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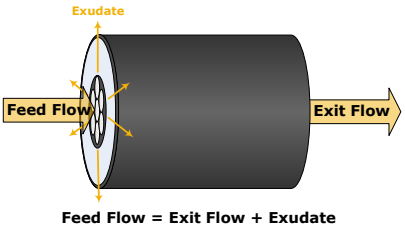
Rejuvenation Instructions Power Cables N-Rex™ Injection

Version 20120112

N-Rex™ (Novinium® Radial Exclusion)

Caution: Working around energized high-voltage systems may cause serious injury or death. Installation should be performed by personnel familiar with good safety practice in handling high-voltage electrical equipment. De-energize, test and ground all electrical systems before installing Injection Adaptors.

The Novinium® radial exclusion process (or N-Rex™) is utilized for submarine and other very long cable lengths. The Novinium rejuvenation instructions (NRIs) in this document supplement other NRIs. The N-Rex process involves 5 distinct phases numbered 0 - IV as outlined in Figure 1 to the right. Circuit owners may choose up to 40 years of life with the introduction of Ultrinium™ 732 fluid in Phase IVa, or perpetual life extension utilizing Phase IVb.



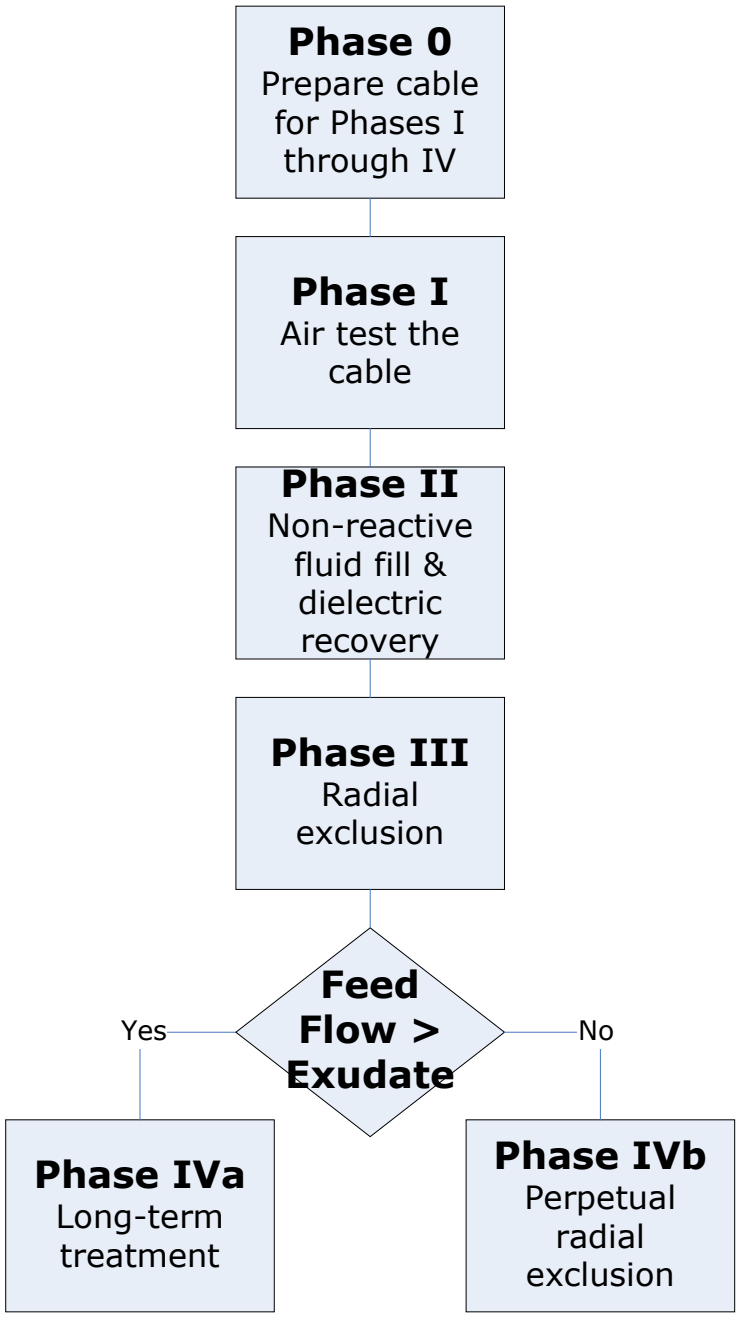


Figure 1. N-Rex™ Process Phases

Phase 0 of the injection process – prepare the cable for injection

1. De-energize, test and ground the cable.

2. Inspect and diagnose the cable as instructed in NRI's 10 and 12. Cable length should be established from construction records or other means of physical measurement for submarine applications.

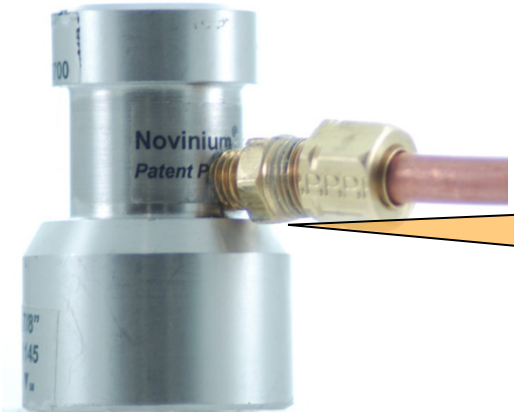
NRI 10: Visual Inspection & measurement

NRI 12: Electronic Cable Diagnosis & Pinpointing

3. Prepare the cable and install injection adaptors (IAs) and terminations as instructed in NRIs 30 and 34. Use an Injection tool for injections anticipated to least 6 months or less; for injections lasting 6 months or longer, drill and tap the injection adapters, and install a compression aligned fitting.

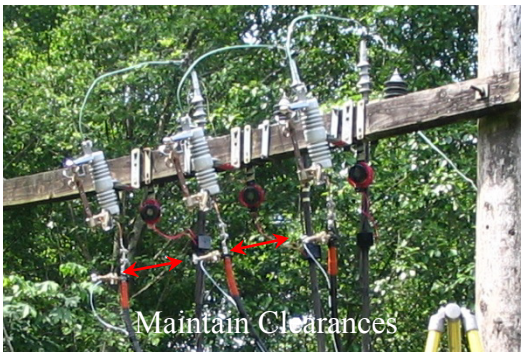
NRI 30: IA Installation – Connector Replacement & Strand Preparation

NRI 34: IA Installation – Live-Front



Modified IA with Compression-Aligned Fitting and tubing installed.

4. Confirm sufficient phase-to-phase and phase-to-ground clearance for all conductive parts including IA's, fittings, valves, tubing, and Injection tools.

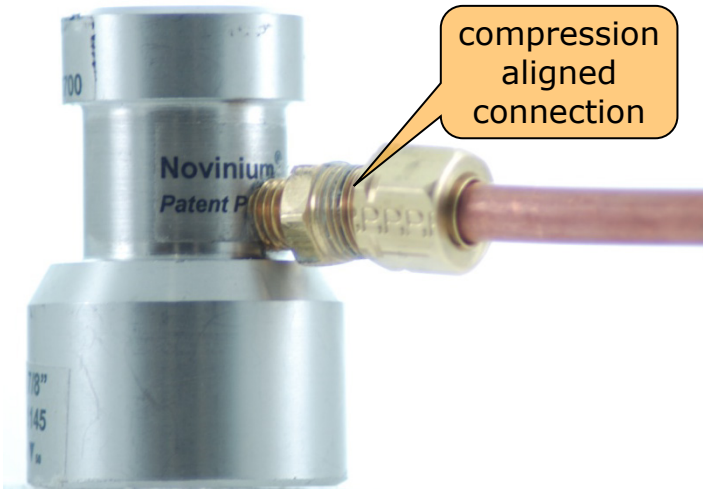


5. Utilize the NRI 50 level 1 instructions to flow and pressure test the lug-compression connector-IA assembly on each cable end along with all tubing, fittings, injection tools, and valves to confirm there is adequate flow and to confirm there are no leaks at the adjusted flow pressure (AFP) determined from NRI 20.

NRI 50: Flow & Pressure Testing

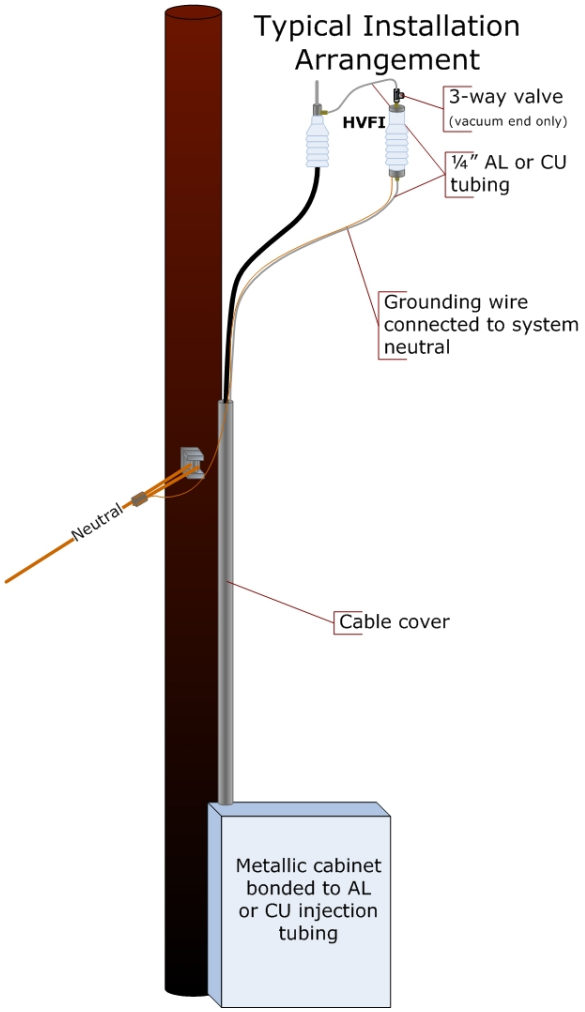
NRI 20: Tailored Formulation™ & Tailored Pressure™

6. Where ITs are used, install rubber boots or wrap 2 half-lap layers of 3M® Scotch® 70 self-fusing silicone rubber tape over the IT to prevent corona or tracking. For injection periods over 6 months, ITs should **not** be utilized. Modified IA's with a compression fitting installed must be used. The IAs should be drilled and tapped and compression aligned connections should be fitted in the tapped hole.

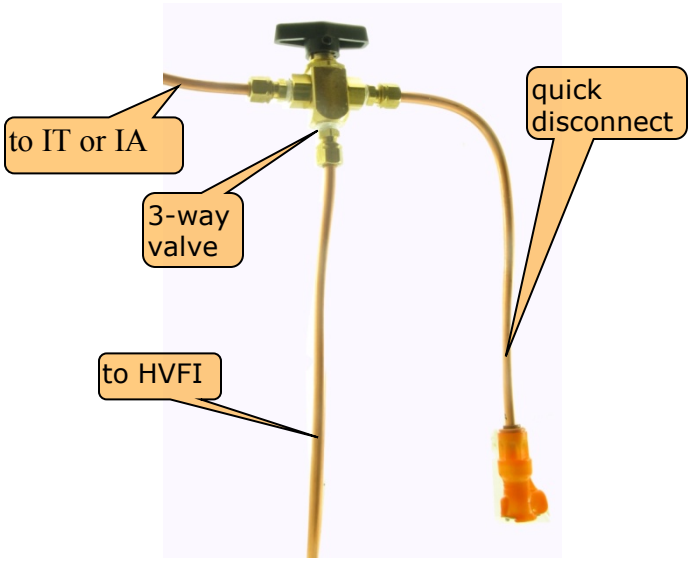


7. On the feed end (the end the cable will be injected from), secure tubing which extends from the injection tool. Maintain appropriate phase-to-phase and phase-to-ground clearance. Use metallic tubing to connect the IA with the top o f a high voltage fluid interface (HVFI). From the bottom of the HVFI run metallic tubing to the injection equipment. Identify each tube end with marking tape to avoid phase confusion. Bond the bottom of the HVFI to the system neutral with a conductor of sufficient ampacity to carry fault current and trip system protective devices in the event of an HVFI fault.

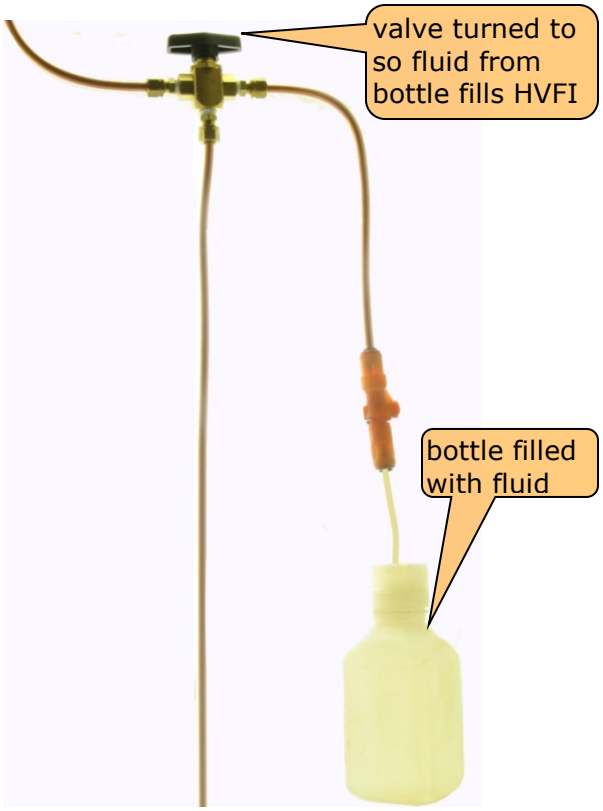
   All injection equipment must be raised above any potential flooding and secured from the public.



8. Connect the vacuum (receiving) end of the cable as in step 7, above. Install a 3 way valve with a quick disconnected attached at the connection between the HVFI and the tubing from the injection adapter or injection tool. Make sure the valve is positioned so that flow from the tubing connect to the AI is selected. Apply a Vacuum to the outlet side of the HVFI.



9. After vacuum has been allowed to fully build in the receiving end of the cable and HVFI, attach a bottle filled with injection fluid (NPN: UP-REL) to the quick disconnect. Turn the valve so that flow is from the tubing going to the quick disconnect, and transfer at least 50 ml of Ultrinium 732 fluid into the HVFI through the tubing. Return the 3 way valve to the IA flow position and remove the bottle from the quick disconnect.

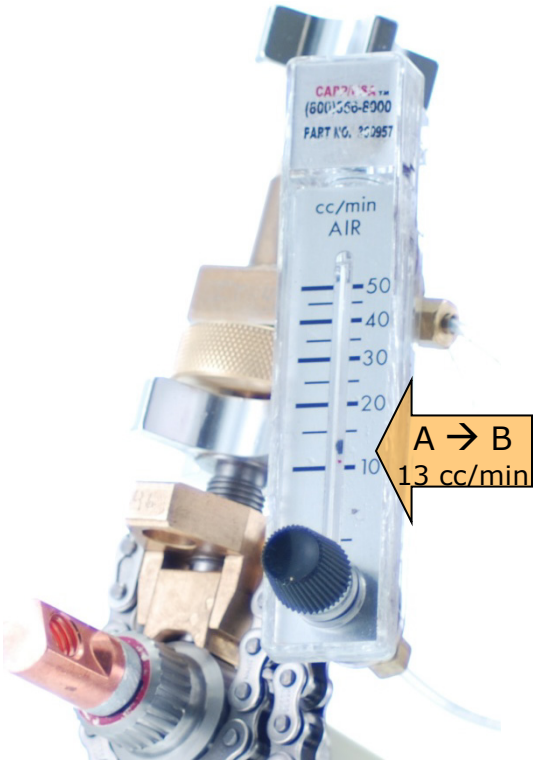


10. The cable may be reenergized at this point. However, if any leaks are detected in Phase I of this procedure, the circuit will have to be de-energized to repair the leak.

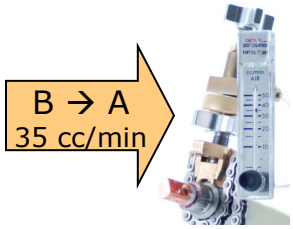
Assure all personnel and equipment are clear.

Phase I of the injection process – air test

1. Inject CO_2 (carbon dioxide) at the AFP into all phases at side A (presumed injection side). Measure inlet (Side A) and outlet (Side B) flow rate with an appropriately sized rotometer. Install water trap at outlet (Side B) before rotometer. Run until the latter of…
   a. at least 10 hours,
   b. the mass flow out is approximately the same as the mass flow in. (i.e. correct the volume flow rates of the rotometers for pressure and temperature differences), and
   c. no liquid water is exiting the cable
2. If there is any chance that there are undetected splices, close the outlet flow valve and allow the entire cable to pressurize to the AFP to confirm there are no leaks. If there are leaks, identify the source and correct before proceeding.
3. Repeat Phase I, step 1 reversing Side A with Side B. Choose the optimum flow direction.
4. If cable was not reenergized before the beginning of Phase I, reenergize now.



Optional: This process may be expedited by introducing CO_2 gas in the outlet at the a slighly lower pressure than the inlet side.



Assure all personnel and equipment are clear.

Phase II of the injection process – fluid fill & dielectric recovery

1. Inject N-Rex™ radial moisture exclusion fluid into the side with the greatest CO_2 flow rate at the AFP. Optionally apply a coarse vacuum (Absolute pressure >2.7 psia or 4.7 in Hg) on the outlet to increase the ΔP. Monitor inlet levels and outlet levels with time to establish the flow rate and interstitial volume. Use N-Rex worksheet to record all values.

2. Monitor and record the inlet flow rate until N-Rex™ fluid reaches the outlet cable end.

3. Continue injection of N-Rex™ fluid until the feed and outlet fluid flow rates are stable (i.e. ±10%) over a 24 hour period.

N-Rex™ fluid

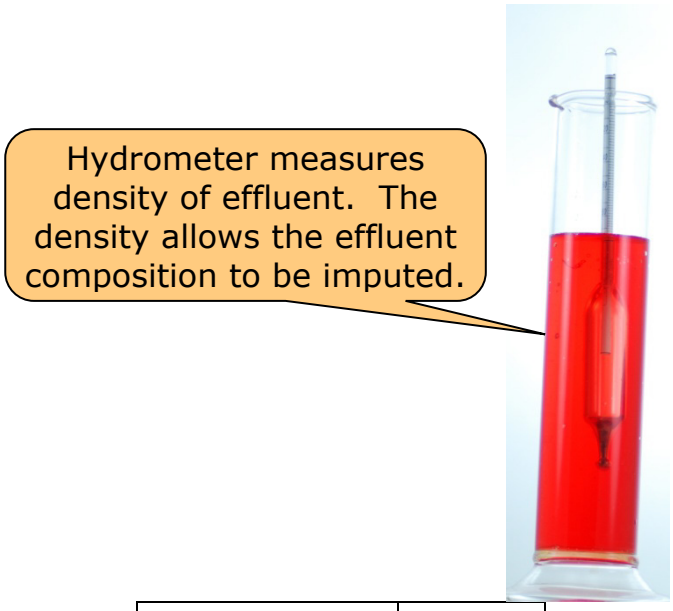
This is a mixture of acetophenone and propylene carbonate. Novinium engineering will provide the optimum starting ratio.

After the flow rate is stable …

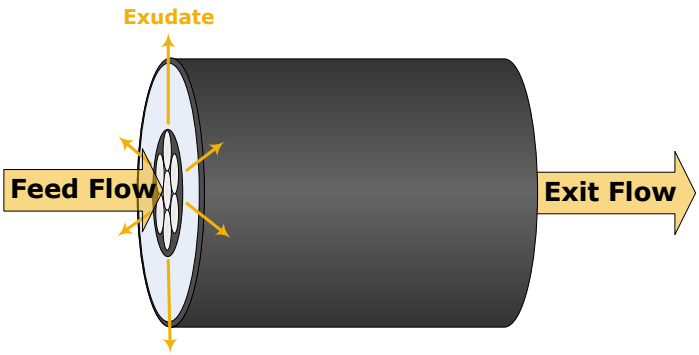
Calculate the fluid dwell time (FDT, days) as the interstitial volume (cc or cm^3) divided by the flow rate (cc/day).

Phase III of the injection process – radial water exclusion

1. Continue injection of N-Rex™ fluid until the following three conditions have all been met:
   a. the measured specific gravity of the effluent fluid is less than 1.15 as measured with a 140 cc sample using hydrometer (Fisherbrand 11-522A with 08-530E cylinder).
   b. the measured specific gravity of the effluent fluid does not change by more than 0.02 over the lesser of the FDT, N from the table below, or 30 days.
   c. N days have transpired since Phase II, Step 2, where N is the number of days from the table below and T is the average conductor temperature over the period of N days. The average conductor temperature is supplied by the circuit owner.
2. Novinium engineering performs a mass balance, flow simulation, and permeation simulation. Circuit owner decides whether to choose Phase IVa process if product of feed flow and radial exclusion fluid concentration in feed is greater than exudate. Otherwise utilize Phase IVb process.



Average Conductor Temperature (°C)	N (days)
T<10	108
10<T<15	63
15<T<20	36
20<T<25	21
25<T<30	12
30<T<35	7
T>35	4



Feed Flow = Exit Flow + Exudate

Phase IVa of the injection process – long term treatment

1. Choose the appropriate Ultrinium™ life extension fluid based upon the anticipated flux weighted temperature of the cable over the post-injection design life of the cable based upon customer input and as described by NRI 20.
2. Use the viscosity of the fluid compared with the viscosity of the N-Rex™ fluid to estimate a flow rate. Use the Phase II mass balance or MFlux to calculate the estimated acetophenone loss of the 732/N0 fluid over the length of the injection. If more than 75% of the acetophenone will be lost during the flush period, add acetophenone to the Ultrinium™ 732 fluid to compensate for the anticipated loss. The additional acetophenone shall be decreased in convenient steps as the injection proceeds.
3. Inject with pressure and optional vacuum and flush Ultrinium™ fluid (modified if necessary per step 2) until the following criteria are met:
   a. 110% of the measured interstitial volume of the cable has been injected.
   b. The specific gravity of the effluent is less than 1.1.

NRI 20: Tailored Formulation™ & Tailored Pressure™

If acetophenone ramp-down is required:

When the advancing fluid front is X% of the way, the added acetophenone is decreased by X%. The submarine injection worksheet, "Novinium Submarine (YYYYMMDD).xls", provides the necessary calculations.

See also NRI 60: Tailored Injection

4. Close outlet flow valve. And reduce the pressure on the inlet side to the Adjusted Tailored Injection Pressure (ATIP) from NRI 20.
5. Terminate the inlet flow when the tailored volume of fluid required to treat the cable is achieved as per NRI 20.
6. De-energize, test and ground the cable.
7. Remove rubber guards or tape from injection tools. Install all remaining plug pins as described in NRI 40 step 14 and step 15. Wipe away any residual fluid, and cover injection adaptor with 3M® Scotch® 70 self-fusing silicone rubber tape.
8. Re-energize cable.

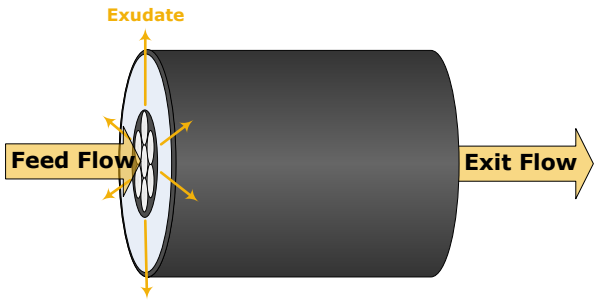
NRI 20: Tailored Formulation™ & Tailored Pressure™

NRI 40: IT Installation & Removal

Assure all personnel and equipment are clear.

Phase IVb of the injection process – Perpetual Radial Exclusion

1. Novinium engineering will provide guidance on fluid formulation, injection pressures, and flow reversal schedule.
2. As long as fluid flow is maintained cable will provide reliable service. If flow is suspended for more than several months, cable reliability will decline.



Feed Flow = Exit Flow + Exudate