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HVDC Labrador – Island Transmission Link Review of in-cloud icing on the Long Range Mountain Ridge

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Abstract:

This report comprises review of climatological monitoring programs of the test towers on the Long Range Mountains.
Also comments on the estimated design radial rime icing and comparison of the information contained with experience in Iceland and Norway. It also includes comments on how to improve evaluation of in-cloud icing and how to improve operational reliability.

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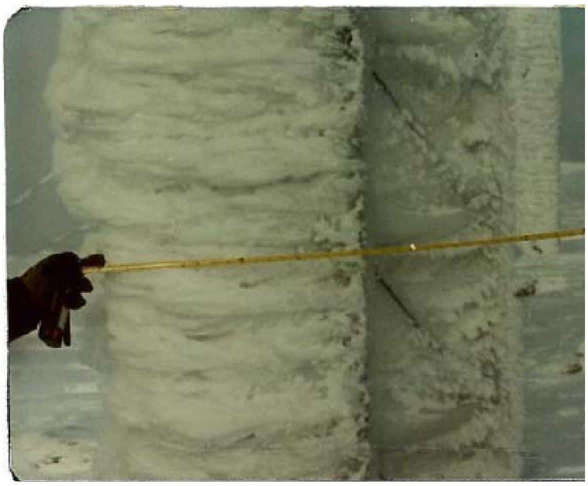
HVDC Labrador – Island Transmission Link

Review of In-Cloud Icing on the Long Range Mountain Ridge

Reykjavík, May 2009



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1 Introduction and main conclusion

1.1 General

This work is performed by EFLA Engineering in cooperation with Landsvirkjun Power for Nalcor Energy. The work involves:

- Review of available reports of test towers on the Long Range Mountains.
- Comparison of the information contained with experience in Iceland and comment on whether the estimate of the design radial Rime icing (amount of 240-280 mm) is low or high.
- High level overview of issues concerning in-cloud icing, and what can be done to go forward, with respect to: design, reliability, and long term maintenance.
- Ultimately comment on if routing through the Long Range Mountains is reasonable.

1.2 Main finding in review of reports on test towers on the Long Range Mountains

Following is the main findings after reviewing of reports from data collection program in 1973-1987.

- Ice loading is very different along the line route. Effects of shelter in reducing ice loadings were demonstrated.
- Gave good indications of main directions of ice accumulation.
- It enabled a more rational selection of HVdc routes and route alternatives in respect to in-cloud icing.
- The data collection program gave indication that specified loading (from 1973) is very conservative for long sections of the line route. It did though not systematically quantify reliable icing data that can be used in extreme value distributions. Thus, the accuracy of the design loading from the 1973 study has not been improved.
- Information on icing is not given in much detail in reports; it would need access to detailed raw data with photos to be able to make quantification with good accuracy. Raw data is not available.
- The measured level of salt contamination was generally very low, but samples were taken at a fixed interval of 2 weeks. By this method of sampling, it is very likely that observers will miss the peak contamination as it can wash off before samples are taken.
- Extreme contamination was measured at Flowers Cove on one occasion in 1981. The day of the sampling was after a very strong wind blowing inland from the ocean.
- In some occasions, higher contamination was measured further from the ocean than close to the shore in Labrador.

1.3 Comment on the estimated design radial rime icing

The design ice load is based on an icing model using meteorological data from weather stations in the period of 1953-1971. The data analysis was presented in a report from 1973 and no modification of the loading has been made since that time.

The icing model was not able to take local topographical effects into consideration and thus all loading is the same for the Long Range Mountains, i.e. it is broad based and covers around 60 km[1]. The test program from 1973-1987 clearly showed that in-cloud icing loading varies in the area and that effect of shelter

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[1] There is some uncertainty on exact length of section, it needs to be checked.

cannot be emphasized too strong. Thus loading should be applied segments wise. Segment wise loading is the usual practice in countries with high in-cloud icing.

Design loading (50 years) for in-cloud icing is given as 9.5" radial ice cover. Density of ice is assumed to be[2] 500 kg/m^3. It is not defined if this loading applies to 10 m above ground and shall be increased further by conductor height. Loading is defined as radial ice cover. It is pointed out that it is more appropriate to define loading as unit loading rather than radial ice for high in-cloud loading.

For 58 mm conductor the loading becomes 113.4 kg/m or 76.2 lb/ft (50 years loading).

This loading is very high compared to design loading for in-cloud icing in most countries, including Iceland, Norway and BC Hydro in Canada. It can also be compared to predefined classes of in-cloud icing (50 years return period) in ISO 12494 where class 9 (of 10) is 50 kg/m but the highest class, 10, has undefined loading.

It was pointed out in the report "Study of Climatological Monitoring Program 1977-1981" in respect to in-cloud rime: *"The MRI estimates are conservative, and it would be desirable to obtain more precise data so that, if possible, some reduction or refinement in the estimates might be made."*

It is the opinion of the authors that by studying the in-cloud icing condition along the line route it should be possible to avoid some of the exposed routes. Loading should be given section wise and the most exposed route should not cover more than few kilometers. Long sections of the line should have much lower loading than specified in 1973. It would not be a surprise that further study would lead to some reduction of maximum ice loading.

1.4 On operational reliability of Overhead Transmission Line (OHTL) over the Long Range Mountains

Experience has shown that OHTL located in areas with frequent and high in-cloud icing may experience operation disturbances if proper design is not made for such condition. When the designer is aware of the conditions and how to approach a suitable design, then the operational reliability is generally good.

The electrical design of insulator strings needs to consider the effect of icing, salt contamination and combination of both.

Steps to improve evaluation of in-cloud icing in the area

- Make new analysis of maximum in-cloud icing in the area (50- and 150 years return period), based on data from nearby weather stations. I.e. repeat similar study as was done 1973 but with data series up to 2009, using better model and calculation methods. It should be tested if models predict high ice load in same months as test tower received high loading. The model can also be calibrated with numerical weather prediction (NWP) model simulation.
- Study the line route section by section. Let persons with extensive experience in defining section wise ice loading (Á.J. Eliasson in Iceland and S. Fikke in Norway) study the line route and review and compare to exposed sites in Iceland, Norway and Greenland.
- Quantify local in-cloud icing severities by using a local scale NWP model for simulations of in-cloud atmospheric icing.
- Install icing test spans in optimized locations.
- Create 3D model of earth surface for study of line routes.
- Install wind and temperature measurement in selected location.

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[2] In tables it is presented as 0.9 of water but it seems to be a misprint comparing the loading that is given (lb/ft).

Steps to improve structural design in the area

- Define special loading cases
- Special consideration in design of insulator and hardware to accommodate ice load, galloping, ice drop, wear etc.
- Good quality check on all stage of design, manufacturing and installation
- Use special design in heavy icing areas and even consider using two single pole lines instead of one double pole line in most exposed section(s).
- Route selection needs to be studied in detail, since sheltering effects of a cliff only about 50-100 m height can give a significant reduction of in-cloud icing.
- Aspects of ice cover, avalanches, deep snow creep and slides need to be considered in tower location.

Steps to improve insulation performance

- Testing of complete insulator strings in a laboratory with respect to ice, contamination and combination of both.

1.5 Main conclusion of investigation

The provisional result of this investigation is that it is possible to design and operate the HVDC transmission link over the Long Range Mountain Ridge with respect to in-cloud icing and salt contamination. Further studies are required on ice condition, design criteria of structures and insulation and detailed line route in order to keep good operational and maintenance performance of the line.

2 Line route passing the Long Range Mountains

The Long Range Mountains are a series of mountains along the west coast of Newfoundland. They are the highest range on the island, extending about 250 miles (400 km) northward from Cape Ray along the western shore. The mountains have an average elevation of nearly 2,200 feet (670 m) and a maximum height of 2,670 feet (814 m) in the Lewis Hills, southwest of Corner Brook.

This ecoregion is divided into three separate upland areas, extending from the southwestern coast to the Northern Peninsula. It is characterized by cool summers and cold winters with a great deal of snow. The mean annual temperature is approximately 4°C, with a mean summer temperature around 12°C and a mean winter temperature around -4°C. The mean annual precipitation ranges from 1000 mm to 1400 mm. This ecoregion is covered by sparsely forested heath and moss barrens. Dwarf patches of black spruce and balsam fir occur, as well as dwarf kalmia and mosses. Exposed sites support mixed evergreen and deciduous shrubs. Elevations range from sea level to approximately 814 m above sea level.

Figure 1. *Long Range Mountain in Newfoundland.*

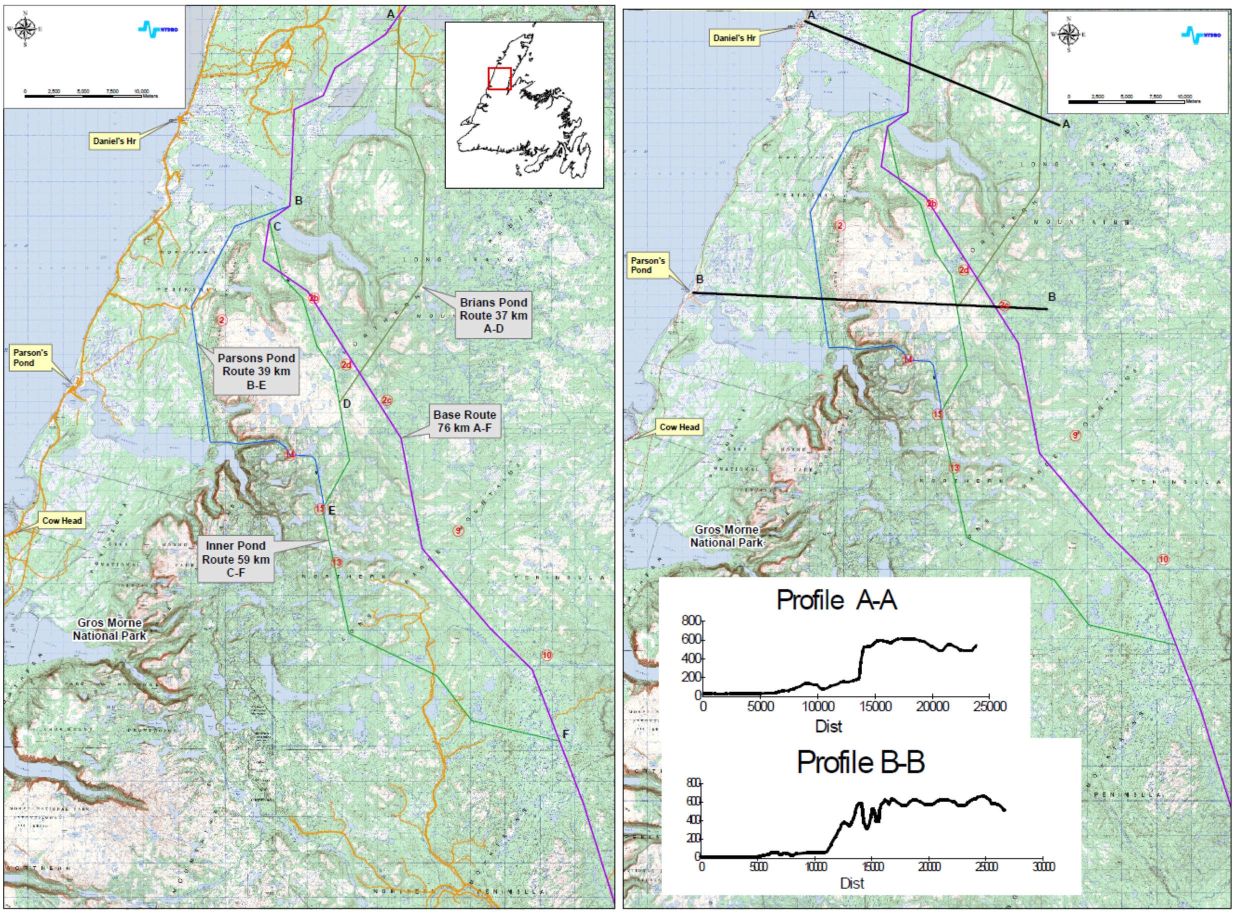

Figure 2. Overview of line route passing the Long Range Mountain, including profile through two sections.

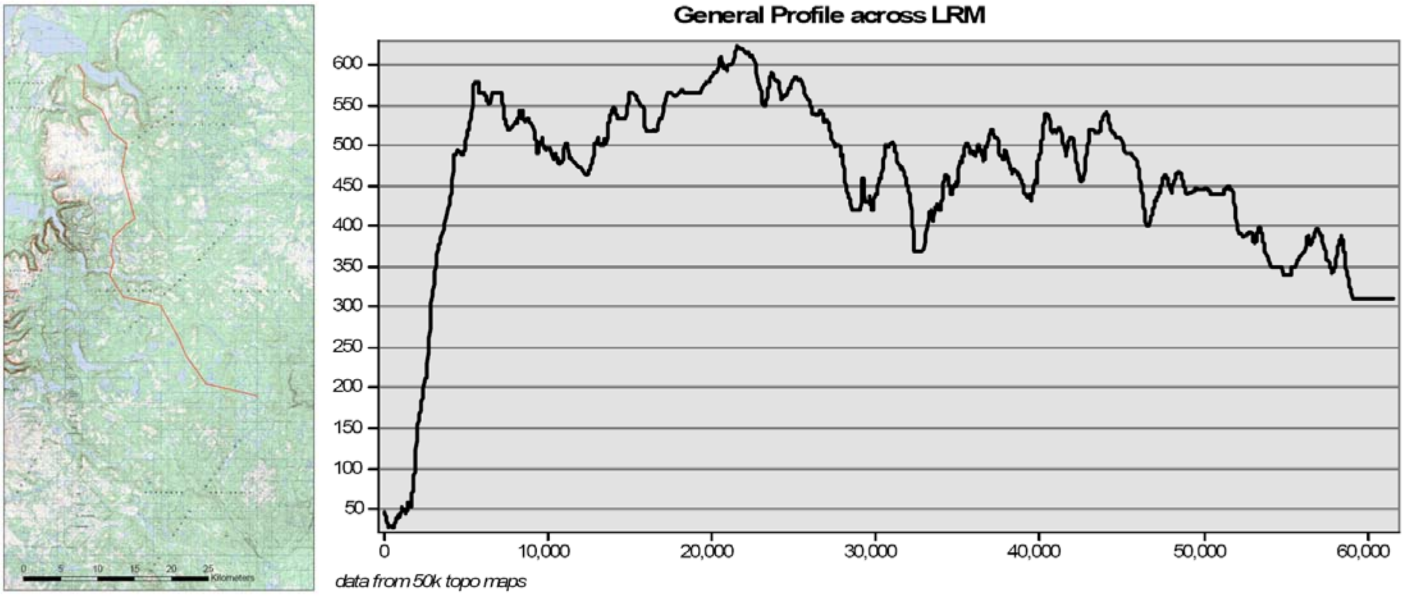

Figure 3. *Profile of possible line route across the Long Range Mountain, m above sea level.*

Figure 4. *Location of line route and test towers in the Long Range Mountain, top view.*

Figure 5. *Location of line route and test towers in the Long Range Mountain, 3D view*

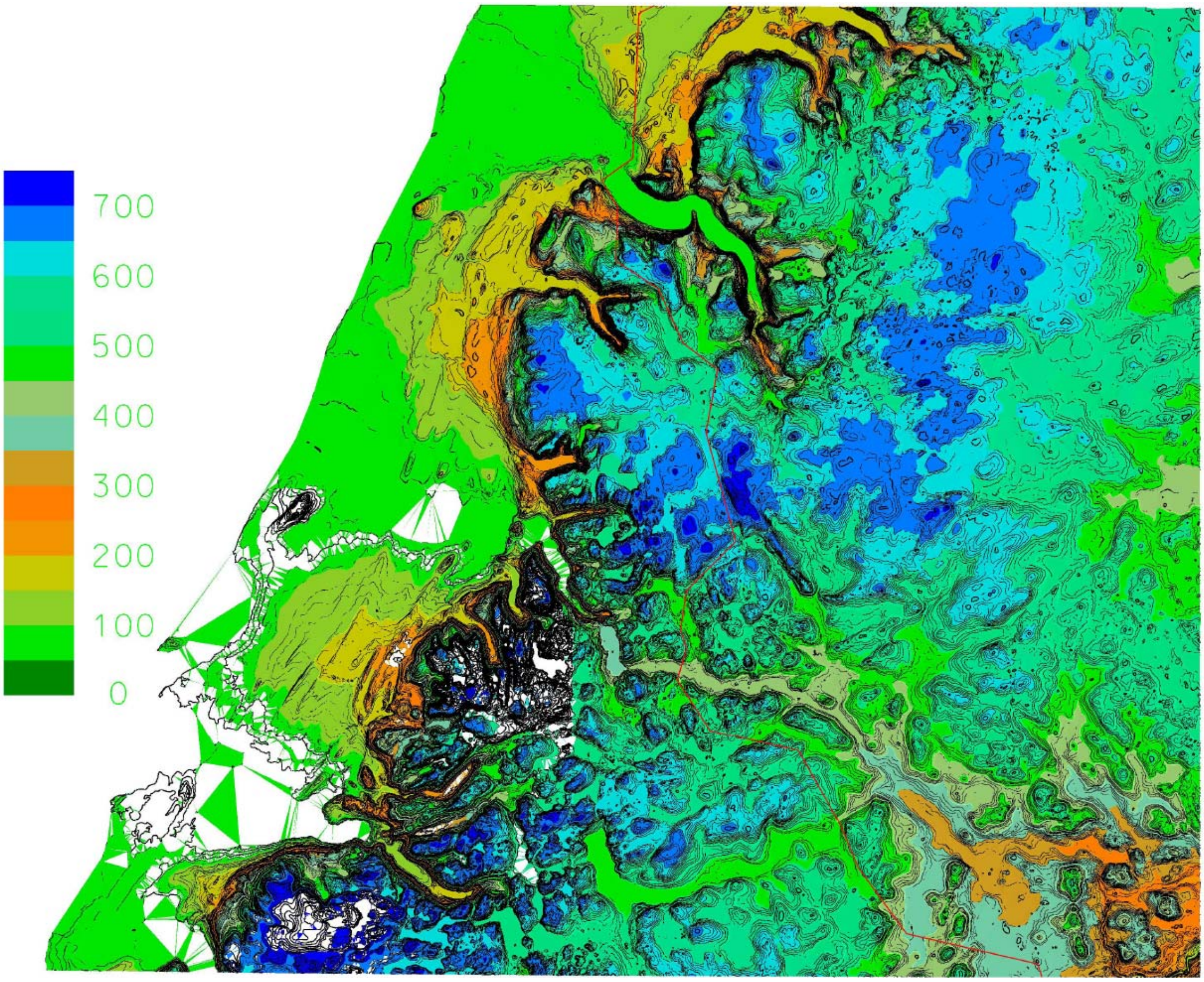

Figure 6. *Line route in the Long Range Mountain, colors shows elevation above sea level [m].*

3 Review of reports on in-cloud icing and salt contamination in Long Range Mountains

3.1 General

In 1973, work was initiated on the design of a transmission facility to transport power to Newfoundland from the proposed GULL ISLAND PROJECT in Labrador. During the fall of 1973 and the summer of 1974, two meteorological evaluations of the potential routes were conducted to establish design parameters. The lack of data necessary to confirm wind and icing predictions in various regions resulted in the establishment of a data collection program at four test tower sites during the winter of 1974/1975, This study encountered such massive ice loading in the vicinity of the ridge of the Long Range Mountains that with project deferment in 1976, it was decided to continue data collection in an effort to optimize the design parameter. In 1977, Hydro expanded the number of test towers and implemented an Island wide meteorological ice data collection program in the form of Passive Ice Meters (Butt 1986).

The Test Towers were guyed triangular lattice masts 10m in height without instrumentation. The mast section is 0.4 m x 0.4 m x 0.4 m. The towers were located at various locations along route alternatives for the transmission facility associated with the Gull Island Project. The towers did not have any instrumentation but were visited on a monthly basis. Any ice accretion was measured (thickness) and photographed, and the type of ice and direction from which the ice accreted, was recorded. In addition, wind speed, direction, and temperature were also recorded.

Two of the towers (#2 and #4[3]) were modified by attaching two horizontal aluminum rods 50 mm in diameter and 1.5 m long to simulate the conductor proposed for the Gull Island Project. The rods were installed in N-S and WE-W directions to examine the effects of wind direction as well as height above ground on ice accretion.

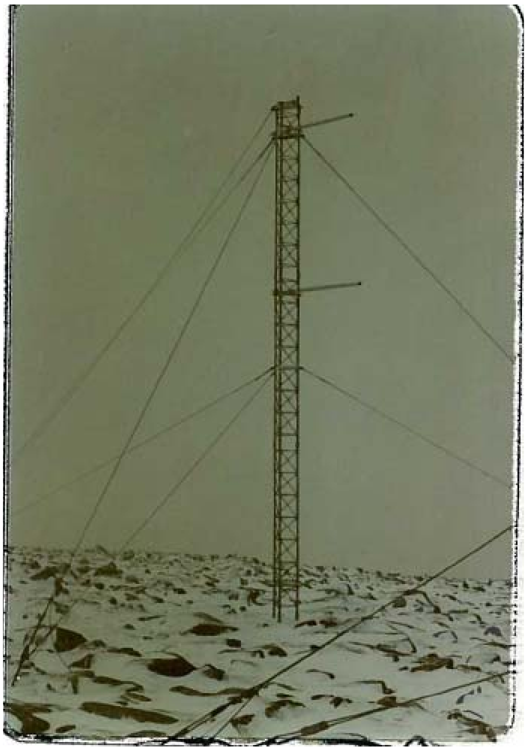

Figure 7. Test tower. Only few towers had two horizontal rods (50 mm) as this tower

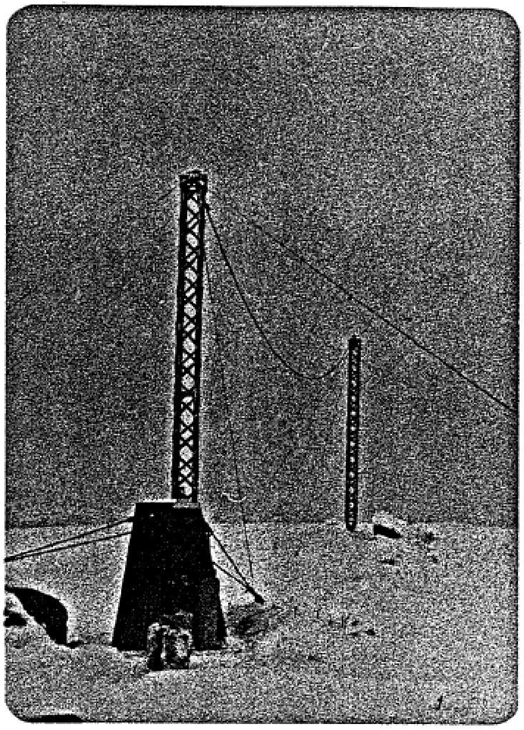

Figure 8. Test span at Brian's Pond. Span length was 40 m

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[3] Site #4 is located in Labrador.

When the first test towers sites were erected (1973-1977) the most exposed sites were selected for observation. Observations of these sites lead to the conclusion that massive ice loading would be encountered along the line route. Additional test towers were later placed either on or adjacent to, the line routing proved this conclusion to be invalid.

The most exposed site at Long Mountain Ridge is site 2, it was located eight miles south-southeast of Portland Creek on a ridge 610 m (2000 ft) above sea level. This site located near the area where the proposed route was expected to cross the ridge is well exposed in all directions.

A new measuring method was added in 1979 when three full scale test spans were erected (Brians Pond, Inner Pond and Parsons Pond). The full scale test spans consisted of two guyed steel towers supporting approximately 40m of 1192.5 MCM ASCR 54/19 conductor. Load cells were installed in two guys and recording equipment is housed in wooden shelters heated by propane. The experience with the instrumented test spans was not successful, no icing data was measured and the measuring system was soon disconnected. The test spans were not instrumented from spring 1982, but visited regularly and treated as passive collectors as the test towers.

The icing data collection program ended in summer 1987. The main findings of the measurements are presented in yearly reports that were prepared from 1977/1978 to 1986/1987.

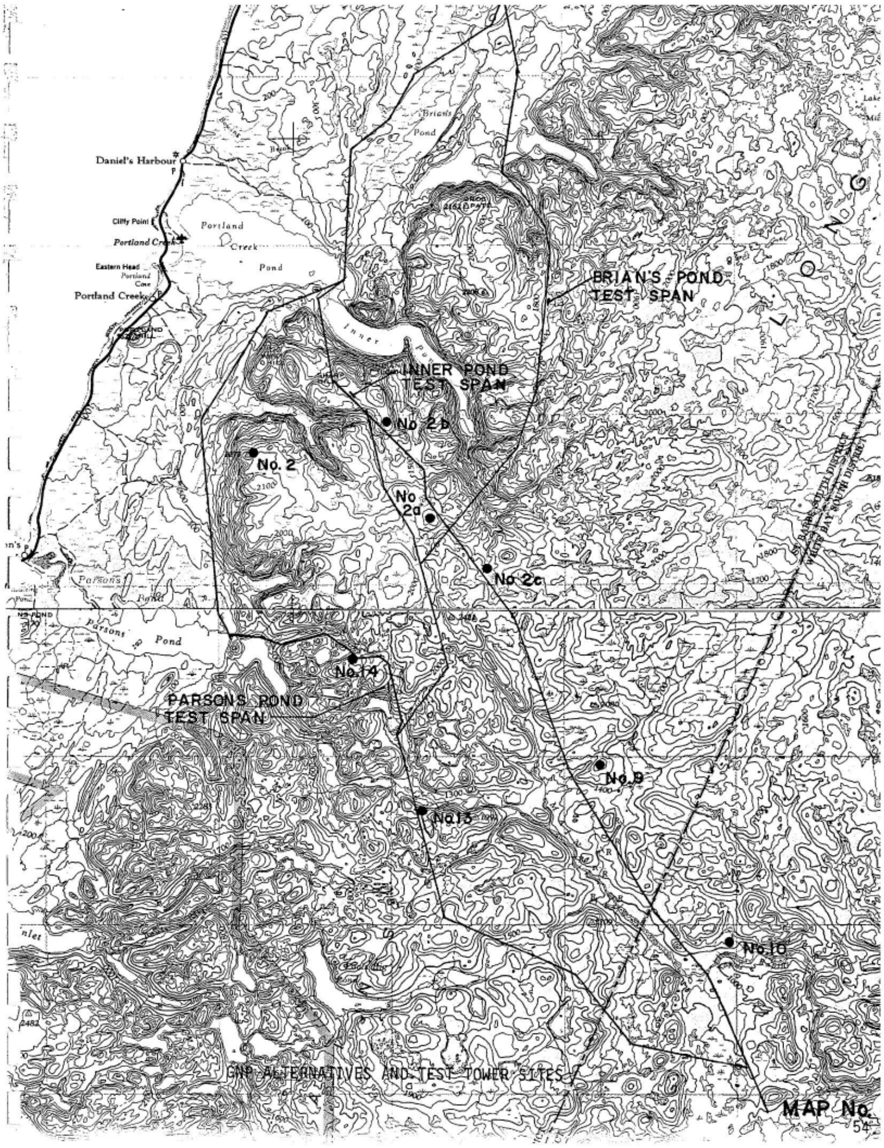


Figure 9. *Location of test spans and test towers.*

Table 1. *List of test towers and test spans in the Long Range Mountains.*

Test tower	X	Y
2	461712	5547734
2a		
2b	469620	5549616
2c	475890	5540822
2d	472396	5543888
2e		
2g		
2h		
2i		
9	482028	5529527
10	489651	5518795
13	471558	5526758
14	467534	5536084
14a		
15	470125	5531389
Brian Pond		
Inner Pond		
Parson Pond		

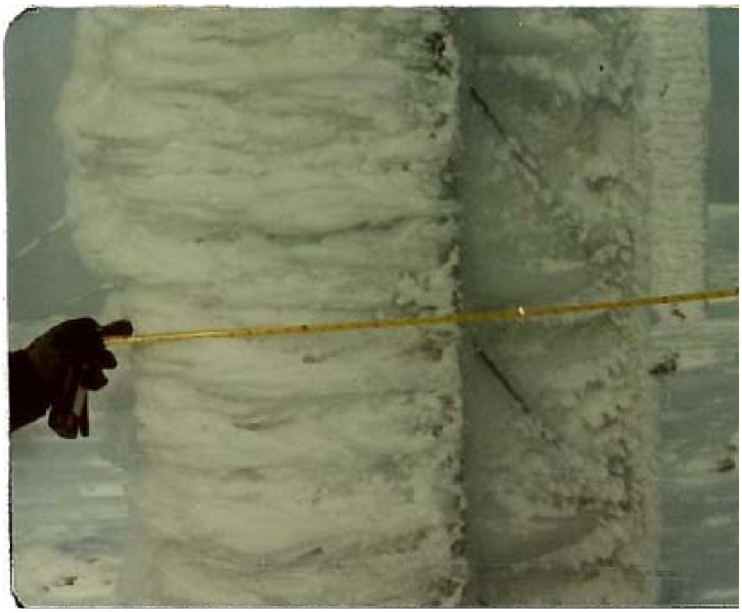


Figure 10. *Site #2. Portland Creek – December 1976.*

Figure 11. *Site #4. In Labrador – Feb. 1977.*

Observations made at the same time at exposed and sheltered sites along the route showed tremendous differences in ice accumulations. The effect of shelter in rime ice situations cannot be emphasized too strongly. Typical examples are shown in following photos of sites #2, #2b and #2c.

Figure 12. *Observation at same time shows tremendous difference in ice accumulation in sheltered areas.*

3.2 Proposed design loading for in-cloud icing at Long Range Mountain Ridge

The maximum loading specified at Long Range Mountain Ridge originates from a meteorological study made in 1973.

The in-cloud ice load was estimated using a climatology study using an ice accretion model with a limited data set obtained from the nearby airport and/or weather stations. The model seems to be based on the empirical model from Leavengood, considering wind speed and duration of icing in determination of diameter of rime ice. The model assumes that the liquid water content in the cloud was 500 kg/m^3 and the cloud drops were about 15 microns in diameter. Conductor diameter was assumed as 50 mm.

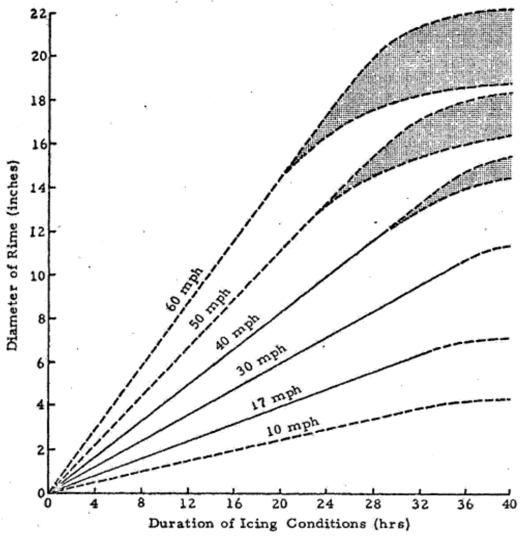
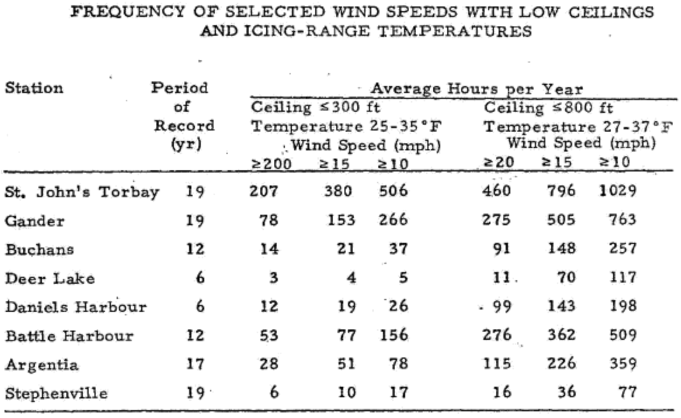


Figure 13. *Empirical relationships for estimating ice accretion diameter, from Leavengood 1972.*



FREQUENCY OF SELECTED WIND SPEEDS WITH LOW CEILINGS AND ICING-RANGE TEMPERATURES

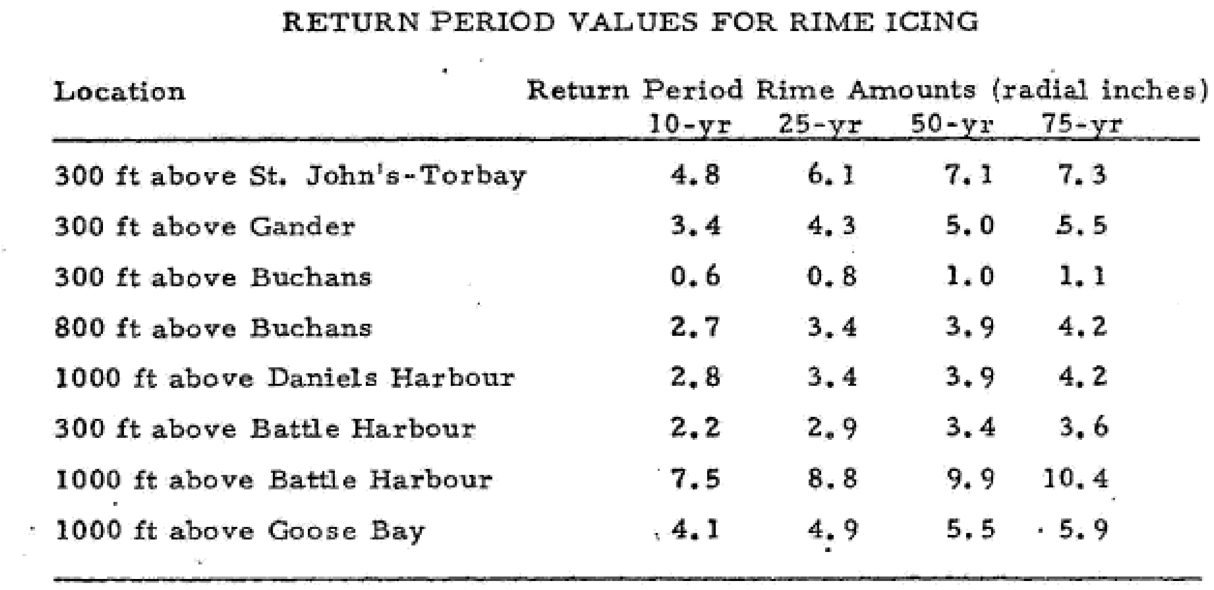
Station	Period of Record (yr)	Average Hours per Year					
		Ceiling ≤300 ft Temperature 25-35°F Wind Speed (mph)			Ceiling ≤800 ft Temperature 27-37°F Wind Speed (mph)		
		≥200	≥15	≥10	≥20	≥15	≥10
St. John's Torbay	19	207	380	506	460	796	1029
Gander	19	78	153	266	275	505	763
Buchans	12	14	21	37	91	148	257
Deer Lake	6	3	4	5	11	70	117
Daniels Harbour	6	12	19	26	99	143	198
Battle Harbour	12	53	77	156	276	362	509
Argentia	17	28	51	78	115	226	359
Stephenville	19	6	10	17	16	36	77

Figure 14. *Frequency of selected wind speeds with low ceilings and icing range temperature.*

In the study, the maximum rime ice which would have been formed in one icing period was determined for each year of record at appropriate heights above stations along the proposed routes. The heights were chosen to represent surrounding terrain. These maximum yearly values were used in extreme distribution.

The values 1000 ft.above Daniels Harbour do not necessarily represent expected conditions on the ridge of the Long Range Mountains. Storms coming in from the east would not have resulted in sufficient wind speeds or low enough ceilings at Daniels Harbour to have been considered.

Table 2. *Return period values for rime icing, results from study presented in 1973.*



RETURN PERIOD VALUES FOR RIME ICING

Location	Return Period Rime Amounts (radial inches) 10-yr	25-yr	50-yr	75-yr
300 ft above St. John's-Torbay	4.8	6.1	7.1	7.3
300 ft above Gander	3.4	4.3	5.0	5.5
300 ft above Buchans	0.6	0.8	1.0	1.1
800 ft above Buchans	2.7	3.4	3.9	4.2
1000 ft above Daniels Harbour	2.8	3.4	3.9	4.2
300 ft above Battle Harbour	2.2	2.9	3.4	3.6
1000 ft above Battle Harbour	7.5	8.8	9.9	10.4
1000 ft above Goose Bay	4.1	4.9	5.5	5.9

The same loading is specified for the Long Range Mountain Range from top of the ridge on north side of Main River (49°50'N) along the ridge to 51°N (1200 to 1800 ft). Following table shows the specified loading. It is pointed out that loading is defined as radial ice cover, it can be argued that it is better to specify loading based on kg/m in case of high in-cloud ice loading.

Table 3. *Loading specified for Long Range Mountain Range, results from study presented in 1973.*

Specified ice load	Unit	Return period of loading (years)			
		10	25	50	75
Radial ice cover	[in]	7.3	8.5	9.5	10.0
	[cm]	18.5	21.6	24.1	25.4
Total ice diameter with 50.8 mm cond.	[in]	16.6	19.0	21.0	22.0
	[cm]	42.1	48.3	53.3	55.9
Unit loading on 50.8 mm cond.	[Lb/ft]	46.2	60.8	74.4	81.7
	[kg/m]	68.8	90.4	110.7	121.6
Unit loading on 58.0 mm cond. [	[Lb/ft]	47.6	62.4	76.2	83.7
	[kg/m]	70.9	92.9	113.4	124.5

It is not specified in the loading assumptions if the ice load is the same for all heights above ground. Usually the in-cloud icing is defined at 10 m above ground and shall increase with height.

In general it has been found that the advantage of using climatological data model, as was used in the 1973 study, is that they can use available data for long periods and with relatively good spatial coverage. The disadvantage is that the correlation between actual icing on structure and icing model using routinely measured weather data may be low and needs to be quantified by site measurements and/or advanced numerical weather models. Another problem is that the data must be extrapolated to the site of interest and largely unverified methods must be used to derive the ice loading.

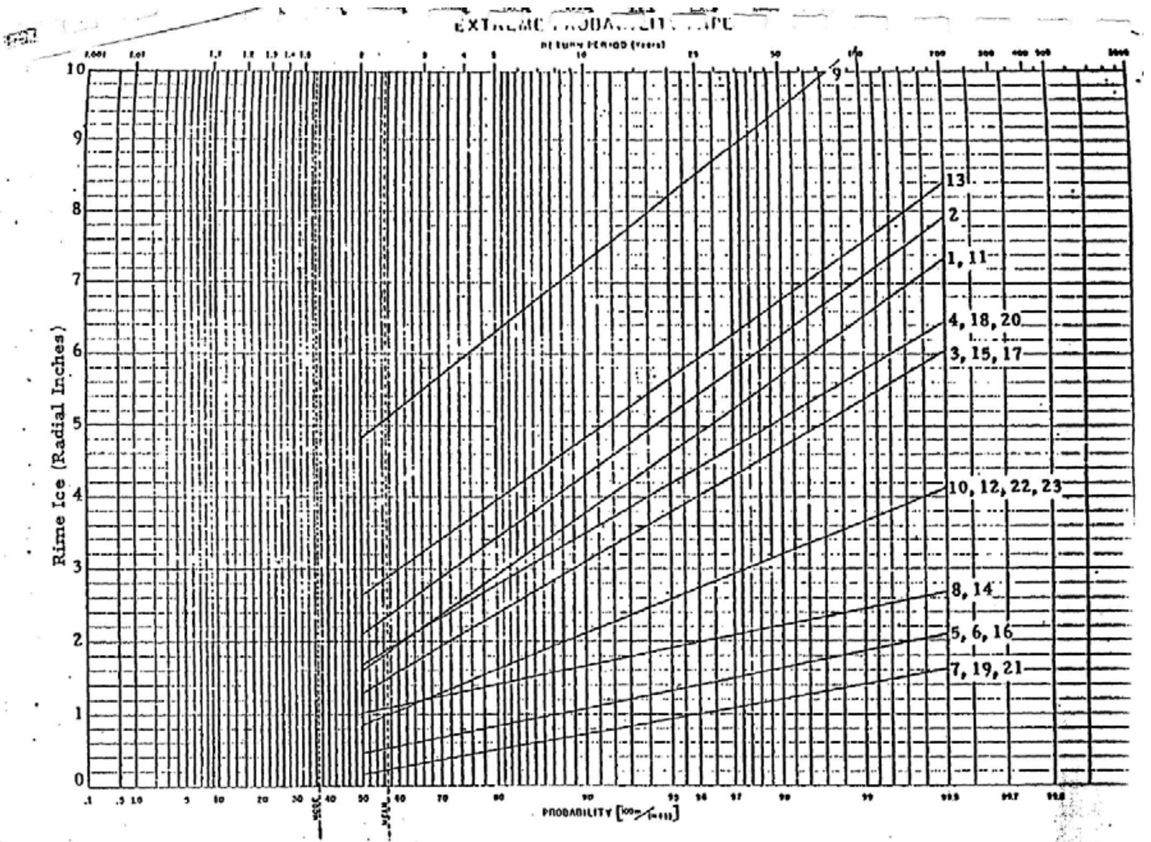


Fig. 31. · MAXIMUM RIME ICING PROBABILITIES BY LINE SEGMENT

Figure 15. *Maximum in-cloud icing probabilities by line sections. Section 9 refers to Long Range Mountain Ridge, others sections in the OHTL are also given by separate lines.*

3.3 Summary of relevant comments in reports of the Climatological Monitoring Program

In this chapter is given a summary of issues that were found relevant in the reports from the study and monitoring program from 1973-1987, Only issues that are connected to in-cloud icing in the Long Range Mountain are of interest.

1974/75 – Report MRI 75 FR -1378 Submitted from MRI to Teshmont

- During the winter 1974-1975, a second phase was conducted of a study to validate and refine values of wind and ice load determined during the previous year. The study consisted of data acquisition, field surveys, analysis of field and climatological data, and revision of line sector values developed during the earlier study.
- Four test towers were erected. At each site two 30-foot towers were erected approximately 54 feet apart, spanned by a cable 1.338 inches in diameter. An ice rate meter (IRM) that measures increased tension due to ice loading was connected to the cable. At top of each tower was a Mechanical Weather Station that recorded wind direction, wind run, temperature, and relative humidity.
- Site #2 was located eight miles S-SE of Portland Creek on a ridge 2000 feet above sea level. This site were located near the area where the proposed route was expected to cross the ridge. Site #2 is well exposed in all directions.
- Significant amounts of ice were measured frequently at Sites #2 and #4 (Labrador). At Site #2 there were 12 periods ranging in duration from 1 to 166 hours when ice accumulations exceeded six pounds per foot of cable. Maximum amounts occurred at the end of the longest icing period,

between January 12-20, when 14.5 pounds per foot was recorded. On the average, about 540 pounds of ice remained on the cable during the entire period.

- The results of the 1974-1975 measurement program did not indicate that a change in the icing estimates from the previous reports were necessary. With the exception of Site #2, no unusual ice loads were recorded or observed during a winter when icing appeared to be below normal at most Newfoundland stations. Site #2 did record severe ice buildups but that was expected as reflected in the 1973 report.
- *"The proposed line has been shifted from its previous location near Site #2 to an area further east. The elevation is generally lower, which affords some sheltering from the east. This should result in less icing although there are several points along the new route that are well exposed to easterly winds, which would be nearly perpendicular to the proposed route. It is difficult to estimate the impact of this channeling effect on the icing amounts in an area where slight changes in elevation or exposure can result in large wind and icing differences. Two areas in question are the high elevations on the west end of Inner Pond and a point on the route almost directly east of Site #2. It is likely that the icing in these areas is similar to that at Site #2, and thus the November 1973, estimates for Segment 9 are still valid. The remaining portion of the route segment crossing the ridge should have perhaps ten percent less ice for each of the return periods."*

1977/78 – Report on Climatological Monitoring Program

- The lack of data necessary to confirm wind and icing predictions in various regions resulted in the establishment of a data collection program at four test sites during the winter of 1974/1975 by Meteorology Research Inc. (MRI). This study encountered such massive loadings in the vicinity of the ridge of the Long Range Mountains near Portland Creek that it was thought prudent to investigate alternative routings for the HVDC in the Northern Peninsula Region.
- Site 2 was modified, by attaching 2-inch aluminum rods to the 20-foot and 30-foot levels of the towers. These rods were installed in N-S and E-W directions so that the effects of prevailing winds on ice accretion might be noted and to simulate the 2" conductor envisaged for the DC line. Actual measurements of ice accumulation are a problem due to installed height of rods. However, a photographic record of the accumulation is useful in that it shows how the build-up on these rods compares with the build-up on the towers and guys.
- Before the winter of 1977/1978 one additional test tower sites (#2a) was completed to study alternatives of rerouting the HVdc along the Eastern Side of the Long Range Mountain is to avoid the excessive loading encountered at site #2.
- Ice loading at site #2a conditions was only 1/3 as those at Site #2.

1978/79 – Report on Climatological Monitoring Program

- Three additional test tower sites were installed along the 28 mile section over the ridge of the Long Range Mountains from Portland Creek to Main River.
- The purpose for the establishment of site #2a in 1977 and then site 2b in 1978 was to determine if the ice accumulation varied due to natural sheltering and difference in elevation. During the 1977/1978 season it became apparent that site #2a received icing which was only 1/3 as severe as site #2 and similarly, in 1978/1979, site #2a received much smaller accumulations than site #2.
- At site #2b, during the 1978/1979 season, the type of ice accumulations were quite similar to those at site #2, however, less ice occurred at site #2b which is further inland and at a lower elevation than site #2.
- Observation indicate that the amount and type of ice accumulation can vary greatly within a small region and hence, great care should be taken in routing any transmission line to ensure maximum benefit is derived from natural sheltering while staying at the lowest possible elevation.

1979/80 – Report on Climatological Monitoring Program

- Prior to the 1979/80 season three additional towers were erected in the area of Long Range Mountains (#2c, #13 and #14). Sites were selected by the SNC-Lavallin line designers in order to avoid areas of heavy icing which had been found to exist. Sites #13 and #14 are located along the Parsons Pond Alternative. Site #14 was located at 1850+ feet of elevations and at the point on the route most exposed to onshore, westerly winds. Site #13 is located further inland and at 1550+ feet of elevation and sheltered from the westerly winds.
- As in the previous year site 2a received less accumulation than sites 2 and 2b. Site 2, as in the past, received the most accumulation of ice. The new site #2c, farther inland and at a higher elevation received very little accumulations. This trend would indicate that as the distance from the costal environment increases a sharp decrease in the amount of icing will occur.
- A new program element was added with erection of three full scale test spans (advised by SNC-Lavalin). The span on the Brians Pond Route was constructed on a well exposed ridge at 1600+ feet of elevation but still well sheltered from any westerly winds. The span on the Inner Pond Route was constructed on the edge of the escarpment just southeast of Sharp Hill at 1850+ feet of elevation and largely exposed to the southwest. The span on the Parsons Pond Tour was constructed at 1900+ feet of elevation and is very sheltered from all sides in a deep valley.
- The full scale test spans consisted of two guyed steel towers supporting approximately 40m of 1192.5 MCM ASCR 54/19 conductor. Load cells were installed in two guys and recording equipment was housed in wooden shelters heated by propane.
- During the first winter of operations only the Brians Pond Span was instrumented. No significant data was recorded.
- The Parsons Pond Test Span location presents a major operational problem as it is buried under excessive amounts of snow for the entire winter. Three feet of snow had accumulated near the towers in early December, by mid January the depth had increased to approximately fifteen feet and during the final visit on May 20, 1980 little change had occurred. These conditions will make it impossible to service equipment and provide ventilation for a heating system housed in a six foot shelter at ground level. To use this site during the coming season it will be necessary to relocate the entire system to a less sheltered area.

1980/81 – Report on Climatological Monitoring Program

- Increased emphasis was placed on Long Range Mountains Crossing in the areas of the proposed routes as selected by SNC Lavalin group. New Test tower sites were established along these routes at sites #2d, #2e and #15.
- The recording equipment used at the Brians Pond span, during the 1979/80 season, was reconditioned and installed at the most exposed, Inner Pond Span before the 1980 winter collection period.
- Data from test spans were analyzed by SNC and they concluded: “The test span and recording system seem to be operating correctly but the loads are too low to be of value in determine ice accumulation“
- The additional year of data collected in the Long Rang Mountains Crossing area confirms the necessity of taking advantage of all natural shelter and routing the line off the high lands.

1981/82 – Report on Climatological Monitoring Program

- Inner Pond Test span was instrumented and data was forwarded for analysis. No icing occurred.
- The test spans at Brian‘s Pond and Parsons Pond were treated as a passive collector and visited regularly.

- Cloud droplet sizes were investigated at 4-Mile Pond, Holyrood site and at the Portland Creek site #2. Mr. B. Power of Weather Engineering concluded that there is a diameter limit for cloud droplet size and that the average droplet size would be less than 10 microns.

1982 –Report from Weather Eng. Corp. Of Canada on Climatological Monitoring Program (1977-1981)

- Installation of test spans (Inner Pond, Brian‘s Pond, Parsons Pond) were made at high elevations in the Long Range Crossing segment, but in fairly sheltered terrain, typical of the majority of the line route in that area. During two winters (1979/80, 1980/81), they have experienced very little ice and have thus served to demonstrate the reality of the dramatic effect of very slight or moderate terrain shelter (100 to 500 ft.) in reducing the ice loading from that occurring at fully exposed site.
- In any future test, it might be advisable to install two test spans at each location, one fully exposed and one in moderate or light shelter, so that a more meaningful comparison could be made.
- Test towers were very successful, producing the basic icing data for the HVdc route selection and line design in the sever loading segments of the Long Range Crossing the Highlands of St. John‘s and in the Labrador Up-slope areas. They are simple, rugged, and reliable and can be considered as the prototype for successful ice determinations for line design under extreme ice conditions in remote, relatively inaccessible areas. The accomplishments are:
  1) Mapping of the quantitative distribution of icing at high exposed sites.
  2) Good indications of the directions of the storm icing winds.
  3) Revealed dramatic difference in ice type (rime, glaze) between different regions which had been unsuspected (e.g. Cat Arm)
  4) Demonstrated the effects of shelter in reducing ice loadings.
  5) Enabled a rational selection of HVdc routes and route alternatives.
  6) Provided data on the seasonal variation in ice severity
  7) Provided data on the physics of ice accretion on various structural shaped members.

  Future work with these towers could well take the form of improvements in parts of the tower geometry in an attempt to improve the ice accumulation measurements so that they can be better interpreted in terms of equivalent ice accumulation on cylindrical conductors. Such innovation is strongly recommended for the Cat Arm Development area.
- Loading results are:
  1) Fully exposed sites (#2, #2b, #4, #11, #12, #5, #8)[4] receive 12-18“ of diameter of rime and/or glaze every 2 to 3 years.
  2) The Long Range Crossing receives the heaviest accumulation of rime ice, whereas the eastern slope (Cat Arm area) and the Labrador up-slope receive mainly cloud glaze.
  3) Mapping of the quantitative distribution of icing at high exposed sites.

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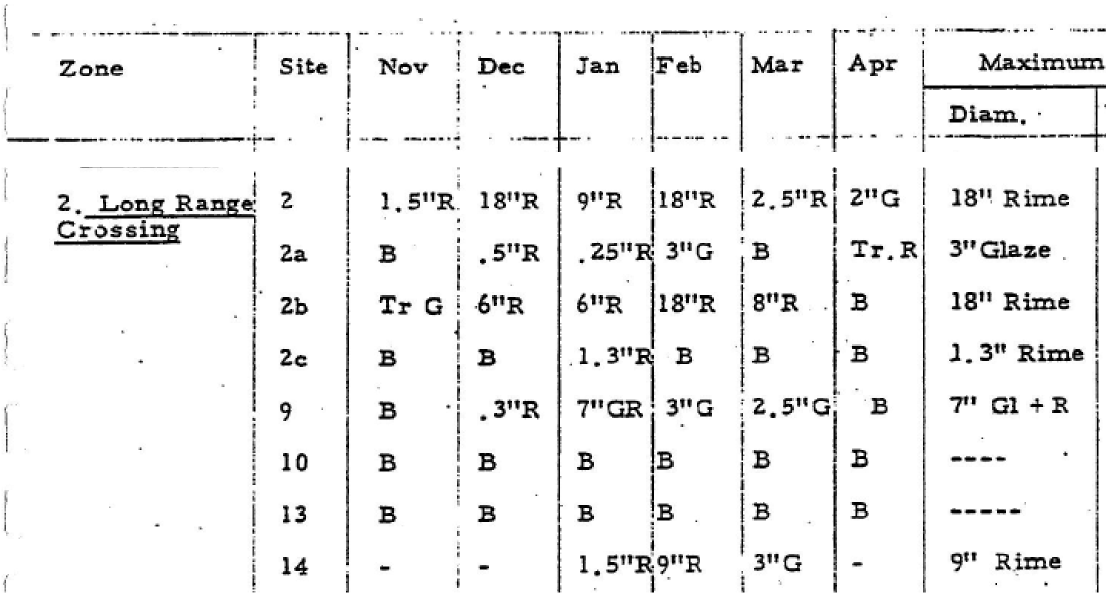
[4] Note that sites #4, #11 and #12 are not in the Long Range Mountains

Table 4. *Maximum ice on test towers (1977-1980) as presented in Report from Weather Eng. Corp. Of Canada on Climatological Monitoring Program (1977-1981).*



Zone	Site	Nov	Dec	Jan	Feb	Mar	Apr	Maximum
								Diam.
2. Long Range Crossing	2	1.5"R	18"R	9"R	18"R	2.5"R	2"G	18" Rime
	2a	B	.5"R	.25"R	3"G	B	Tr.R	3"Glaze
	2b	Tr G	6"R	6"R	18"R	8"R	B	18" Rime
	2c	B	B	1.3"R	B	B	B	1.3" Rime
	9	B	.3"R	7"GR	3"G	2.5"G	B	7" Gl + R
	10	B	B	B	B	B	B	----
	13	B	B	B	B	B	B	-----
	14	-	-	1.5"R	9"R	3"G	-	9" Rime

- In-cloud rime. The distribution and severity of cloud rime ice is fairly well known from the MRI HVDC estimates, and the CMP test tower observations. The MRI estimates are conservative, and it would be desirable to obtain more precise data so that, if possible, some reductions or refinement in the estimates might be made. The CMP has produced observational evidence on rime severity, its local distribution, and on the marked effect of slight topographic shelter in reducing the icing loadings.

1982/83 – Report on Climatological Monitoring Program

- This winter was unusually mild thus no substantial accumulations were observed.
- The three test span were not instrumented, but visited regularly and treated as passive collectors.

1983/84 – Report on Climatological Monitoring Program

- This winter was fairly mild with no substantial accumulations observed.
- The three test span were not instrumented, but visited regularly and treated as passive collectors.

1984/85 – Report on Climatological Monitoring Program

- The winter was fairly mild with no substantial accumulations observed.
- It has been observed over the last few years that there is a vast difference in ice accumulation between exposed and sheltered sites. For example, exposed site 2b may have 30" of pendant rime while the test span on Inner Pond at a sheltered site has relatively little ice. It is felt that in order to get the true picture of what accumulation would be along the proposed routes (Inner Pond and Parsons Pond) the test towers should be on the routes. It is recommended, therefore, that some existing test towers be relocated to the actual line routes prior to the 1986 session.
- Tower at site #2 were down in 85-02-13 due to failed turn buckle

1985/86 – Report on Climatological Monitoring Program

- The winter was fairly mild with no substantial accumulations observed.
- As recommended in the 1984/85, some existing towers were relocated in 1985 to the actual line routes, to see the difference in ice accumulation from exposed areas to sheltered areas. Although the ice accumulations for 1985/86 were relatively small, the difference in ice accretion from the actual line route to exposed test tower sites was dramatic. In most cases, the test towers on

exposed sites would have large accumulations while the test towers or the sheltered line routes were bare.

- Tower site #2a relocated to new site #14a. Tower site #2c relocated to new site #2h. Tower site #2d relocated to new site #2i.
- Test spans. During January 1986 vandals struck the test span at Inner Pond toppling one of the towers. The remaining tower is now being monitored as a test tower. The test span at Brian's Pond remained intact.

1986/87 – Report on Climatological Monitoring Program

- Sites 2, 2b and 14 show an increase in accumulation of Rime over the previous year, but are similar to the accumulations recorded for the 1984/85 seasons. There were no marked differences in any of the other sites with accumulations ranging from 0 to 8".

3.4 Yearly maximum loading at test sites at Long Range Mountain

The following is an attempt to quantify the yearly maximum loading for each test site at Long Range Mountain. The classification is made according to ice class and has similarity to the classification in ISO 12494. Classification of data needs to be taken with much caution due to great uncertainty in evaluation. Information on icing is not given in much detail[5] and it would need access to detailed raw data with photos to be able to make quantification with good accuracy.

It needs to be mentioned that maximum loading may be missing from the data series since towers were only visited monthly and no information is available on icing between visits.

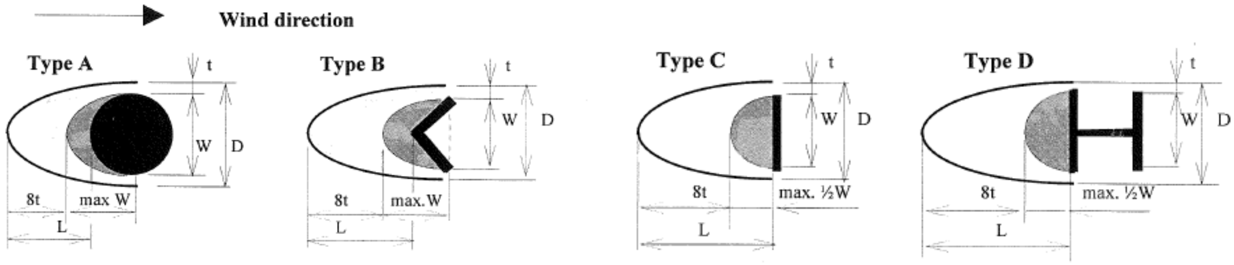


Figure 16. *Ice accretion model for rime ice in* ISO 12494.

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[5] Example of uncertainity: Size of bars in tower is not available, limited description is given when tower is completely encased, weight/m is never measured, photos are not available, often unclear if deposit is pennants etc. , density of ice not measured.

Table 5. *Ice class for rime ice according to ISO 12494 with density of ice = 500 kg/m, valid only for in-cloud icing.*

Ice class	Ice mass	Rotating circular ref. ice collector (d=30mm)		Ice dimension for vane shaped accreted ice on bars							
				Type A & B with W=30mm				Type C & D with W=30mm			
IC	m	D		L		D		L		D	
	(kg/m)	(m)	(inc)	(m)	(inc)	(m)	(inc)	(m)	(inc)	(m)	(inc)
R1	0,5	47	1,9	34	1,3	35	1,4	36	1,4	35	1,4
R2	0,9	56	2,2	54	2,1	40	1,6	57	2,2	40	1,6
R3	1,6	71	2,8	82	3,2	47	1,9	86	3,4	48	1,9
R4	2,8	90	3,5	120	4,7	56	2,2	124	4,9	57	2,2
R5	5,0	117	4,6	174	6,9	70	2,8	179	7,0	71	2,8
R6	8,9	154	6,1	247	9,7	88	3,5	253	10,0	90	3,5
R7	16,0	204	8,0	348	13,7	112	4,4	355	14,0	115	4,5
R8	28,0	269	10,6	478	18,8	146	5,7	484	19,1	147	5,8
R9	50,0	358	14,1	656	25,8	190	7,5	663	26,1	192	7,6
R10	extreme ice accretions										

Table 6. *Classification of yearly maximum loading for each test site at Long Range Mountain. Classification system (1-10) takes notice of ice class in ISO 12494. Evaluations contain great uncertainty since initial registration and photos were not available.*

Site	76-77	77-78	78-79	79-80	80-81	81-82	82-83	83-84	84-85	85-86	86-87	MAX
2	8	7	7	7,5	3,5	7	3	6,5	8	1	8	8
2a		4	6	4,5	2	2	5	2	2			6
2b				7	7	7	5	7	7,5	5	7,5	7,5
2c				1	1	1	1	1				1
2d					4	4	5,5	1	6			6
2e					0	0	0	0	0	0	2	2
2g										2	1	2
2h										1	1	1
2i										1	3	3
9			4	4	1	3	3	1	0			4
10			0	0	0	0	0	0	0	0	0	0
13				0	1	1	1	0	0	2	0	2
14				7	5	5	5,5	6	1	2	6	7
14a											4	4
15					0	1	1		0	0	0	1
Inner Pond										1	4,5	4,5
Brian Pond											0	0

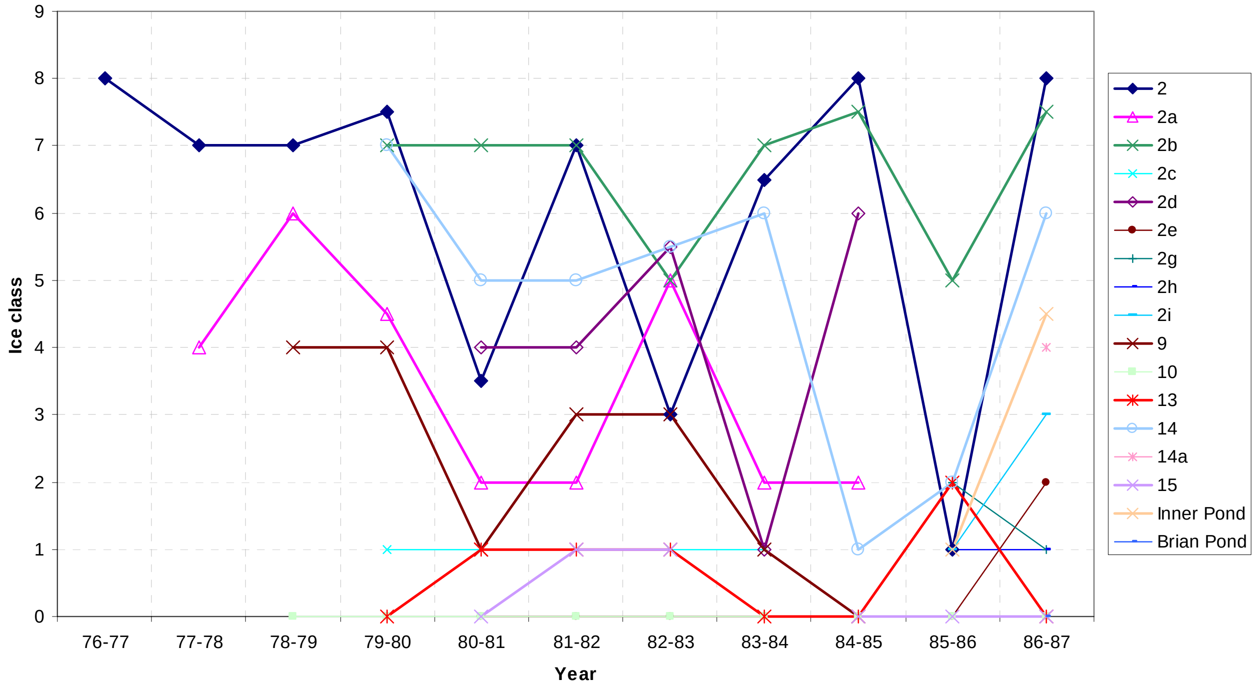


Figure 17. *Yearly maximum loading for each test site at Long Range Mountain according to ice classification.*

From Figure 17 and Table 5 it can be seen that loading is very site dependent. Some sites get high loading most years while others get limited loading most years.

- Test sites with low in-cloud loading: #2c, #2e, #2g, #2h, #2i, #10, #13, #15, Brian Pond
- Test sites with moderate in-cloud loading: #9, #14a, Inner Pond
- Test sites with medium-high in-cloud loading: #2a, #2d
- Test sites with high in-cloud loading: #2, #2b, #14

The question is, if icing on a tower can be used for quantifying ice load to an actual conductor? It has been shown in tests that extrapolation of ice load of some kilograms measured on a non-rotating fixed small sampler to real power line conductor can be made reasonable for small ice load but must be exercised with great care for large ice loads (>10 kg). To use icing on the lattice tower is then more difficult than using single rod (typically horizontal cylindrical 30 mm) due to complicated evaluation with encasing of the tower. A thorough study needs to be undertaken before the ice description from test towers can be used to quantify loading on conductor.

3.5 Measurement of salt contamination in the line route

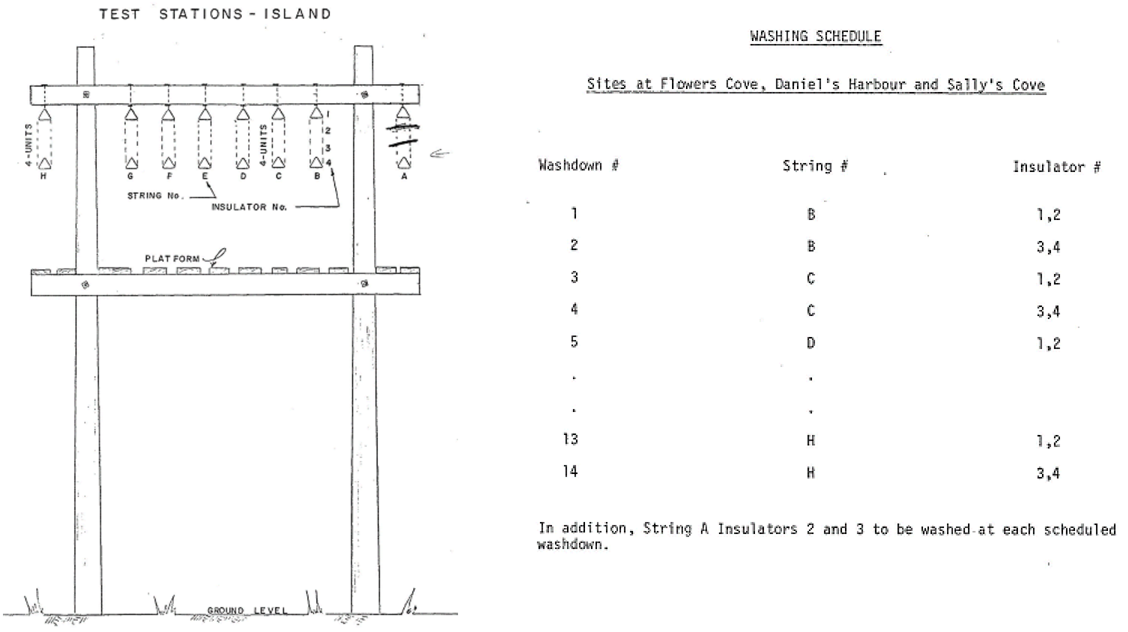
Measurement of salt contamination was started in 1978 to monitor natural contamination levels at various points along the Great Northern Peninsula and in Southern Labrador. No data is given after 1981.

1978/79 – Report on Climatological Monitoring Program

- There were basically two objectives of this program:
    1) To determine if there is a reduction in contamination levels as distance from the ocean increases.

2) To determine if there is any change in contamination levels along the coast of the Great Northern Peninsula.

- It was anticipated that the following information would be provided:
  1) Determine contamination levels at both sides of the straits crossing, and determine any reductions in levels moving inland from both sides of the crossing.
  2) To determine levels moving inland from the sea at Daniel's Harbour.
  3) To determine levels moving inland from the sea at Sally's Cove.
  4) To determine if a pattern of contamination exists moving north from Sally's Cove to Flowers Cove.
- For measurement of salt contamination, test towers were erected with insulator strings which were washed and the salt content measured according to a schedule (every two weeks). The program started in January 1979 with the eight (8) stations at Daniel's Harbour and Sally's Cove and two Labrador sites providing reliable information.



WASHING SCHEDULE

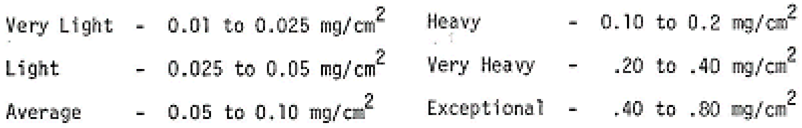
Sites at Flowers Cove, Daniel's Harbour and Sally's Cove

Washdown #	String #	Insulator #
1	B	1,2
2	B	3,4
3	C	1,2
4	C	3,4
5	D	1,2
.	.	
.	.	
13	H	1,2
14	H	3,4

In addition, String A Insulators 2 and 3 to be washed at each scheduled washdown.

Figure 18. *Test tower for salt contamination.*

- The salt contamination on the insulator sheds is measured in ESDD (Equivalent Salt Deposit Density, in mg/cm^2)) and is classified according to;



Very Light	-	0.01 to 0.025 mg/cm^2	Heavy	-	0.10 to 0.2 mg/cm^2
Light	-	0.025 to 0.05 mg/cm^2	Very Heavy	-	.20 to .40 mg/cm^2
Average	-	0.05 to 0.10 mg/cm^2	Exceptional	-	.40 to .80 mg/cm^2

- The results of the measurements showed “Little” or “Very Little” contamination level.

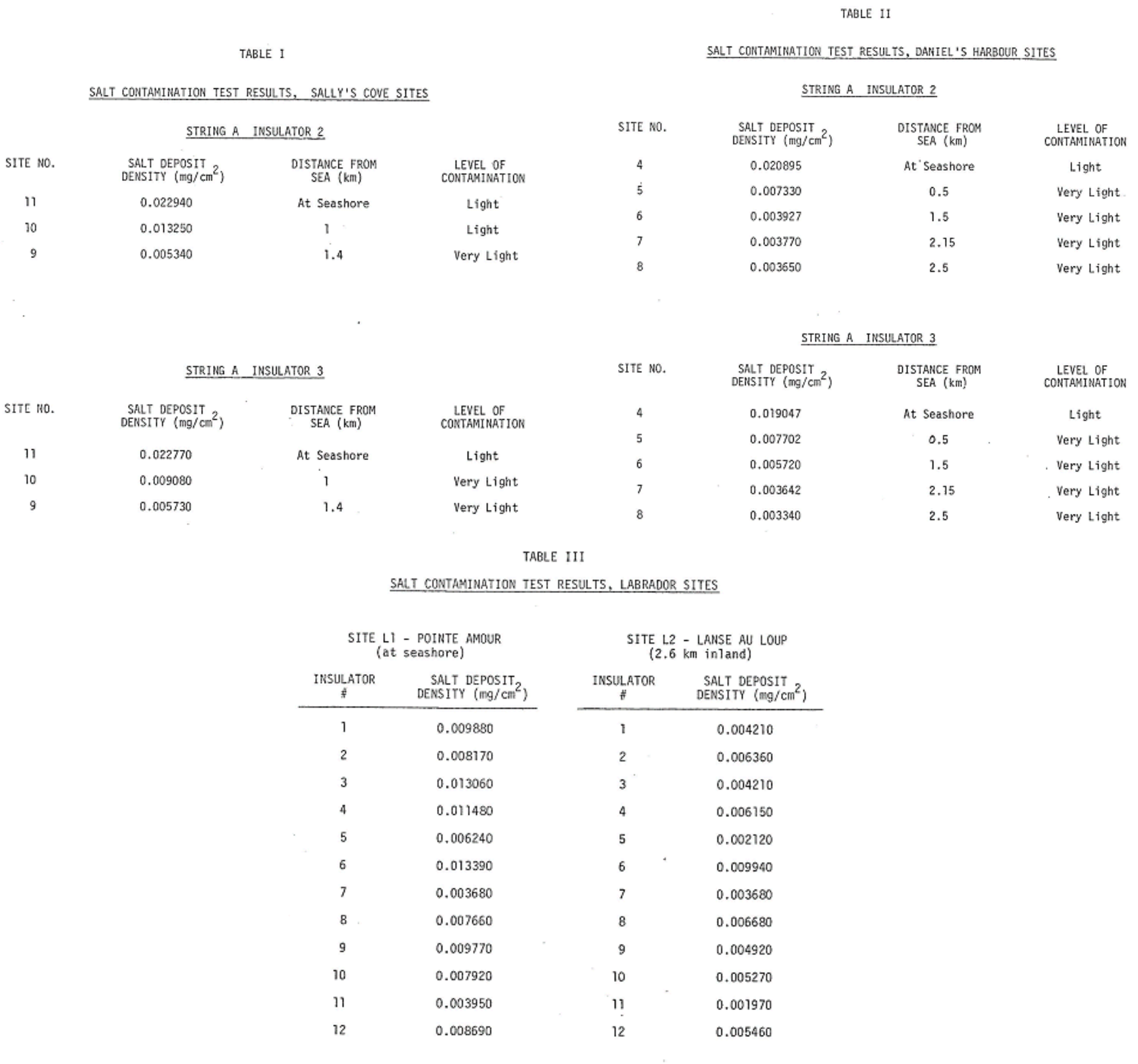


TABLE I

SALT CONTAMINATION TEST RESULTS, SALLY'S COVE SITES

STRING A INSULATOR 2

SITE NO.	SALT DEPOSIT DENSITY (mg/cm^2)	DISTANCE FROM SEA (km)	LEVEL OF CONTAMINATION
11	0.022940	At Seashore	Light
10	0.013250	1	Light
9	0.005340	1.4	Very Light

STRING A INSULATOR 3

SITE NO.	SALT DEPOSIT DENSITY (mg/cm^2)	DISTANCE FROM SEA (km)	LEVEL OF CONTAMINATION
11	0.022770	At Seashore	Light
10	0.009080	1	Very Light
9	0.005730	1.4	Very Light

TABLE II

SALT CONTAMINATION TEST RESULTS, DANIEL'S HARBOUR SITES

STRING A INSULATOR 2

SITE NO.	SALT DEPOSIT DENSITY (mg/cm^2)	DISTANCE FROM SEA (km)	LEVEL OF CONTAMINATION
4	0.020895	At Seashore	Light
5	0.007330	0.5	Very Light
6	0.003927	1.5	Very Light
7	0.003770	2.15	Very Light
8	0.003650	2.5	Very Light

STRING A INSULATOR 3

SITE NO.	SALT DEPOSIT DENSITY (mg/cm^2)	DISTANCE FROM SEA (km)	LEVEL OF CONTAMINATION
4	0.019047	At Seashore	Light
5	0.007702	0.5	Very Light
6	0.005720	1.5	Very Light
7	0.003642	2.15	Very Light
8	0.003340	2.5	Very Light

TABLE III

SALT CONTAMINATION TEST RESULTS, LABRADOR SITES

SITE L1 - POINTE AMOUR (at seashore)		SITE L2 - LANSE AU LOUP (2.6 km inland)	
INSULATOR #	SALT DEPOSIT DENSITY (mg/cm^2)	INSULATOR #	SALT DEPOSIT DENSITY (mg/cm^2)
1	0.009880	1	0.004210
2	0.008170	2	0.006360
3	0.013060	3	0.004210
4	0.011480	4	0.006150
5	0.006240	5	0.002120
6	0.013390	6	0.009940
7	0.003680	7	0.003680
8	0.007660	8	0.006680
9	0.009770	9	0.004920
10	0.007920	10	0.005270
11	0.003950	11	0.001970
12	0.008690	12	0.005460

Figure 19. *Results of salt contamination measurements.*

1979/80 – Report on Climatological Monitoring Program

- Collection of data from test sites in Labrador were terminated as it was very difficult to get there due to snow in the winter.
- Collection of data from the Great Northern Peninsula was very successful.

1981/82 – Report on Climatological Monitoring Program

- The Salt Contamination Program was terminated in January 1981.
- It was felt that sufficient collaborating data had been collected.
- The emphasis was placed on the termination sites at Labrador and Yankee Point and the surrounding areas.
- **An extreme contamination level was reached during late October 1981. A review of climatological conditions at that time revealed strong onshore winds (64-72 km/h or 18-20 m/sec) occurred one day before the insulators were collected.** Hence, it has been concluded that

a heavy salt buildup had occurred and that no natural washing had taken place. Also those previous levels which have been recorded as being very low are due to the high frequency of natural washing.

- This extreme contamination was measured at Flowers Cove on the Newfoundland side of the strait (Point F1).

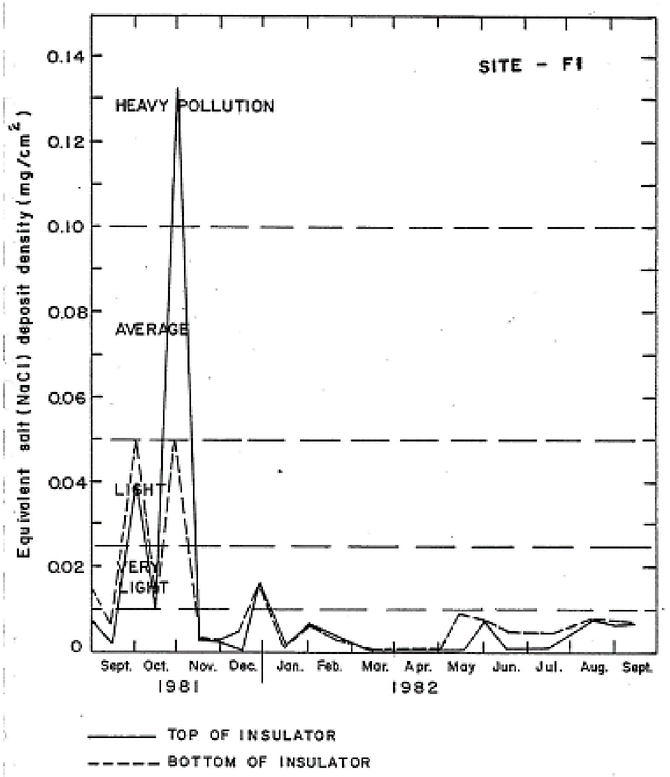
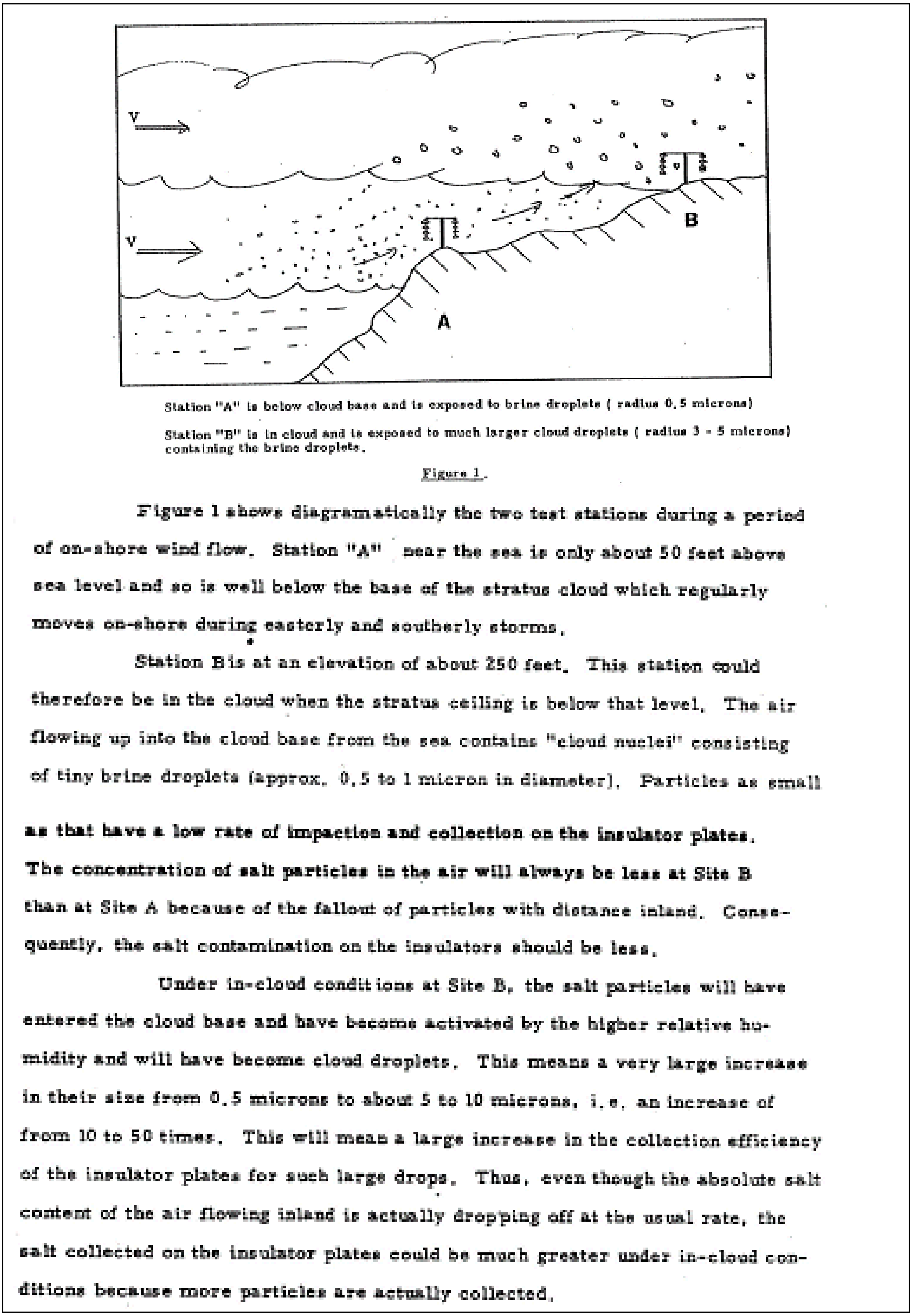


Figure 20. *Contamination measured at Flowers Cove.*

- The findings have been that salt contamination drops off rapidly with distance inland from the sea, so that it is not a serious concern more than a mile inland. However, recent observations from the two new test sites on the Labrador side of the Strait of Belle Isle Crossing cast some doubt on the decay rate with distance inland previously found. Here, a new site about a mile inland has recorded higher salt levels than the station right at the coast. This information was recently brought to WECAN's attention and the following possible explanation has been offered.



Station "A" is below cloud base and is exposed to brine droplets (radius 0.5 microns)

Station "B" is in cloud and is exposed to much larger cloud droplets (radius 3 - 5 microns) containing the brine droplets.

Figure 1.

Figure 1 shows diagramatically the two test stations during a period of on-shore wind flow. Station "A" near the sea is only about 50 feet above sea level and so is well below the base of the stratus cloud which regularly moves on-shore during easterly and southerly storms.

Station B is at an elevation of about 250 feet. This station could therefore be in the cloud when the stratus ceiling is below that level. The air flowing up into the cloud base from the sea contains "cloud nuclei" consisting of tiny brine droplets (approx. 0.5 to 1 micron in diameter). Particles as small as that have a low rate of impaction and collection on the insulator plates. The concentration of salt particles in the air will always be less at Site B than at Site A because of the fallout of particles with distance inland. Consequently, the salt contamination on the insulators should be less.

Under in-cloud conditions at Site B, the salt particles will have entered the cloud base and have become activated by the higher relative humidity and will have become cloud droplets. This means a very large increase in their size from 0.5 microns to about 5 to 10 microns, i.e. an increase of from 10 to 50 times. This will mean a large increase in the collection efficiency of the insulator plates for such large drops. Thus, even though the absolute salt content of the air flowing inland is actually dropping off at the usual rate, the salt collected on the insulator plates could be much greater under in-cloud conditions because more particles are actually collected.

Figure 21. *On decay rate with distance inland.*

4 On design radial rime icing at Long Range Mountain Ridge

4.1 Example of in-cloud icing at exposed sites

In-cloud icing affects high altitude structures in many countries. In northern parts of Scandinavia it may however be found below 400 m above sea level.

In order to quantify size of in-cloud icing it would be convenient to have a statistic of maximum ice load that has occurred or been used in design in different countries. No thorough investigation presenting such data is available. In following a brief survey is made on data that has been presented in literature (mainly IWAIS).

4.1.1 Iceland.

Possibility of in-cloud icing is considered when the transmission line is above 300 m above sea level in coastal area. Most critical are line routes in high altitude close to the sea. Especially where humid air and strong wind from the ocean can be expected. Also inland for lines that are higher than 800 m and the line route is higher than the surrounding area.

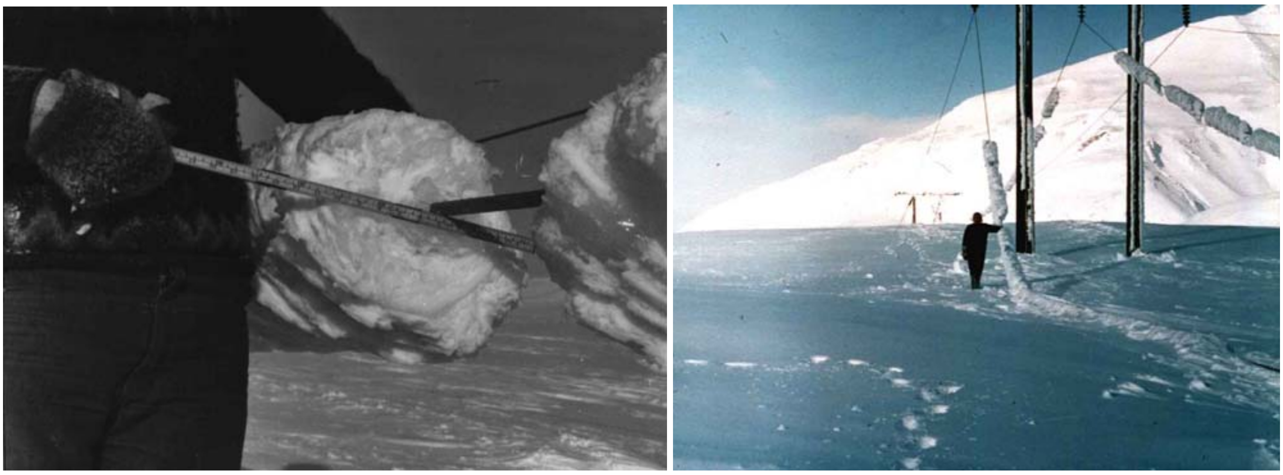


Figure 22. Icing at Hallsteinsvarp 28.02.1978. Ice weight 29.4 kg/m. Density 420 kg/m3.

Figure 23. In-cloud icing on a guy wire.

Figure 24. In-cloud icing on a 132 kV OHTL at Hallormsstadarhals.

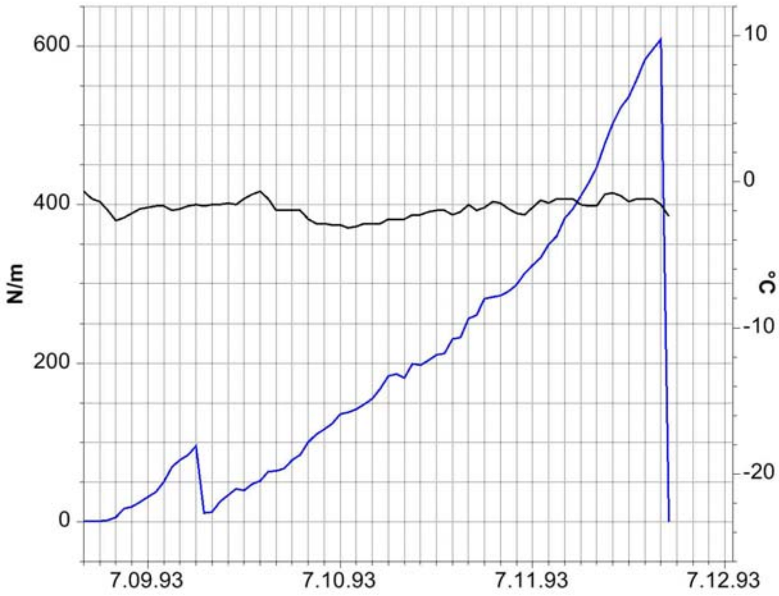
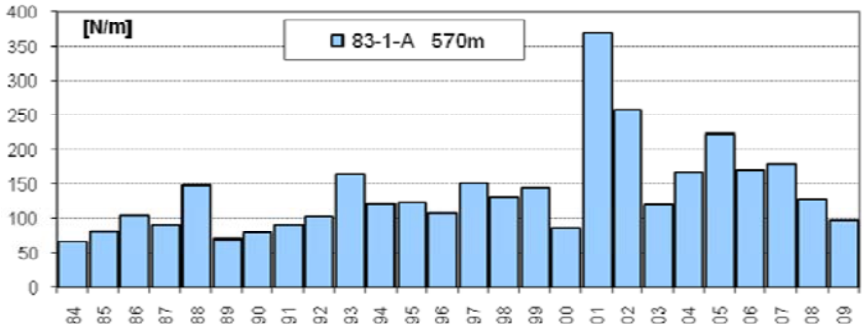


Figure 25. *Maximum ice loading measured in a test span(85-1-B) in Iceland. Icing was in July. Test span broke before accumulation stopped.*

Figure 26. *Icing in a test span (80m)*

Figure 27. *Test spans (3 spans) at Hallormsstadarhals (83-1).*



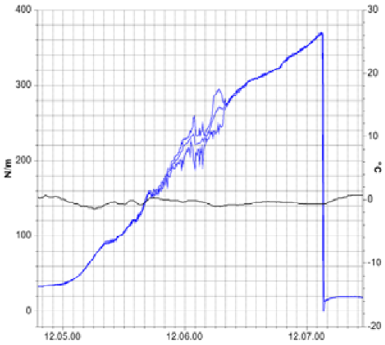


Figure 28. *Yearly maximum loading in test span (83-1-A).*

Figure 29. *Highest loading in test span 83-1-A.*

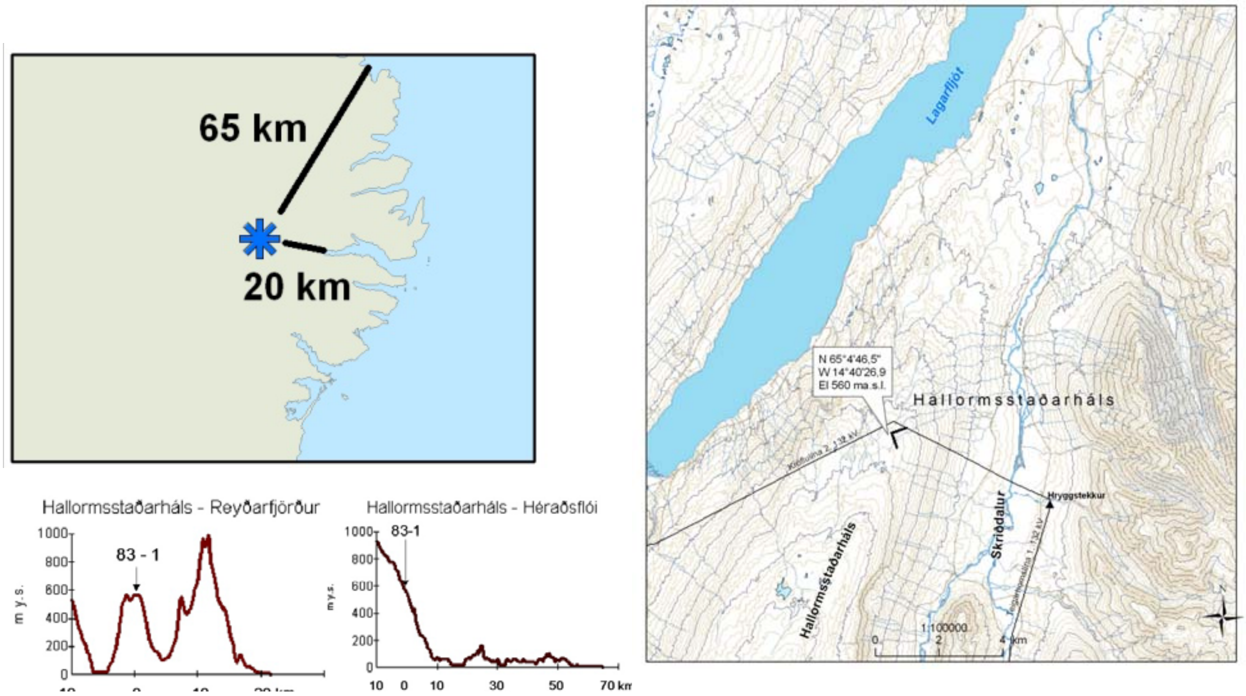


Figure 30. *Description of test site at Hallormsstadarhals (83-1) where OHTL's and test spans often experience in-cloud icing.*

The ice load is estimated for each new OHTL (50 years value for 30 mm conductor). Ice load is decided for each line section and can vary much lot along the same line route, according to different topographical and weather condition.

Maximum value that has been used in design so far is 42.5 kg/m (33 cm in diameter). By using 500 years loading and 49 mm conductor it became 70 kg/m.

Maximum ice loading that has been measured in test span (length 80 m) is 64 kg/m, see Figure 25.

4.1.2 Norway

- The biggest ice load ever recorded on an OHTL occurred in Norway 1961, 1400m above sea level. The accretion had an elliptic shape with the longer diameter of 1,4m and the shorter as 0.95 m. Accretion weighted 305 kg/m. It was a 22 kV wooden pole line
- The great dependence of in-cloud icing on topography results in that the main grid of Norway is designed span by span to the expected ice load.

Figure 31. Photo: O. Wist. The most famous photos of in-cloud icing. Ice load 305 kg/m.

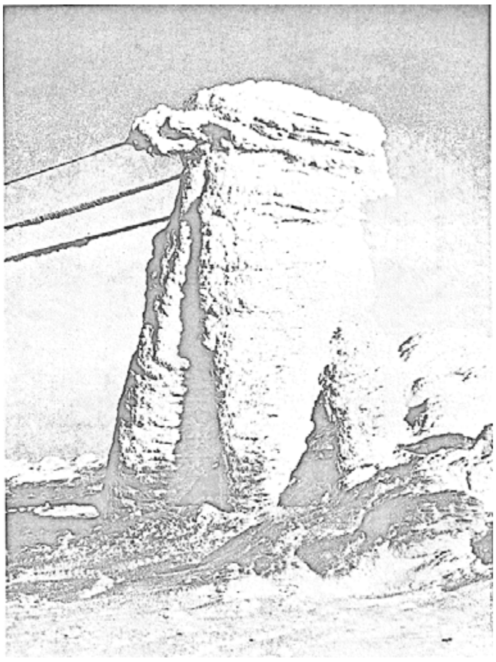


Figure 32. Dead end tower in a 20 kV line 1666 m a.s.l. During 5 years period there were never difficulties.

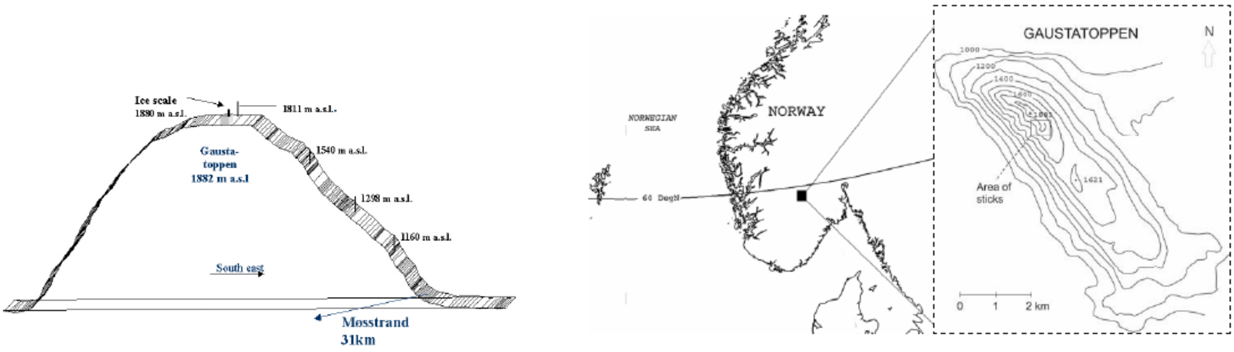


Figure 33. *Gaustatoppen in Norway*

- Gaustatoppen in Norway has been used by Statnett to measure ice load in a test line and to check performance of hardware and fittings and various setups of conductors.

- The peak is 1883 m a.s.l. And the mean level of terrain surrounding the mountain within 10 km is approx. 950 m
- The peak is exposed to heavy icing in all directions except from northerly directions
- It is a saying that if hardware last one month in Gaustatoppen then it is suitable for most conditions in Norway. If it last for one year then it can be used for severe condition in Norway
- It is informed that at least 120 kg/m have been measured on test span at Gaustatoppen, (Cigré 1969. R.R. Johnsen). Higher values have been measured on rods.

The present design ice loads in Norway vary within a wide range because of considerable variation in altitude and climatic conditions. From the lower figures of 2-5 kg/m it very often amount to 10-15 kg/m. 15-30 kg/m ice load is not rare, whilst 30 kg/m and upwards against 100, 200 and 300 kg/m happen to occur. (Hohsen et. al.).

4.1.3 Canada –British Columbia.

In-cloud icing has been an issue at Mission Ridge where BC-Hydro has on OHTL. Mission Ridge is a 2000 m high ridge exposed to frequent heavy in-cloud icing. Located 120 km north of Vancouver, British Columbia. In a paper by Barry C. Anderson it is described how a study on ice loading recommended that the new OHTL should be designed for considerable lower loading that older existing line was designed for.

- Original design (5L42) had section with loading: 30, 45, 60 and 75 kg/m. The 75 kg/m loading resulted in a single 76 mm conductor.
- Recommended design loading for a new line (5L46) based on operating experience of existing line (5L42) resulted in a design load of 37 kg/m for a heavy loading area and 22 kg/m for moderate loading area

In 1950/52 a unit design load was defined about 60 kg/m in Kildala Pass on the route between the Alcan powerhouse at Kitimat and the smelter at Kitimat in British Columbia. The elevation of the pass was around 1525m (5000 ft) and the loading included both sides down to an elevation of less than 300m. The loading assumptions were based on test line that were operated for two years and gave indication of a severe icing potential. Some guidance from experts with experience in the mountains of Europe led to the design requirement. (B.H. White 1999).

4.2 Topography influence on in-cloud icing

Severity of in-cloud icing accumulation is very dependent on exposure. Higher mountain elevations upwind filter out the moisture while very local topography can produce large differences in ice deposits from span to span. A span sheltered by an up wind ridge may be completely unloaded while the adjacent span at the ridge will get the maximum icing load.

- In-cloud icing occurs only above cloud base, but cloud base varies scientifically with topography.
- The most severe rime icing occurs at freely exposed mountains (coastal or inland), or where mountain valleys are forcing moist air through passes, and by this both lift the air and strengthen the wind over the pass
- In a mountain area a local face of a cliff only about 50-100 m height can give a significant reduction of in-cloud icing in the leeward vicinity of the cliff
- Ice load correlate with elevation in relation to mean level of surrounding area
- Rime level on hills and mountain is at a higher altitude the higher the hill

4.3 Comment on specified in-cloud ice loading at Long Range Mountain Ridge

The design ice load is based on an icing model using meteorological data from weather stations in the period of 1953-1971. The data analysis was presented in a report from 1973 and no modification of the loading has been made from that time.

The icing model was not able to take local topographical effects into consideration and thus is all loading the same for the Long Range Mountains, i.e. it is broad based and covers around 60 km[6]. The test program from 1973-1987 clearly showed that in-cloud icing loading varies much in the area and that effect of shelter cannot be emphasized too strong. Thus loading should be applied section wise. Section wise loading is the usual practice in countries with high in-cloud icing.

Design loading (50 years) for in-cloud icing is given as 9.5" radial ice cover. Density of ice is assumed to be[7] 500 kg/m^3. It is not defined if loading applies to 10m above ground and shall be increased further by conductor height. Loading is defined as radial ice cover. It is pointed out that it is more appropriate to define loading as unit loading rather than radial ice for high in-cloud loading.

For 58 mm conductor the loading becomes 113.4 kg/m or 76.2 lb/ft (50 years loading).

This loading is very high compared to design loading for in-cloud icing in most countries, including Iceland, Norway and BC Hydro in Canada. It can also be compared to predefined classes of in-cloud icing (50 years return period) in ISO 12494 where class 9 (of 10) is 50 kg/m but the highest class, 10, has undefined loading.

It was pointed out in the report "Study of Climatological Monitoring Program 1977-1981" in respect to in-cloud rime: *"The MRI estimates are conservative, and it would be desirable to obtain more precise data so that, if possible, some reduction or refinement in the estimates might be made."*

It is the opinion of the authors that by studying the in-cloud icing condition along the line route it should be possible to avoid some of the exposed routes. Loading should be given segment wise and the most exposed route should not cover more than few kilometers. Long sections of the line should have much lower loading than specified 1973. It would not be a surprise that further study would lead to some reduction of maximum ice loading.

Specifying in-cloud icing for important HVdc line through the Long Range Mountain Ridge must have been a challanging task in 1973. The line route goes through uninhabited regions where limited climatological data had been collected, an area which is known to experience some of the worst icing storms in North America. Moreover, the evaluation seems to be made without any actual measurement or experience of in-cloud icing with similar condition. It can easily been understood that there should be used some conservativeness in the evaluation due to limited information.

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[6] There is some uncertainity on exact length of section, it needs to be checked.

[7] In tables it is presented as 0.9 of water but it seems to be a misprint comparing the loading that is given (lb/ft).

5 Measurement of Salt Contamination in Iceland

The National Power Company started measurement of salt contamination in 1993 by setting up three different measuring sites. Two of these sites are at hydro power plants owned by the company but the third was located at a farmer. By choosing these locations, it was assumed that some indications of dividing the country into "contamination areas" would be possible.

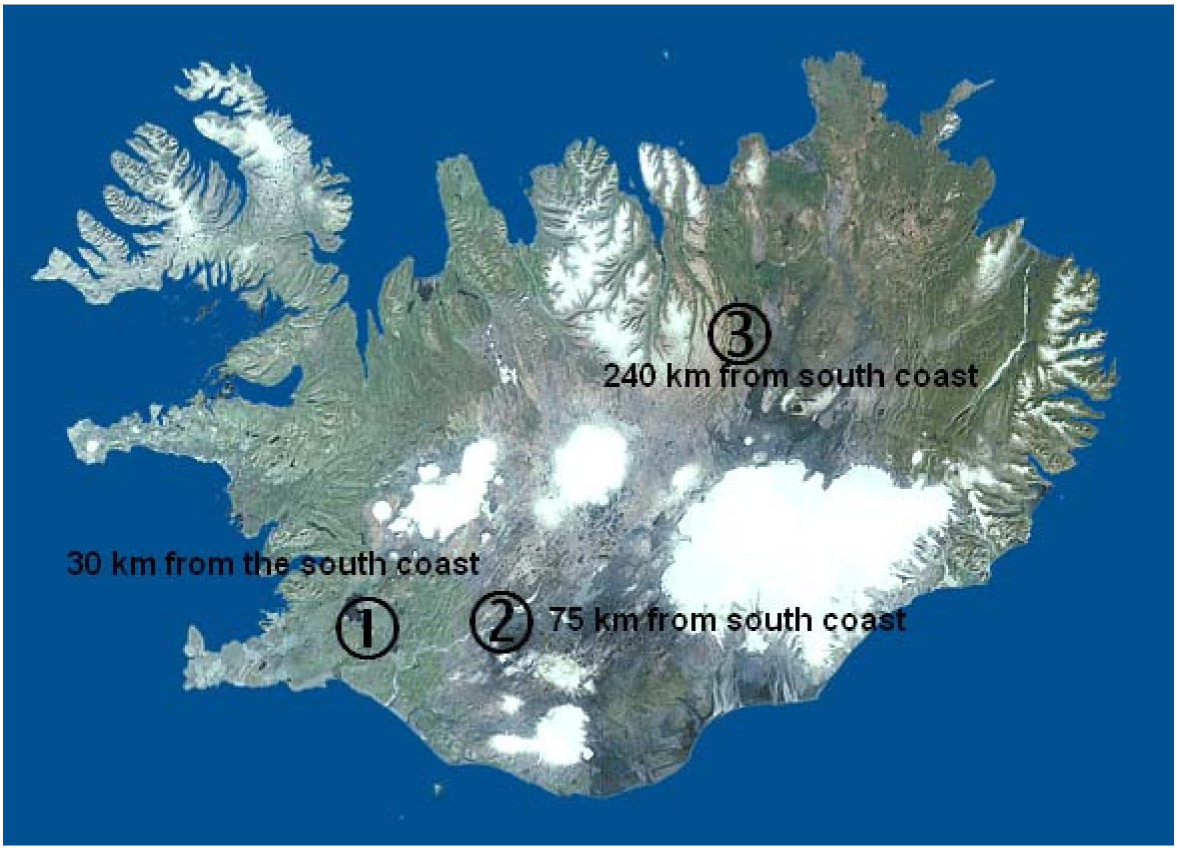


Figure 34. *Location of measuring sites for salt contamination in Iceland.*

Site no. 1 is located by the river Sog in the lowlands, only 30 km from south coast. Site no. 2 is at the Hrauneyjafoss hydro power plant some 35 km from the start of the highland plate, at about 340 m above sea level and 75 km from the coast. Site no 3 is at the farm Svartárkot on the northern edge of the highland plate at about 400 m above sea level.

The pollution level in Iceland is classified according to IEC 815, as seen below.

Table 7. *Classification of pollution level according to IEC 815.*

Class	Pollution level	Minimum creepage distance of insulation	Max equivalent salt contamination [mg NaCl/cm^2]
I	Light	16 mm/kV	0,03 – 0,06*
II	Medium	20 mm/kV	0,1 – 0,2*
III	Heavy	25 mm/kV	0,3 – 0,6*
IV	Very Heavy	31 mm/kV	-

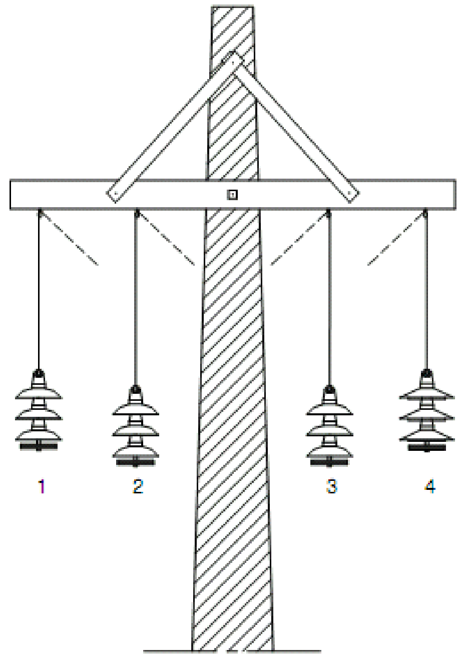
The Canadian standard (CAN3-C308-M85) from 1986 classifies salt contamination a little differently,

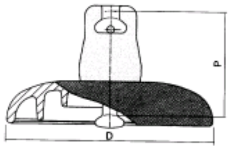
Table 8. *Classification of pollution level according to Canadian standard (CAN3-C308-M85) from 1986.*

Class	Pollution level	Max salt deposit density [mg NaCl /cm2]
1	Very Light	< 0,03
2	Light	0,06
3	Moderate	0,12
4	Heavy	0,3
5	Extreme	> 0,3

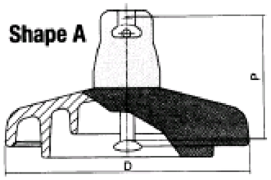
5.1 Basic setup of salt contamination measurement

The basic setup is shown on the figure below. There are four insulator strings, each composed of three insulator units. Strings 1 to 3 are with standard shape insulator units and string 4 has fog type units.





Standard shape – F160/146



Fog type – F160P/170

Figure 35. *Basic setup of salt contamination measurement.*

The measurements are taken from the center insulator units of the strings according a specified schedule. The upper and lower side of the insulator units is cleaned separately and salt contents measured. The purpose and schedule is as follows:

Table 9. *Contamination measurements, washing schedule and purpose.*

String #	Washing Schedule	Purpose
1	First day of the week	Investigate the short term buildup of contaminatio
2	Always after weather with severe salt contamination, before rain cleans the units.	To measure the maximum contamination level.
3 and 4	Every four weeks	Comparison of long term contamination buildup standard shape units and fog type units

It was considered of utmost importance to get the measurements from string 2 after weather with severe salt contamination, which is clearly visible on window glass in homes and cars.

5.2 *Results of 10 year measurements, 1993-2002*

The results of the measurements were analyzed by AFL Engineering (now EFLA) in a report in 2004. The report showed that the maximum salt contamination was strongly related to the following weather parameters;

- Low pressure area coming from south-west, with strong wind blowing from the south, south-west or west.
- The strong wind has been blowing over sea for long distances and it “tears” salt from the sea.
- Temperature around 0°C
- Only sporadic precipitation
- Results in;
    - The most severe operating problems in the Icelandic power system due to salt contamination
    - Salt contamination all over the country, not only near the coast.

Unfortunately, the personnel at Site #1 did not fulfill their duty of measuring the salt contamination following severe salt weather so it is only possible to compare sites 2 and 3.

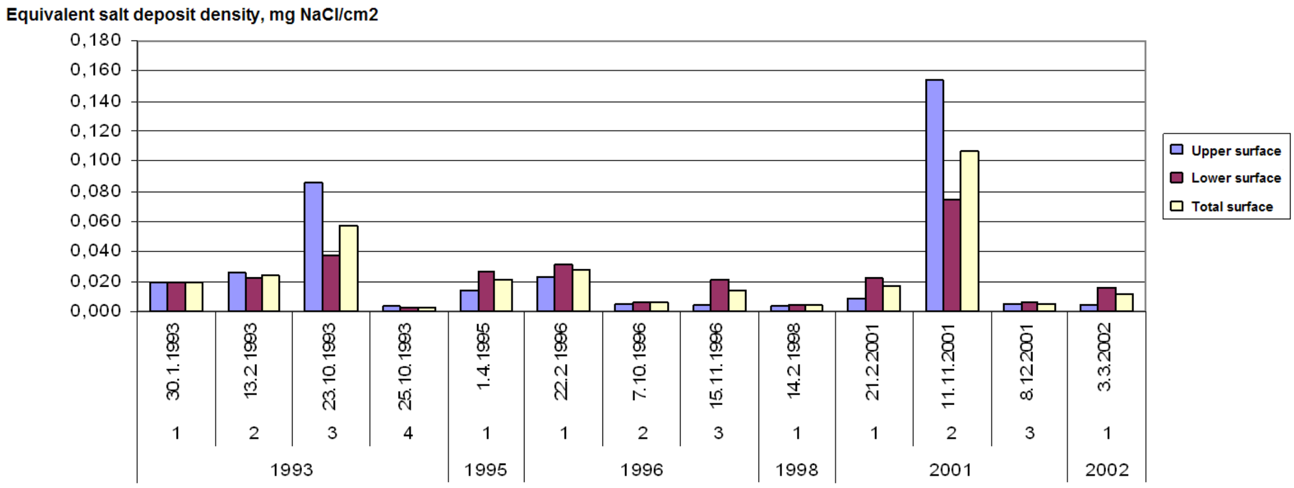


Figure 36. *Measurement of salt contamination on string setup 2 at Svartárkot 1993-2002.*

Maximum measured ESDD in g/cm^2 at Site #3, upper side (blue), lower side (red), all glass area (yellow).

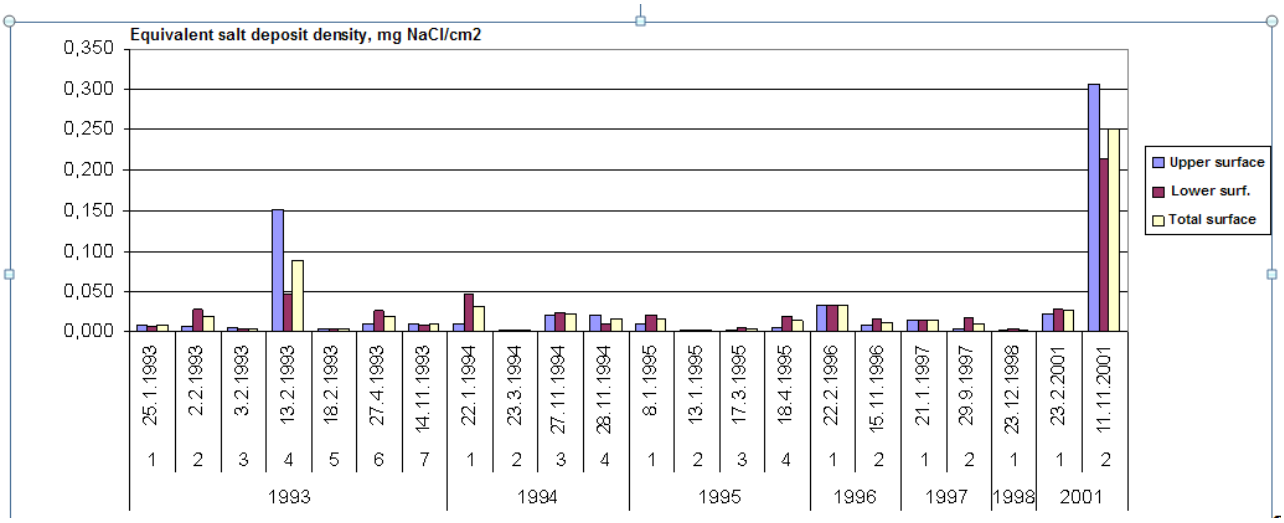


Figure 37. *Measurement of salt contamination on string setup 2 at Hrauneyjafoss 1993-2002.*

Maximum measured ESDD in g/cm2 at Site #2, upper side (blue), lower side (red), all glass area (yellow).

During this 10 years period there was an extreme salt weather event on 11th of November 2001 which resulted in widespread power outages due to flashovers in the outdoor substations and on lines at 132 kV and below, which have shorter creepage distance per kV than 220 kV lines. That day, a very strong wind was blowing inland from the south and southwest, with temperature around zero and only sporadic rain. The contamination level at Site 2, 75 km from the coast and at an elevation of 340 m is according to class III (Heavy) of the IEC classification. It is also important to observe, that the contamination level at site 3, 240 km from the south coast was high, even though it was only 40% of the level at the southern part of the highland. During this weather, an outdoor switchyard at a hydro power plant close to Site 2 was lightened up by leakage currents on the insulators in the yard.

6 Design issues for operational reliability

6.1 Basic information on planned HVdc transmission line at Long Range Mountains

- Tower will carry three wires, i.e. two conductors and one ground wire, with/without fiber optic cable.
- Phase conductor is planned to be simplex conductor approx. 58mm in diameter. The reason for using single conductor instead of bundle conductor is due to significant icing issues along sections of the HVdc corridor.
- Tower height will generally be in range of 38-49m with average approx. 43 m in height
- Span length will vary. It is assumed that ruling span will be around 375 m in normal loading zone and 285 m in higher loading zones.
- There will be approx. 3600 towers in the whole line, length approximately 1300 km.
- Design will comply with Standard C22.3 No.1 – Overhead Systems and Standard C22.3 No. 60826 – Design Criteria of Overhead Transmission Lines.
- Right of way will be cleared on average with 60m and up to 80 m.
- Foundation will consist of steel grillage structures.

Figure 38. *A typical tower in a HVdc line. Structurally the transmission line will be similar to other transmission lines in Newfoundland and Labrador and elsewhere.*

6.2 Insulation of HVdc Lines

The design of insulation of HVdc lines takes into account the normal operating voltage, switching and lightning overvoltage. Service experience has shown that the contamination, salt, ice and snow play a critical role in selecting the number and type of insulator units.

6.2.1 Contamination-based decision of number of units in string

Accumulation of contaminants on insulation surfaces is more severe under DC than AC and for the same level of contamination, the withstand strength of DC insulation is lower than of AC. The following figure shows the flashover voltage of suspension insulators for different ESDD [Li Wufeng et al; ”Contamination flashover Performance of Insulator Strings and Post Insulators used for ± 500 kV HVdc System”, 2005]

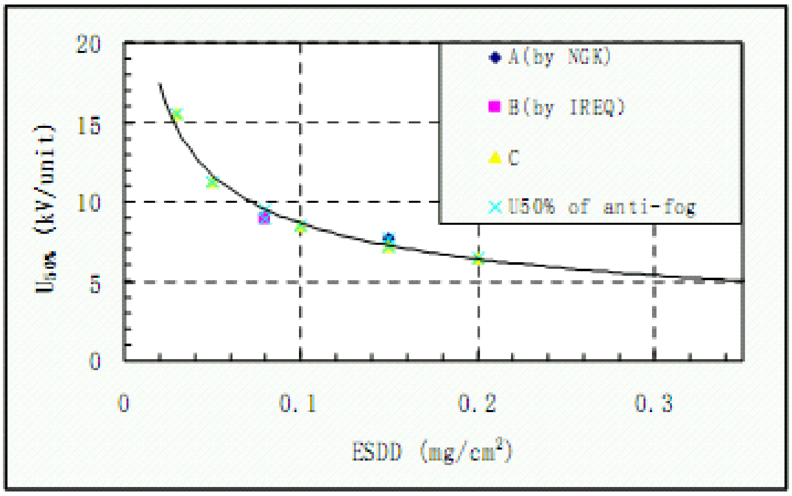
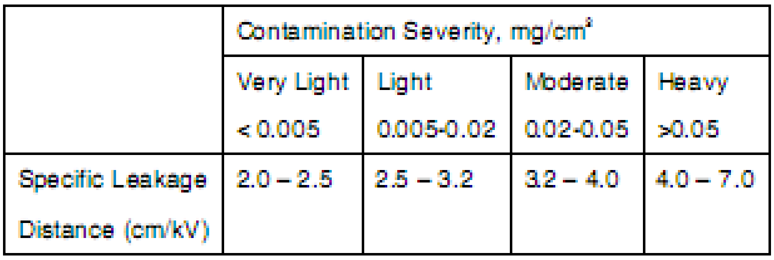


Figure 39. *Contamination flashover voltage of suspension insulators at different ESDD.*

A typical guideline for design of insulator strings from EPRI [Advanced HVDC Systems at ± 800 kV and above, 2006] is;



	Contamination Severity, mg/cm^2			
	Very Light < 0.005	Light 0.005-0.02	Moderate 0.02-0.05	Heavy >0.05
Specific Leakage Distance (cm/kV)	2.0 – 2.5	2.5 – 3.2	3.2 – 4.0	4.0 – 7.0

Figure 40. *Guidelines for Design of Ceramic insulators.*

If the values of the table are put into context with the required number of insulators the results are as follows based on an insulator unit of 550 mm leakage distance and 450 kV DC (Switching and Lightning withstand requirements calls for higher number than required for leakage distance only for Very Light Contamination);

Very Light:	17-21 units.
Light:	21-27 units. Length 3.57m to 4.59m (insulators only)
Moderate:	27-33 units. Length 4.59m to 5.61m (insulators only)
Heavy:	33-58 units. Length 5.61 m to 9.86m (insulators only)

The highest contamination measured in Flowers Cove was 0.15 mg/cm^2 (1981) or high into the “Heavy” classification. To meet such a high level, a high number of insulator units is required.

6.2.2 Influence of icing on the decision of number of units in string

It is known that icing on insulator strings reduces the flashover strength. For moderate icing the shape of insulator units and the sheds can affect the withstand strength but for extreme ice the withstand strength is more related to the length. The withstand strength per unit length is also reduced with increased length, i.e. the withstand strength is not proportional to the length. This is shown on a figure below [Li Peng;"DC flashover performance of long insulator strings coated with ice"];

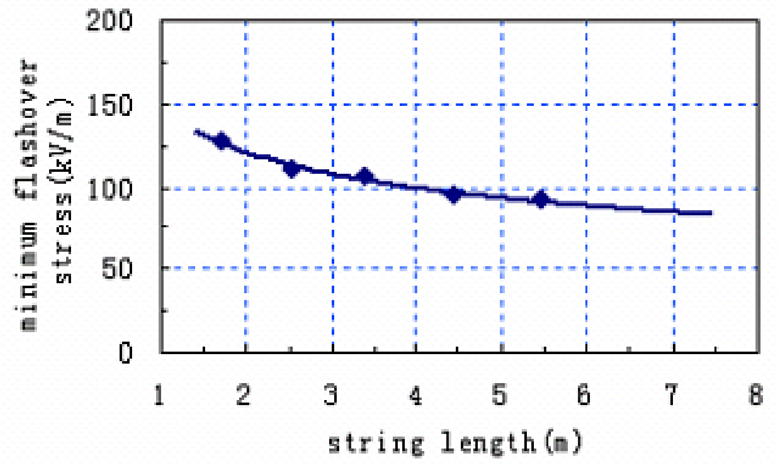


Figure 41. *Minimum flashover stress of DC icing insulator string under different string length.*

6.2.3 Combination of icing and contamination

The icing flashover voltage is also relative to the water conductivity. With increasing conductivity of the water making up the ice, the flashover voltage decreases. This is shown below [Li Peng;"DC flashover performance of long insulator strings coated with ice"]. The figure also shows how the withstand strength per unit length is less with long strings than shorter strings.

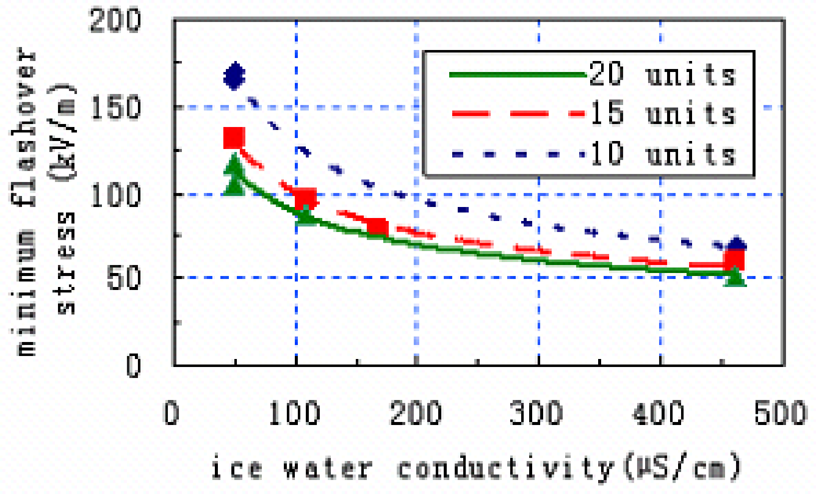


Figure 42. *Curves of DC insulator strings, icing flashover stress against water conductivity under different string length*

In the case of this HVDC line it is also probable that contamination can build up on the ice itself, forming a leakage path of similar length as the insulator string.

6.3 Steps to improve knowledge of in-cloud icing

It is recommended that following steps should be taken to improve evaluation of in-cloud icing.

- Make new analysis of maximum in-cloud icing in the area of Long Range Mountain, based on data from nearby weather stations. I.e. repeat similar study as was done in 1973 but with longer data series (up to 2009), using better model and calculation methods. It should be tested if models predict high ice load in same months as test tower received high loading. This study gives evaluation on if results from 1973 are reasonable. Furthermore, the model can be checked by comparing available icing in test towers to model prediction to verify analysis.
- Analyze condition for in-cloud icing section by section. Let persons with extensive experience in determine section wise ice loading (Á.J.Eliasson in Iceland and S.Fikke in Norway) study the line route and review and compare to conditions in Iceland, Norway and Greenland. 3D model of the earth surface should be made to use in study of line routes.
- Quantify local in-cloud icing severities by using a local scale numerical weather prediction (NWP) model for simulations of in-cloud icing. Models such as WRF (Weather Research and Forecasting) have recently demonstrated that numerical weather prediction models are useful tools for assessing ice loads on structures. By performing simulation of selected weathers it should be possible to quantifying the in-cloud icing risk along the line route. Some quantification of maximum ice load can be derived and simulation can also be used to improve model using data from nearby weather stations. Reference is made to papers presented by Bjørn Egil K. Nygaard in IWAIS 2007.
- It is strongly recommended that few icing test spans similar to the spans in Iceland will be erected and operated for few years. They should be installed in optimized locations. Results from test spans can be used to verify icing models, give quantitative information on size of icing, ice accumulation, how long ice stays on conductor and about ice shedding. A lot of information should be collected within 3-5 years of operation.

6.4 On operational reliability

Experience has shown that OHTL located in areas with frequent and high in-cloud icing may get operation disturbances if proper design were not made for such condition. When the designers are aware of the conditions and how to approach a suitable design, then the operational reliability should be good.

Among issues that should be addressed are:

- Define special loading cases
- Diverse consideration in design of insulator and hardware
- Good quality check on all stage of design, manufacture and installation
- Use special design in heavy icing areas and even consider using two single pole lines instead of one double pole line.
- Route selection is of vital importance, since sheltering effects of a cliff only about 50-100 m height can give a significant reduction of in-cloud icing.

Some of the issues that should be considered are addressed in following.

6.4.1 Use of single conductor instead of conductor bundle

Bundle conductor gets more ice accumulation to begin with. Total ice load becomes more questionable for high ice load due to increased torsional stiffness and more frequent ice shedding of bundle conductor (due to irregular ice shape) than simplex.

Bundle conductor in high ice areas often lead to more operational and maintenance problems due to more frequent galloping and severe conditions for spacers (can lead to wear of conductor).

Many/most utilities use single conductor instead of bundle conductor in high ice areas. Following list shows example of single conductors

- BC Hydro have used a 76 mm conductor (UTS=1462 kN) on a 500 kV line, Mission Ridge
- Norway – 57 mm single in icing areas to replace twin conductors
- Iceland – 49,9 mm single (UTS=604 kN) in icing areas to replace twin conductors on 400 kV

6.4.2 Special requirement to spacers in case of bundle conductor

Spacers need to be selected with great care in heavy icing areas where bundle conductor is used. Use of armor rod underneath of spacer clamp can be considered.

6.4.3 Consider bundle collapse in case of bundle conductor

Few cases exist on bundle collapse in icing condition. The risk can be reduced by selecting suitable spacer type and increase number of spacers.

6.4.4 Use of single insulator in suspensions strings, i.e. avoid clashing of double insulators

Double insulator strings can cause break due to clashing of strings in case of galloping and ice shedding.

- Insulator clashing in double strings during frequent (in Rime ice areas) galloping and ice shedding can cause insulator breakage
- Single string will require a higher strength insulator which is not standard. It may be necessary to develop a new high strength dc insulator. New 530 kN ac insulator was developed for use in Iceland
- Additional horizontal spacing is possible in case of double string. Insulator spacers can be considered but only known example is in 1150 kV line in Russia.

6.4.5 Split pins in insulator strings

Few examples exist where split pins in insulator units have been flattened due to galloping and/or ice shedding. This has mainly been a problem in units with small split pins.

6.4.6 All fittings must be selected carefully

Frequent gallop and ice drop will usually follow heavy in-cloud icing areas. Consequently hardware will suffer wear during galloping and ice shedding and initial design must accommodate dynamic loads and movements.

The following should be considered in design for heavy in-cloud icing areas:

- Protecting the conductor at suspension point (for example with AGS clamps)
- Over dimensioning of connecting pins

6.4.7 Consider effect of ice shedding

- When icing falls off it causes the conductor to jump up and it can lead to short circuit
- The conductor jump is more severe for: large span, low weight span/span and low initial stringing.
- Conductor jump can lead to mechanical damages of insulators and hardware
- There are examples where split pins in insulator units have been flattened due to ice shedding.

6.4.8 Consider effect of falling ice block on tower elements

Damage can occur on structural elements, when ice from higher parts in tower fall down and hit lower elements in the structure. This risk depends on tower type and no special risk is involved with the proposed tower type.

6.4.9 Effect of galloping on jumper loop

It has recently been noticed in Iceland and in Japan that conductor galloping can lead to excessive galloping in jumper loop. Detailing of jumper loop shall consider this.

6.4.10 Clearance due to more icing on ground wire than on conductor

There are many known cases where ground wire gets more icing than the conductor, due to lower torsional stiffness, lower temperature and higher above ground. Increased Clearance must be considered with ice on ground wire and phase without ice.

6.4.11 Ground wire can lead to operational problems

Galloping sometimes leads to operational disturbances. Operational reliability can sometimes be increased be skipping ground wire.

6.4.12 Consider insertion of a link between tension insulator strings and towers to reduce the risk of snow bridging

Installing a link between the tension insulator string and the tower reduce the risk of snow bridging. However, it causes the heavy tension insulator to move further away from the attachment point. In case of galloping it can lead to higher mechanical loading.

6.4.13 Dampers

Some utilities have experienced numerous fatigue failures of various Stockbridge-type dampers on its lines. Studies aimed at understanding the phenomenon have led researchers to conclude that aeolian vibrations under icy conditions could cause this fatigue problem.

Loop dampers (Bretelle) are used in Iceland and Norway. Some examples are where loop slips from the parallel clamp in heavy icing condition.

6.4.14 Counterweights

It is recommended that counterweights should have no rotating part in heavy icing areas to minimize risk of premature wear due to galloping, ice shedding etc.

6.4.15 V-string vs. I-string

V-string

- Electrically better under icing condition, they don’t swing and improve clearance to tower and have smaller ROW
- Less ice bridging (needs to be investigated if it applies to extreme Rime accumulation
- Downwind insulator in compression during high wind may be an issue

I-String

- Fewer insulators, shorter arms, easier installation

6.4.16 Loading for suspension towers

- Suspension towers in hilly terrain may experience big longitudinal loading due to unbalanced ice load. Unbalanced load trains for icing should be considered and checked if they are more dominant that cascading loading cases.
- Design for some limited dynamic load (containment and security).
- Wind combination with in-cloud icing should be considered in detail.

- Ice accumulation on tower and guys should be specified. Special consideration may be needed for guy system.

6.4.17 Loading combination for tension towers

Most standards do not specify realistic unbalanced ice combination for angle tension towers. Usually it is only assumed that full icing is present in both front and back span. Unbalanced ice loading should be considered

6.4.18 Snow depth

Snow depth has to be considered

6.4.19 Orientation of tension insulator in steep slope

When insulator string is in steep upward slope it may be better to orient it backward in order to reduce ice filling grade of the insulator units.

6.4.20 On danger of overdesign for in-cloud icing

In-cloud icing is almost always with hilly or mountainous terrain. Selection of extremely heavy in-cloud ice loading can then have somewhat opposite effect on reliability than planned, especially if heavy loading is conservatively defined for long section instead of defining it for the few critical spans. The high loading leads to short spans and many towers. Lines built in mountainous terrain and in their often steep sided river valleys face the problems of site locations secure from avalanches, deep snow creep and slides at the river bed changes that are so frequent as the snow pack melts. The low-tension sagging forced selection of many dubious tower sites can lead to that the hazards of the sites were much more onerous than the threat of extreme ice loads (B.H. White 1999).

6.4.21 Study of tower location

Aspects of ice cover, avalanches, deep snow creep and slides need to be considered in tower location.

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Ref. 34 Eliasson Á.J., Thorsteins E. Ice load measurements in test spns for 30 years. 12th IWAIS, Yokohama, October 2007.

Ref. 35 Eliasson Á.J., Gunnlaugsson P.Þ., Thorsteins E. Ice accumulation at measuring site Hallormsstadahals. 13 IWAIS 2009, Andermatt September 2009

Ref. 36 Li Peng et al. DC flashover performance of long insulator strings coated with ice. XIVth International Symposium on High Voltage Engineering, 2005.

Ref. 37 Li Wufeng et al. Contamination Flashover Performance of Insulator Strings and Post Insulators used for Estimation of ±500 kV HVDC System. XIVth International Symposium on High Voltage Engineering, 2005.

Ref. 38 Advanced HVDC Systems at ±800 kV and Above. EPRI 2006

8 Appendix A – Photos as a reference for measurement

Figure 43. *Site #2. Portland Creek – December 1976. Description was:*

Massive accumulation of mixed glaze and rime on tower and guys 18" tower completely encased and measured 3' wide at 5' above ground and increased to 4' at 10" above ground ¼" guy wire surrounded by 14" of same mixture.

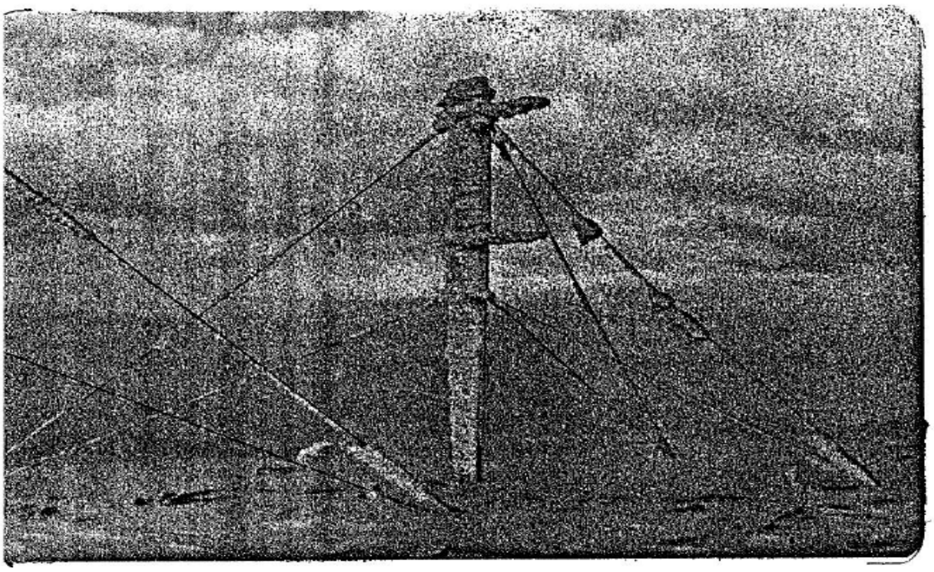


Figure 44. *Site #2. Feb. 11/80. Description was:*

Massive deposits of soft rime. Tower completely encased and deposit measuring 3' across at eye level and 4.5 ' at tower top. 1.5-2' wing shaped formation on rods. Direction of accumulation 270°.

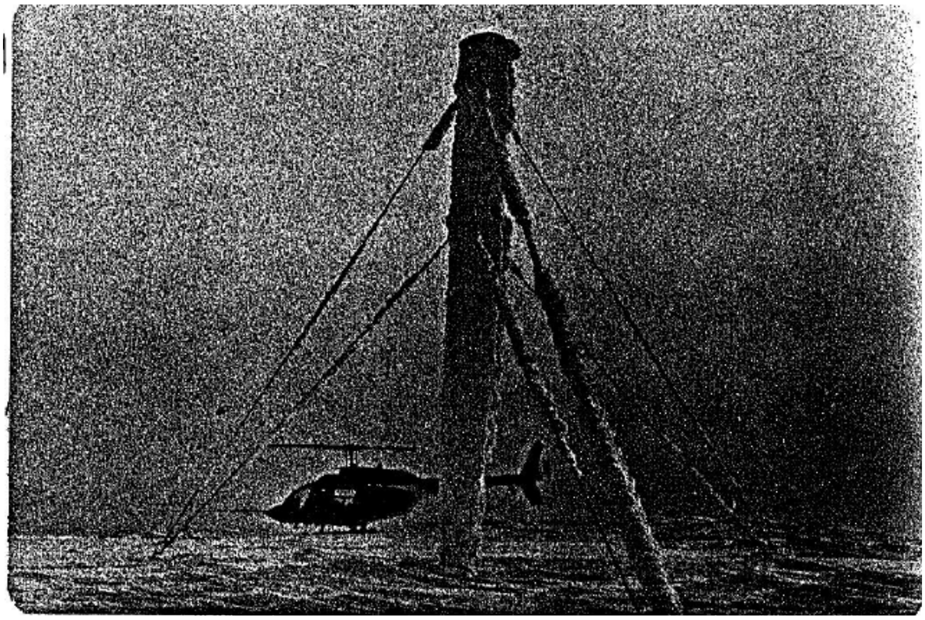
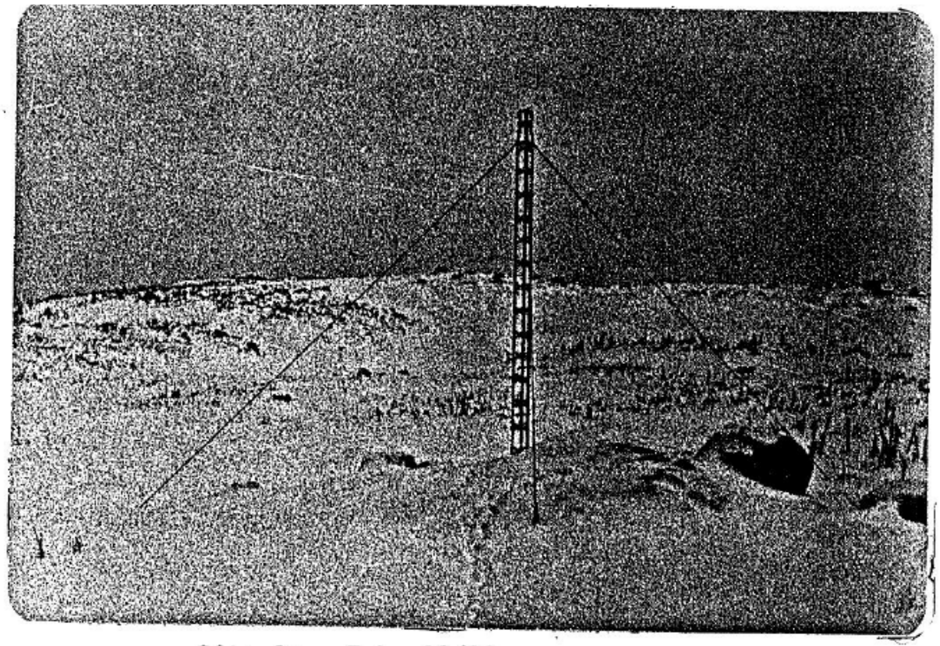


Figure 45. *Site #2b. Feb. 11/80. Description was:*

Massive deposits of soft rime. Tower completely encased in a deposit of soft rime. 1.5' across at 5' level of tower and 2'-2.5' across at top. Direction of accumulation 270°.



Site 2c Feb. 11/80

Figure 46. *Site #2c. Feb. 11/80. Description was: Tower Bare.*

Figure 47. *Site #4 (in Labrador). February 1977. Description was:*

Tower and guys were completely encased in glaze covered by a little rime. Guys were covered by 8”-10” of solid ice. Lower portion of 18” tower was covered by ice measuring 28” across the face. The top measurements were estimated at 36” across the face. Direction East.

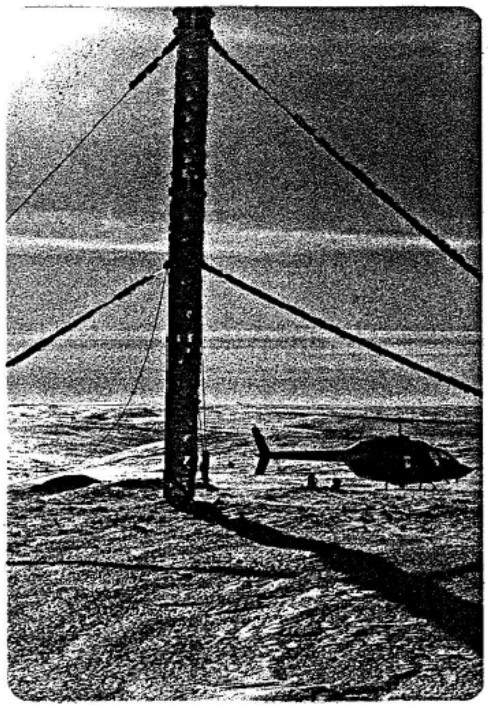


Figure 48. *Site #4. February 12/80. Description was:*

Massive deposits of glaze covered by soft rime. Deposits on guy 7”-8” across the 10” deep. Tower almost encased.

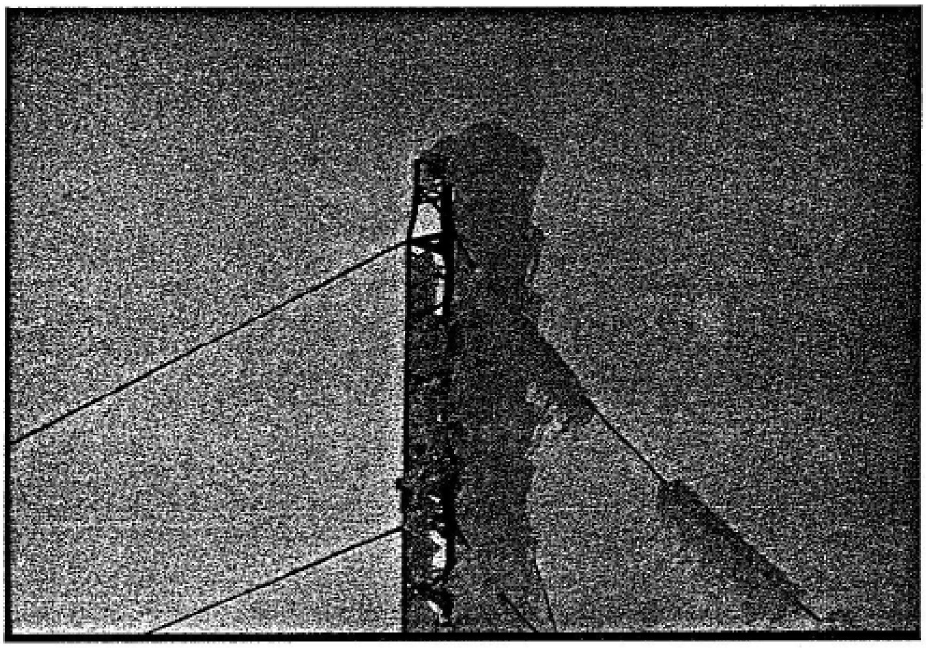


Figure 49. *Site #5. 14-02-79. Description was:*

Massive accumulation glaze on tower and guys. Approximately 30" thick on tower and 12" thick by 40" wide between guys and ground. Severe damage to tower. Direction of accumulation East-Northeast.

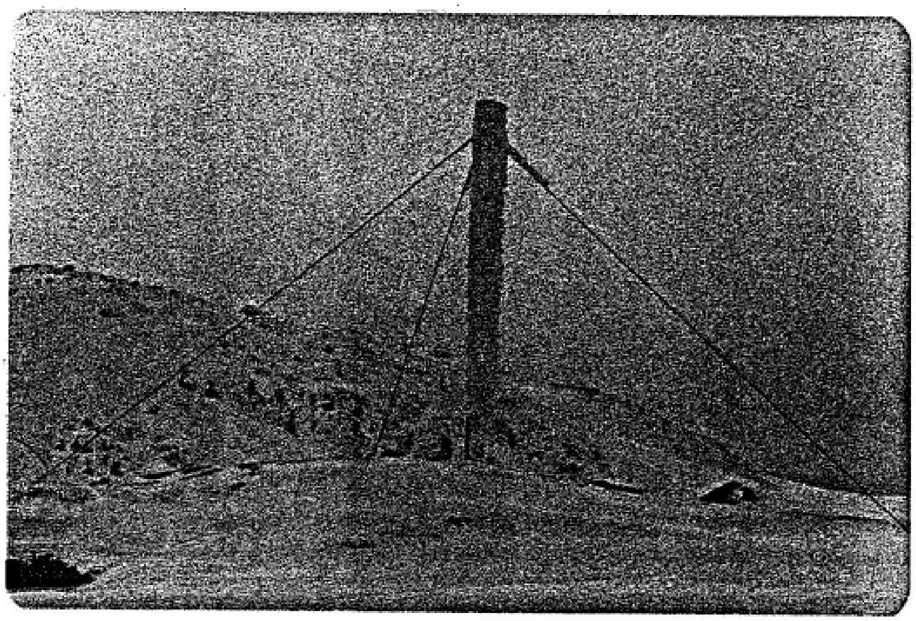


Figure 50. *Site #14. February 11/80. Description was:*

Massive deposits of soft rime 9"-12" across at 5' level of tower and increasing towards tower top. Ice direction 270°.

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