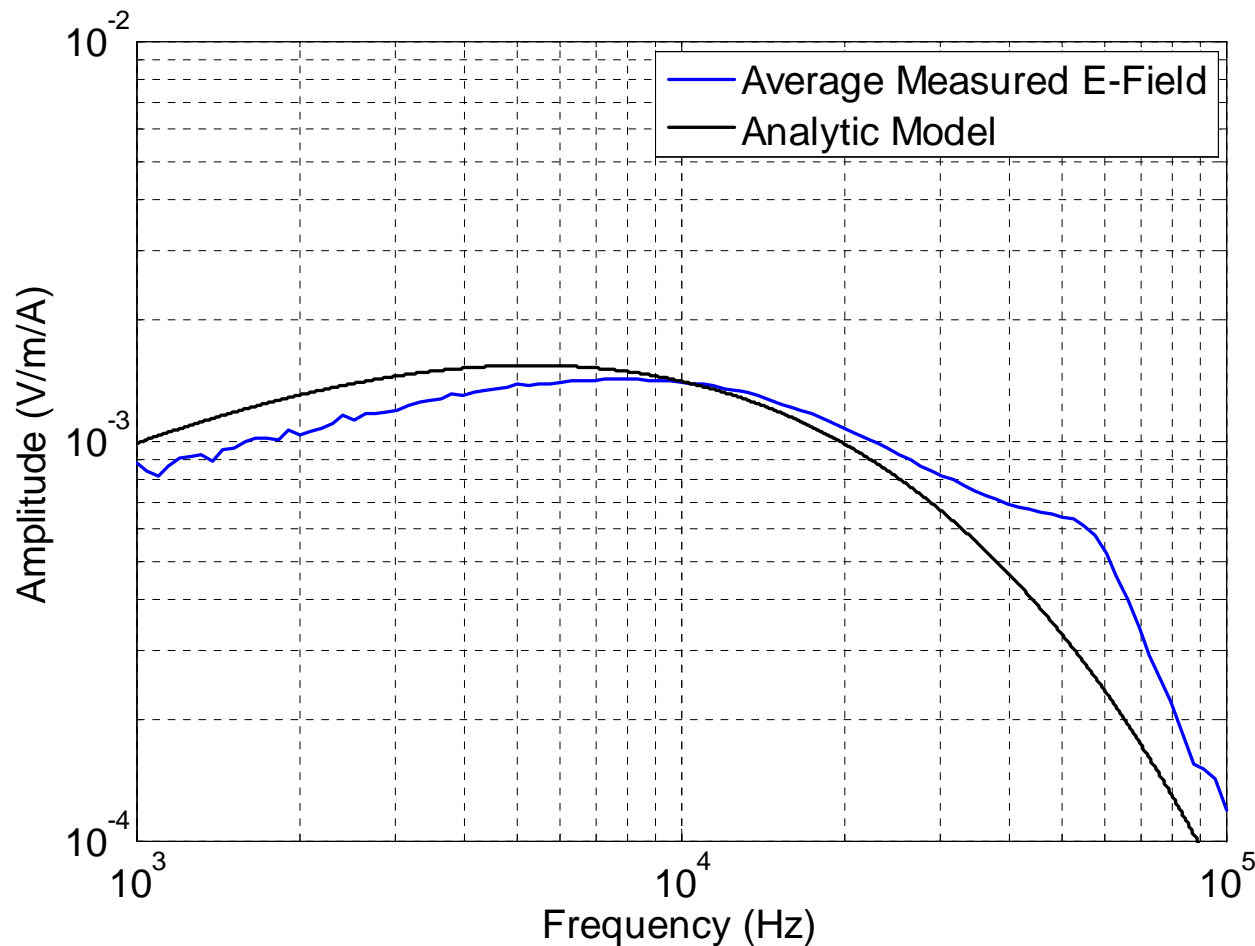


Pump cable and surface drive orientation



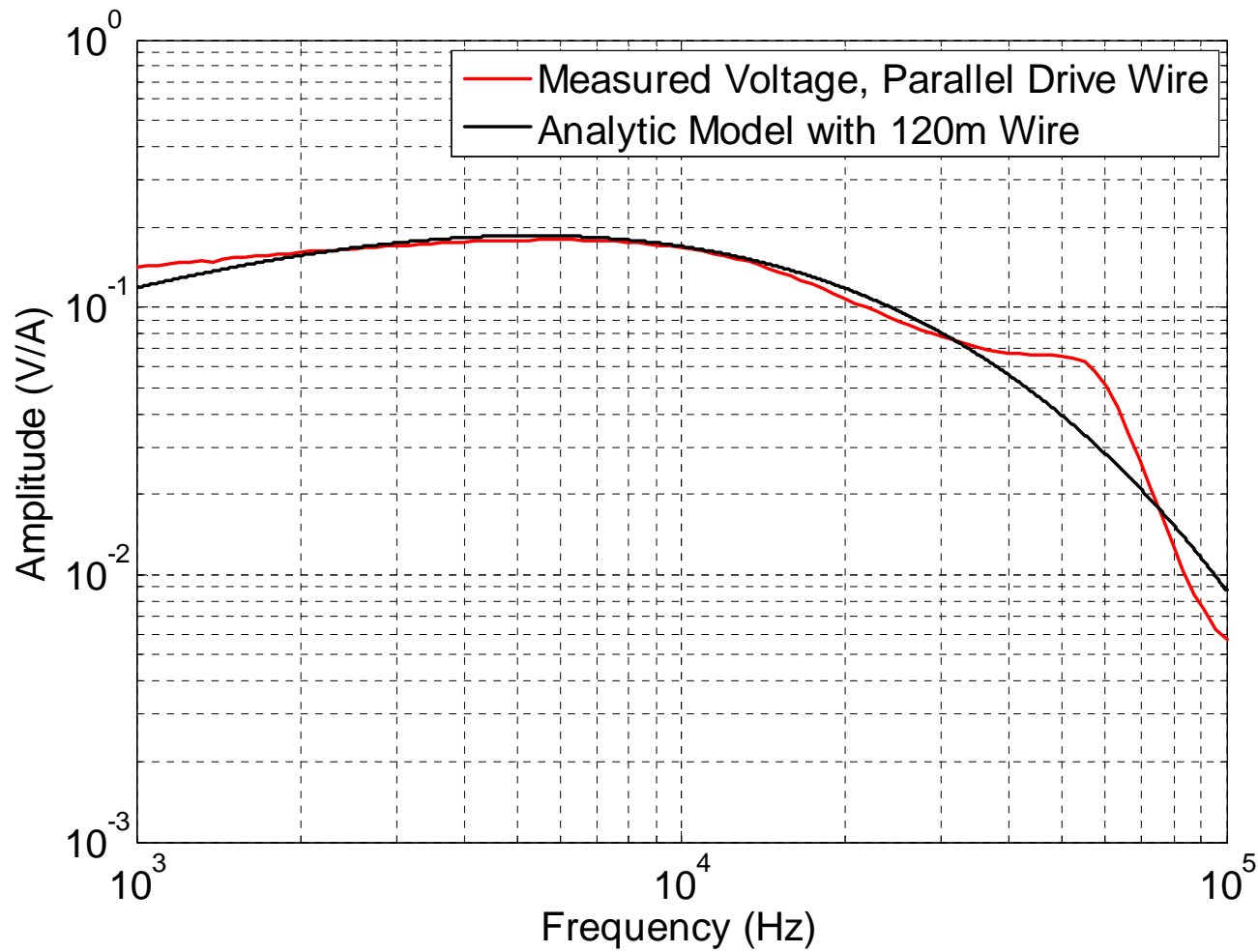
Indirect-drive electric field measurements agree with analytical model

$$\text{Electric field transfer function} = \frac{\text{Electric field in sealed area (V/m)}}{\text{Input (surface) current (A)}}$$



Indirect-drive voltage measurements agree with analytical model

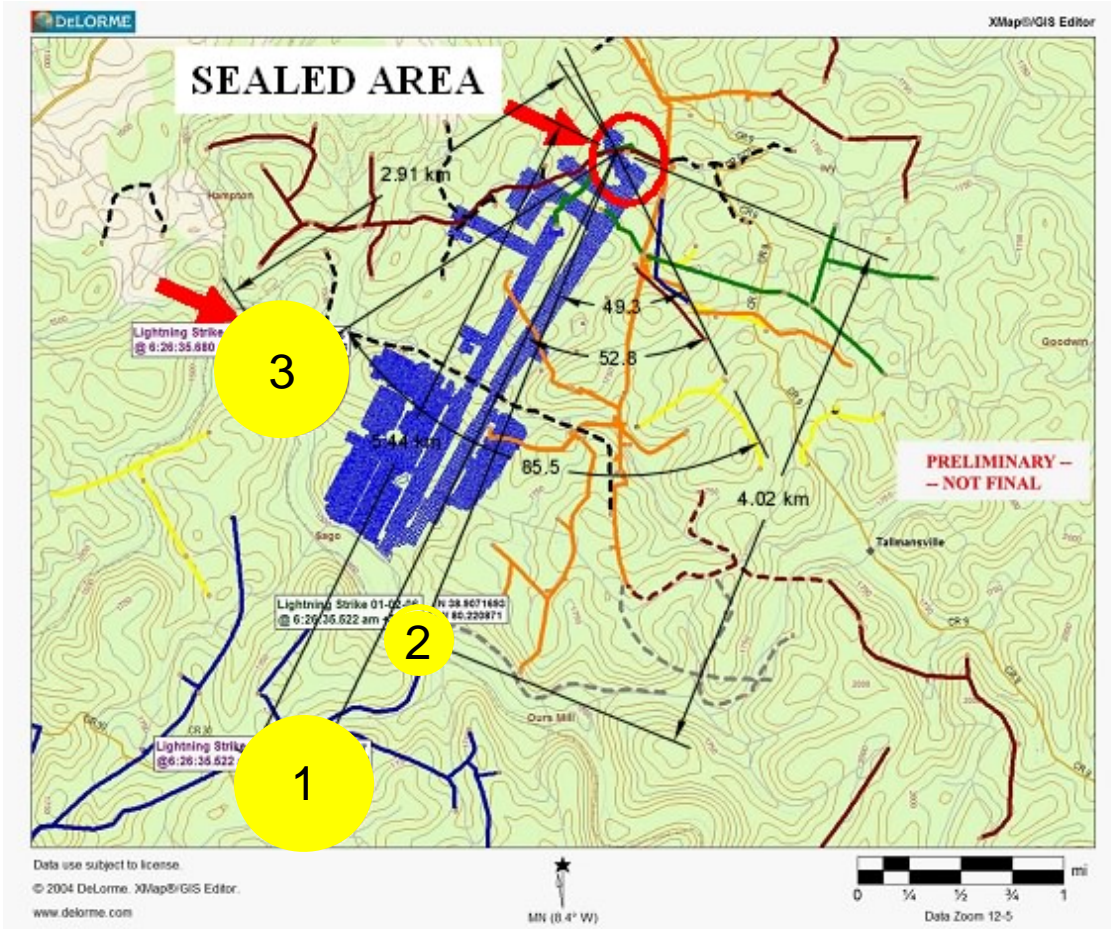
$$\text{Voltage transfer function} = \frac{\text{Voltage on pump cable in sealed area (V)}}{\text{Input (surface) current (A)}}$$



Next, voltage on the pump cable is calculated given lightning strokes in the area

- Use recorded lightning strokes, assuming vertical cloud-to-ground geometry
- Use a recorded lightning stroke, assuming horizontal geometry of lightning arc channel
- Assume a vertical cloud-to-ground lightning stroke close to sealed area

Data record of lightning activity in the area



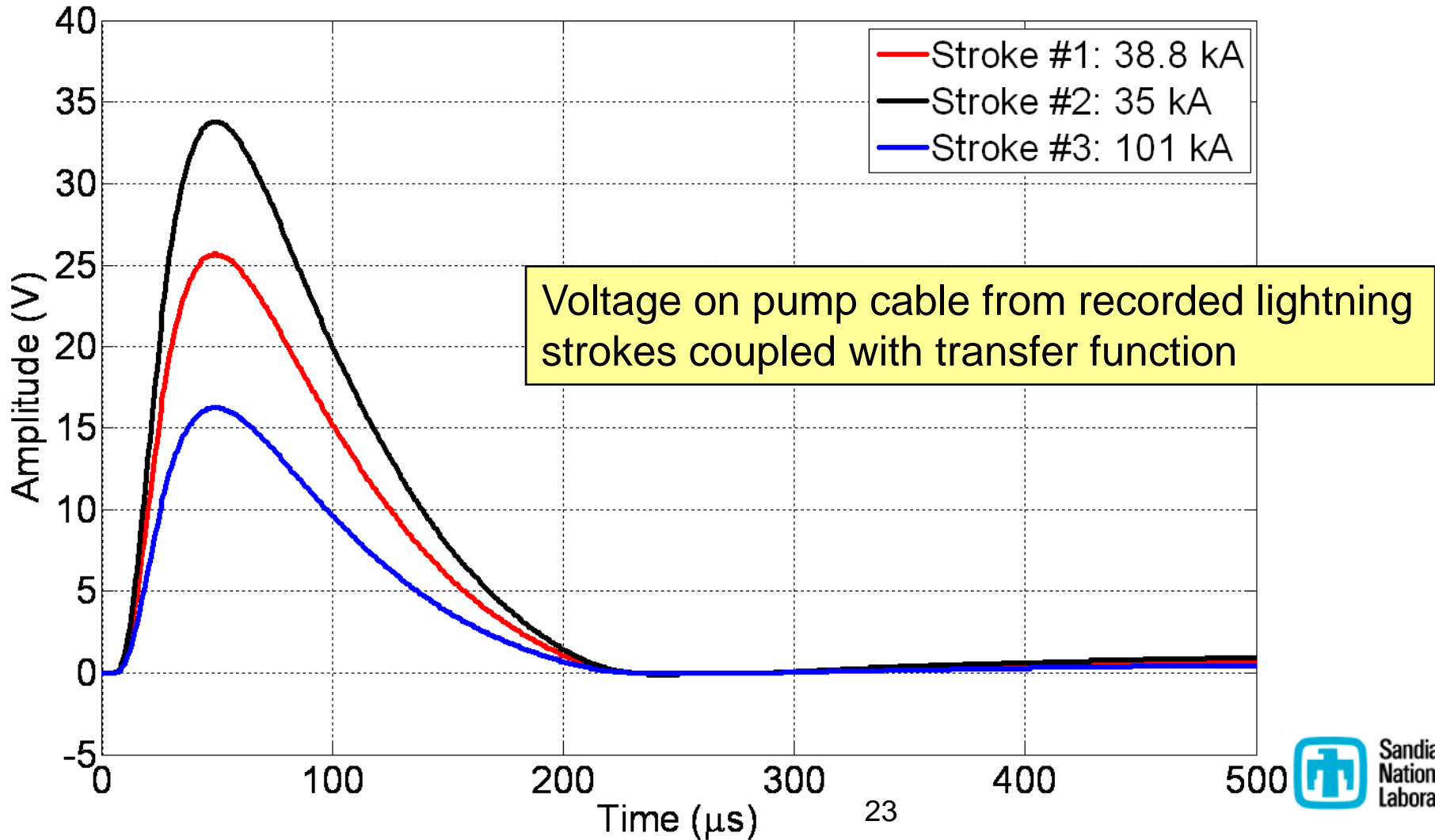
Lightning Strokes detected @ 6:26:35 am on Jan 2, 2006 around Sago:

Stroke 1: +38.8 kA (NLDN)*
Stroke 2: +35 kA (USPLN)*
Stroke 3: +101 kA (NLDN)

* Independent analysis indicates that Stroke 1 and Stroke 2 represent one stroke

NLDN = National Lightning Detection Network
USPLN = United States Precision Lightning Network

Vertical cloud-to-ground lightning stroke data does not support high-voltage arcing on the pump cable

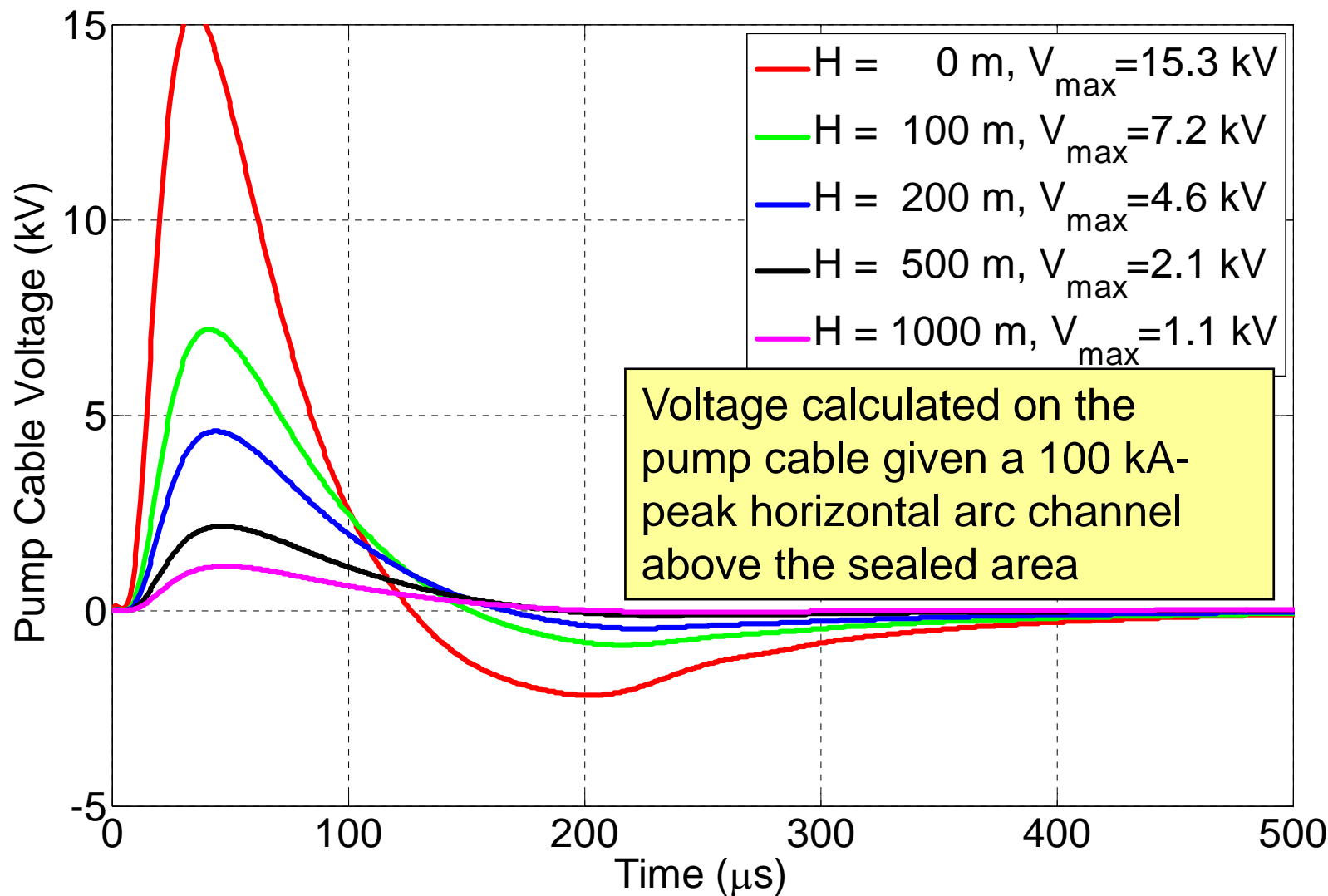


The lightning detection network data is limited

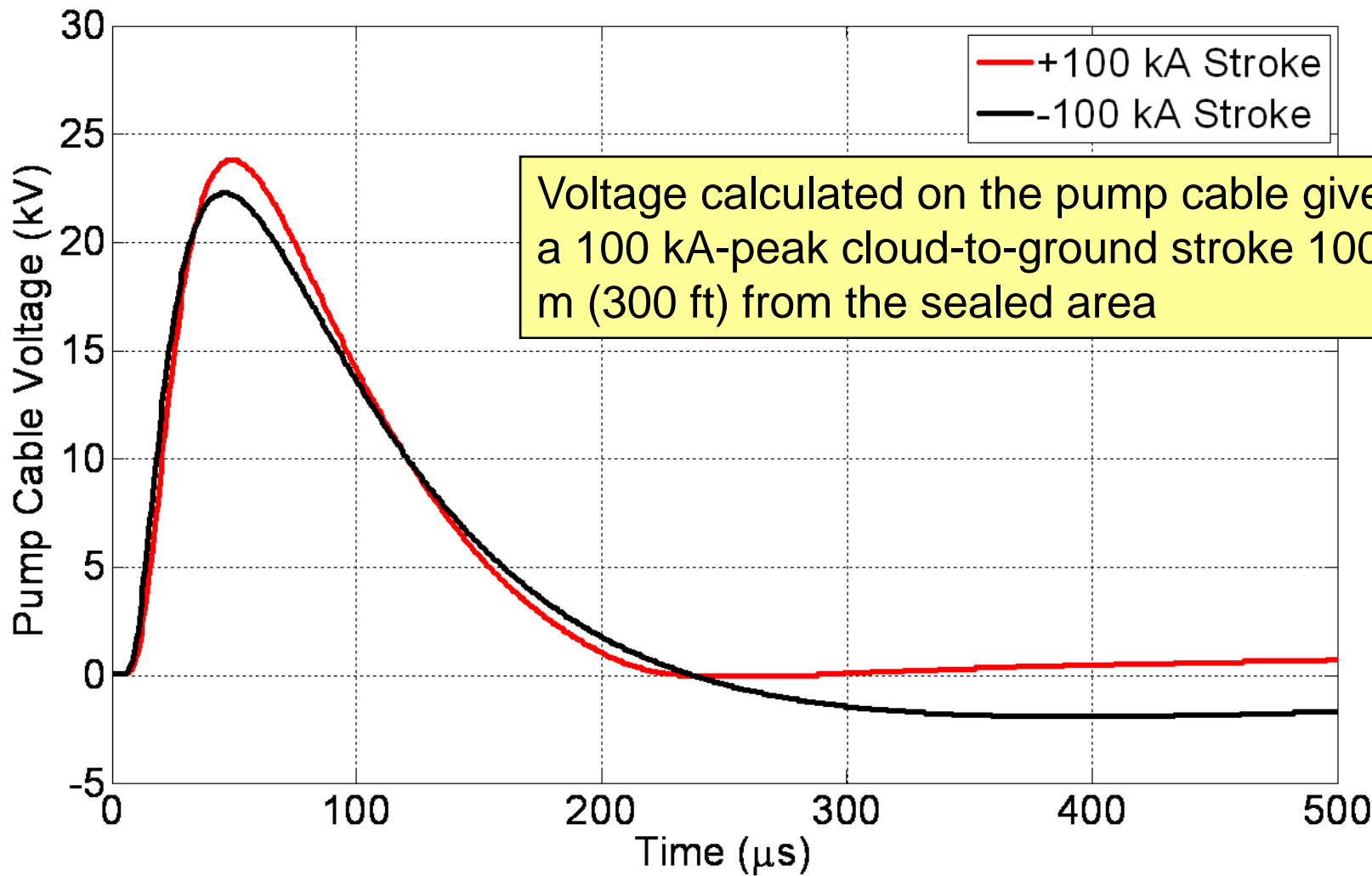
- In general, the lightning detection networks detect approximately 80 – 90% of cloud-to-ground flashes and approximately 50 - 70% of individual strokes within a flash.
- Presence of horizontal arc portions of lightning strokes are not resolved by the lightning detection network sensors.
- Positive, upward-going lightning initiated from tall structures are generally not detected by the sensors. Communication towers are within a mile of the sealed area.



Case 1: Horizontal arc channel above the sealed area does support high voltage arcing on the pump cable



Case 2: Undetected lightning stroke close to the sealed area does support high voltage arcing on the pump cable



Voltage calculated on the pump cable given a 100 kA-peak cloud-to-ground stroke 100 m (300 ft) from the sealed area

Could lightning have created an electrical arc in the sealed area at Sago?

- From measured direct drive paths --- **No**
- From 2 recorded lightning strokes (assuming vertical cloud-to-ground geometry) --- **No**
- From recorded lightning stroke (assuming horizontal arc channel over the sealed area) --- **Yes**
- From undetected cloud-to-ground lightning stroke close to the sealed area --- **Yes**