SNO-STR-92-036

Rope Properties

Compiled at Guelph by
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1. Rope selection criteria & candidates

a. Usage & Quantity:

The rope will be used to suspend the Acrylic vessel which will contain 1000 tons of heavy water and placed in the light water. It consists of a set of 10 ropes of 100 feet each. The total amount of rope we need is then 1,000 feet. Due to the end terminations, the total amont of rope to be ordered should be slightly more then 1,000 feet. We may also need at least one spare rope.

b. Strength:

Each of 20 ropes (10 loops) will continuously be loaded to 5 tons (totaly 100 tons which is the difference between 1000 tons of heavy water and light water) for a minimum duration of 10 years. The rope will be loaded to 10% or less of its breaking strength, which is a critical number. This means that the breaking strength of each rope would be at least 50 tons.

c. Radioactivity:

From report of ***Skensved, Roberston and Frati*** : If the ropes contribute half as much as Acrylic vessel , then an acceptable rope radioactivity could be as high as ~1 ppb.

d. Candidates:

We have analyzed three kinds of rope since 1990. Recently the ropes are under ***New controlled shipment*** in the form of fibers. The three rope candidates are ***Kevlar, Spectra & Vectran***. ***Spectra*** is out of running because it is not resistant enough to long-term creep.

e. Cost:

An old estimate for 1,200 feet of rope was **$6,300** for ***Kevlar*** and **$29,000** for ***Vectran***. The difference between the two ropes is not negligible. But we have to find a good one to suit **SNO** criteria.

2. Physical properties

a. Materials:

Vectran is a thermotropic **Liquid Crystal Polymer** and manufactured by a melt spinning process. ***Kevlar*** is lyotropic and is solvent spun. ***Spectra*** is an Ultra-high molecular weight polyethylene and is gel spun.

Vectran can subsequently be remelt at a high temperature. ***Kevlar*** decomposes at high temperature and ***Spectra*** melts at a relatively low temperature.

Vectran fiber has very high orientation with no chain folding. ***Kevlar &*** ***Spectra*** are conventional Polyester and their fibers have orientation with chain folding.

b. Construction :

The rope will be made of fibers (thread lines), with 300 fibres forming a 1500 denier bundle. 4-5 bundles form a Yarn, 4-5 Yarns a Strand, and 12 Strands form the Rope. This kind of ***Vectran*** rope will have a 1.25" diameter.

c. Strength:

Vectran has the similar tensile properties to those of ***Kevlar***, except *Vectran* has very low degradation of properties or weight gain due to moisture. The break strength of three ropes are similar. The following table shows a set of 0.5 inch rope's strength.

0.5" rope	Vectran	Kevlar	Spectra
Weight of rope	80g/m	80g/m	64g/m
Break Strength	12.4 tons	13.0 tons	13.6 tons
Estimation for 1.25" rope			
Weight of rope	500g/m		
Break Strength	77.5 tons		

d. Creep:

Vectran fiber has excellent creep resistance. According to the report from TTI, creep has not been observed in various tests at different conditions. ***Kevlar*** showed reasonable creep resistance. ***Spectra*** fiber not only has large creep, but also does not show constant creep growth over logarithmic time increments. The recommendation from TTI is that the ***Spectra*** will not be suitable for **SNO** project. Here represents some testing results on three fiber materials.

Material	Load to Break	Testing Time	Observation
Vectran	35%	569 days	No creep observed.
	50%	40 days	No creep observed.
	2.5 tpi twist, 50%	115 days	No creep observed.
Kevlar	25%	70 days	0.24%
Spectra	20%	30 days	0.5%
	50%	72 hours	2%

e. Abrasion resistance:

A Cycles-to-failure result represents the abrasion resistance. The higher the number of cycles-to-failure, the better the abrasion resistance. Below are the abrasion test results from TTI and Samson Ocean.

TTI test	Vectran	Kevlar
Fiber Dry test 800g load	3,581	422
Fiber Wet test 800g load	16,524	1,719
Samson Ocean Test		
No Marine finish 600lb load	288	83
With Marine finish 600lb load	1250	93

3. Rope radioactivity

a. Method of analysis

Three **SNO** institutes have been utilized as rope radioactivity measurement places and received rope samples. They are **CRL, Guelph and LBL.** Only results from **CRL** and **Guelph** are available.

1). TIMS at CRL

Chalk River Laboratory (CRL) uses Thermal-Ionization-Mass-Spectroscopy (TIMS) to measure radioactivity.

The sample was first vaporized in a quartz tube. The residue which contains **U/Th** was diluted into a certain acid solution . Then it underwent mass spectroscopy. An amount of Th^{239} isotope was added into the final solution for **TIMS** as analysis standard. The average weight of samples was 30 grams.

2). NAA at Guelph

Guelph uses Neutron-Activation-Analysis (NAA) to measure radioactivity. The sample was first irradiated by neutrons with a nominal flux of 10^{13} n/sec/cm^2 at McMaster nuclear reactor for 2 to 4 hours. We then counted gamma rays from the radioactive products with Ge detector. An **Al** foil with known **Th** & **U** concentration was used as standard and simultaneously irradiated with samples. The average weight of samples was 10 grams.

$$^{238}\mathrm{U} + n \rightarrow {}^{239}\mathrm{U} \rightarrow {}^{239}\mathrm{Np} \xrightarrow{56h} \gamma\ (106, 227, 278\ \mathrm{keV})$$
$$^{232}\mathrm{Th} + n \rightarrow {}^{233}\mathrm{Th} \rightarrow {}^{233}\mathrm{Pa} \xrightarrow[27d]{} \gamma\ (312\ \mathrm{keV})$$

We counted twice for each sample, a count at one week delay for **U (Np)** and a count at two week delay for relatively long lived **Th (Pa)** .

For some rope samples such as *Kevlar* fibers, short lived radioactivity like Na & P are very strong . The count with one week delay for U was then impossible. For those samples only Th result is available.

b. Results of radioactivity (U & Th) measurements:

CRL analyzed 19 rope samples in total since 1990. They consisted of 8 ***Kevlar*** (3 ropes & 5 fibers); 5 ***Spectra*** (2 ropes, 2 powders & 1 fiber) and 6 ***Vectran*** (1 rope, 1 beads, 2 sand filtered fiber & 2 metal filtered fiber) samples.

Guelph analyzed 14 rope samples in total since 1990. They consisted of 5 ***Kevlar*** (2 ropes & 3 fibers), 2 ***Spectra*** (1 rope & 1 fiber) and 7 ***Vectran*** (2 ropes, 1 beads & 2 sand filtered fiber & 2 metal filtered fibers) samples.

All rope samples analyzed were random samples while the ***New controlled shipment*** consisted of beads, powders & fibers. The attached table and figure show the results.

All the concentrations of **U** and **Th** measured were under 1ppb except some ***Kevlar*** samples measured at CRL. The highest numbers from CRL for ***Kevlar*** are 5.5ppb (fiber) and 16ppb (rope). Results for ***Kevlar*** measured at CRL are much higher then those for ***Vectran***. This was less significant with Guelph's results. The results for ***Vectran*** fibers measured at CRL are much lower than those at Guelph. According to Dr. Davis Earle, this is due to the undissolvable residue of ***Vectran*** fibers.

At Guelph, we believe that the rope manufaturing process will not introduce a large amount of radioactivity. From existing data, the difference in radioactivity between polymer and fiber is as large as that between polymer and rope itself, even though the ropes were not in the controlled shipment.

4. Discussion

According to the engineering testing for three rope materials, ***Spectra*** is too weak to be considered as a good candidate for **SNO**. We should concentrate on ***Kevlar*** or ***Vectran***. And we must make the decision in a few months. Two kinds of opinions have evolved for this matter. One opinion is that we should measure more samples for both ***Kevlar*** and ***Vectran*** due to the large difference in the cost. If the ***Kevlar*** is not so bad compared to ***Vectran*** we should consider ***Kevlar.*** The other opinion is that the extra radioactivity analysis would also require extra cost.

First, we need clear rope criteria from the collaboration. What are the extreme levels for radioactivity and other parameters? What more information do we need about ropes? Second, we will finish analyzing ***Vectran*** now so that we have one rope material well qualified.

A clean room process to manufacture the ropes has been proposed. This may not be necessary. The fibers have already been manufactured and radioactivity added at this stage. The manufacture of ropes from fiber under normal circumstances leads to little added radioactivity.

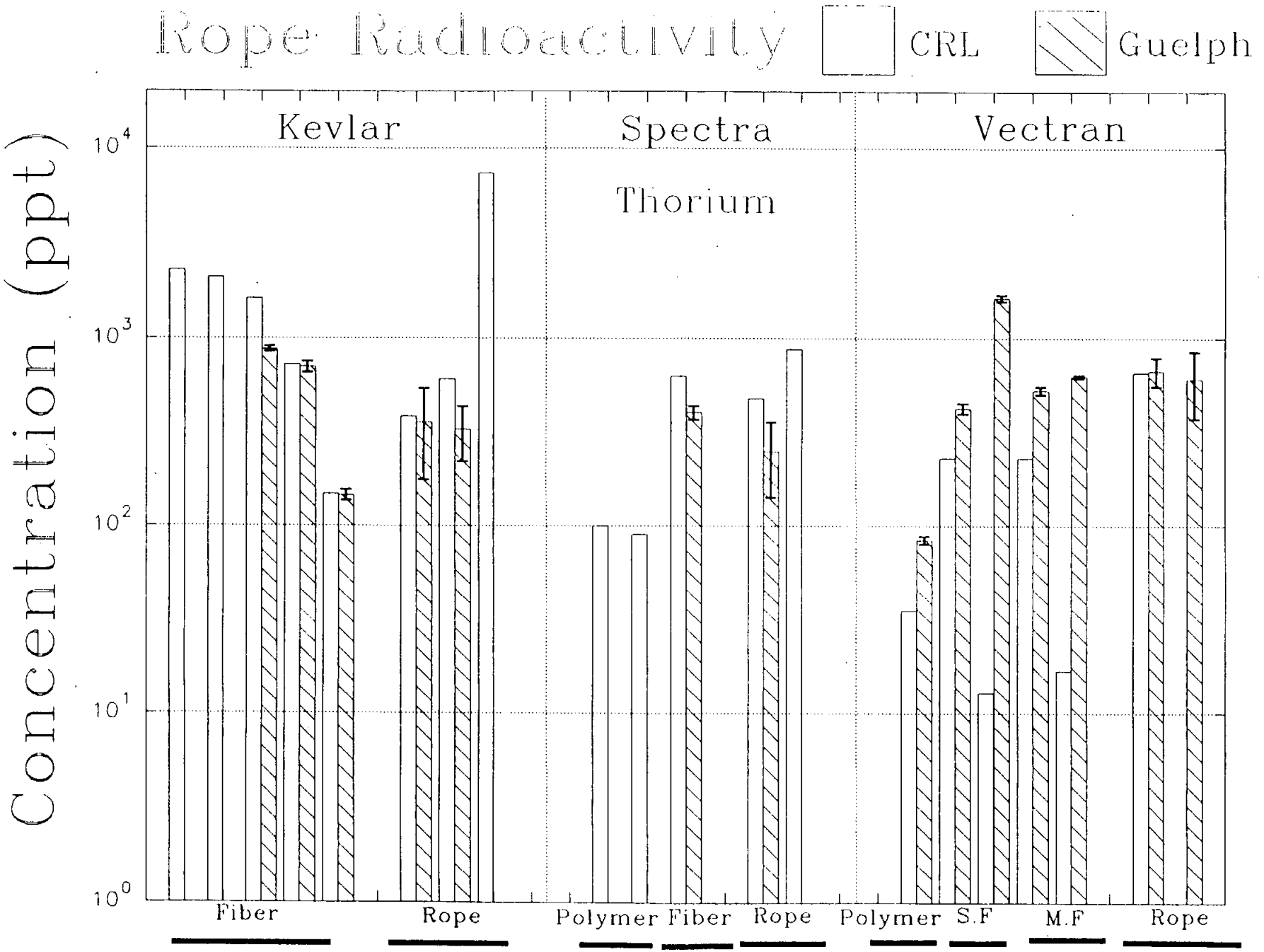
We think that if we have to order ropes right now, then ***Vectran*** is the rope to order. Also, if we decide to order ***Vectran*** we could order ***Kevlar*** as well, because of the little added extra cost involved. And we can do more research on both ropes until the final decision date.

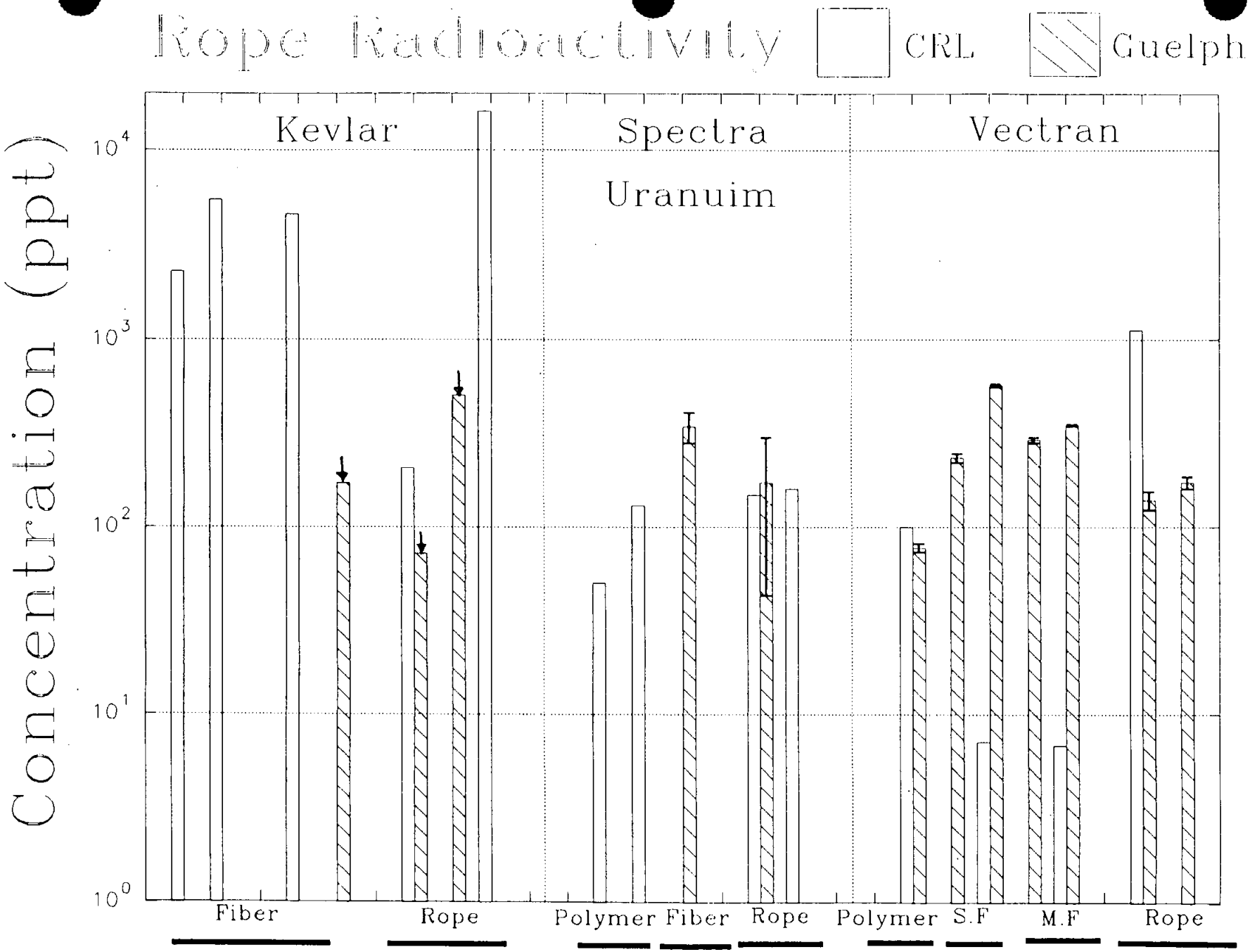
5. Refferences

1. Jan Wouters SNO collaboration communications
2. Davis Earle SNO collaboration communications
3. Peter Doe SNO collaboration communications
4. D.E. Beers & J.E. Ramirez Vectran fiber ropes and cables
   Hoechst Celanese Co.
5. Walter Paul Draft specification for Vectran HS (LCP) fibers
   Tension technology international

Table of Rope Radioactivity Measured at CRL and Guelph

Sample Name	CRL Results		Guelph Results	
	U(ppt)	Th(ppt)	U(ppt)	Th(ppt)
Kevlar fiber	2300	2300	--	--
	5480	2100	--	--
	--	1633	--	880±30
	4580	730	--	706±47
	--	148	<172@68%	146±10
Rope	207	385	<72@68%	359±183
	--	610	<508@68%	328±108
	16000	7400	--	--
Spectra Polymer	50	100	--	--
	-130	90	--	--
Fiber	--	630	345±64	404±34
Rope	148	481	173±130	250±108
	160	880	--	--
Vectran Polymer	100	35	78±4	84±4
Sand fiber	--	230	235±13	425±26
	7.2	12.9	573±12	1635±64
Metal fiber	--	230	293±10	530±26
	6.9	16.8	353±4	629±11
Rope	1128	660	139±16	675±117
	--	--	173±13	611±237


Rope Radioactivity
CRL
Guelph
Kevlar
Spectra
Vectran
Thorium
Concentration (ppt)
10^4
10^3
10^2
10^1
10^0
Fiber
Rope
Polymer Fiber
Rope
Polymer
S.F
M.F
Rope


Rope Radioactivity
CRL
Guelph
Kevlar
Spectra
Vectran
Uranuim
Concentration (ppt)
10^4
10^3
10^2
10^1
10^0
Fiber
Rope
Polymer Fiber
Rope
Polymer
S.F
M.F
Rope

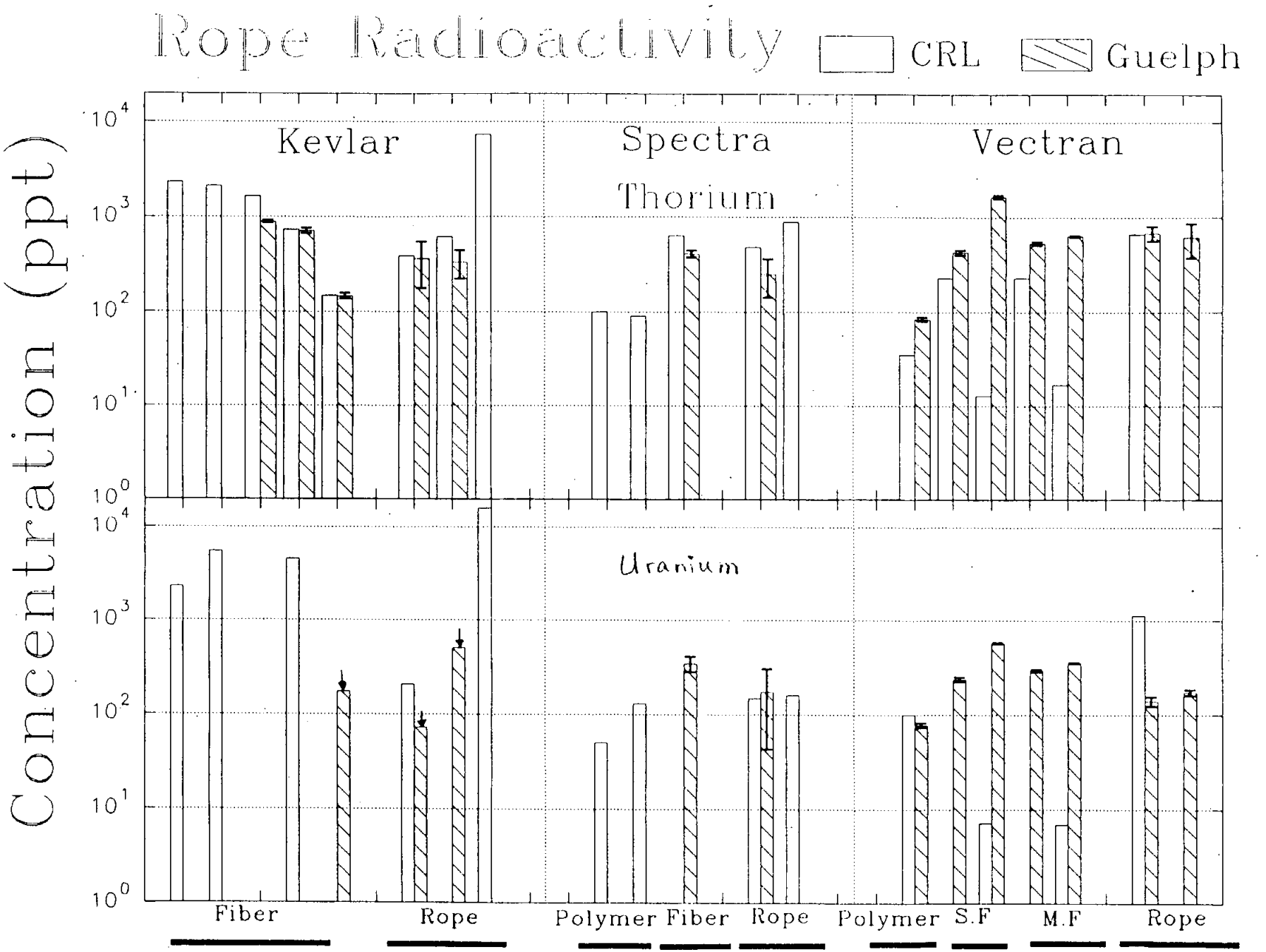

Rope Radioactivity
CRL
Guelph
Concentration (ppt)
Kevlar
Spectra
Vectran
Thorium
Uranium
Fiber
Rope
Polymer Fiber
Rope
Polymer S.F
M.F
Rope

Figure 1: Schematic Of Molecular Chain Structure Of Fiber

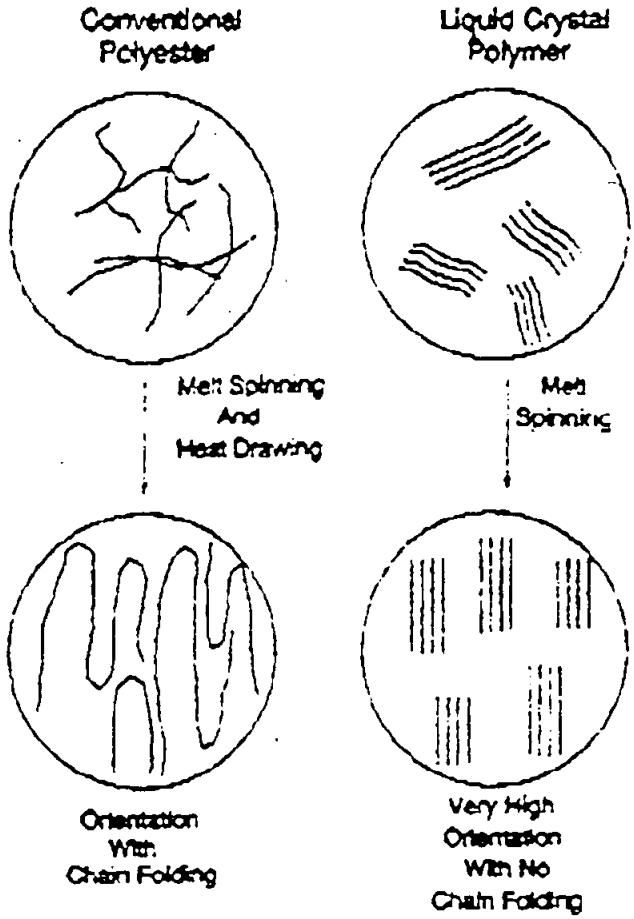
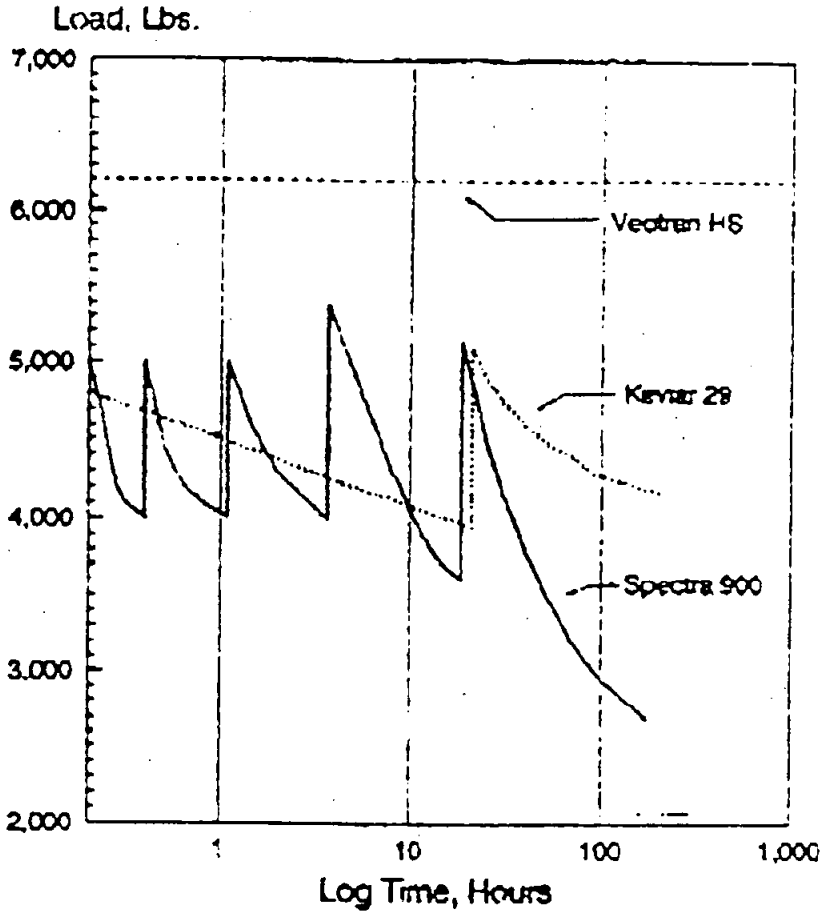


Figure 2: Vectran HS Wire Rope Creep



Whitehill Manufacturing Corporation
WMCJETS/JETSTRAN I-A VEC 1/2" Rope

Original record of CRL results.

Rope Mass Spect.

			ROPE (May 7-92)								
Date	Weight gms	Tube	ID	U ng	U ppt	Th ng	Th ppt	Th/U	Cut	Cleaned	Comments
Oct 15-90	58	7	Bkgd	0.12		0.26					Th & U separation
			Kevlar Rope	12.4	207	22.3	385				using anion column
			3 rd rinse	0.55		1.1					first
	50.7	7	Bkgd	0.18		0.2					some of vapor
			Spectra Rope	7.2	148	24.4	481			Alc/H2O	condensed outside
			3rd rinse	0.9		0.8					oven
Nov 20-90	33	7	Bkgd	0.03		0.12					
			Spectra Rope	5.3	160	29.1	880			no	
			3 rd rinse	0.37		0.8					
Jan 31-91	29.5	7	Bkgd			1					Sample passed thru'
			Kevlar Rope	small		18	610				anion column first
			3 rd rinse			1.2					Dissolved solids
Mar 6-91	16	Q1	Bkgd	0.62		1.1					Uncertain, black
			Kevlar fibre	36.8	2300	37.8	2300				mess after vaporise
			2n rinse	0.63		0.77					filters used also
May 8-91	32.1	Q2	Bkgd	0.7		0.8					Much mess to
			Kevlar fibre	>176	5480	>67.7	2100				handle
			5 th rinse	0.1		0.1					
Nov 1-91	7	Q3	Bkgd	2.1		2.9					
			Kevlar rope	113.2	16000	51.9	7400			Alc/H2O	
			4th rinse	4.9		2.7					

Rope Mass Spect.

Date	Weigh	Tube	ID	U	U	Th	Th	Th/U	Cut	Cleaned	Comments
	gms			ng	ppt	ng	ppt				
Nov 28-91	6.68	Q8A	Bkgd	0.9		1.7					
			Kevlar fibre	24.6	4580	8.3	<730			Alc/H2O	
			4th rinse	6.4		2.6					
Dec 5 91	8.6	Q8A	Bkgd	3.8		1.2					
			Vectran Rope	14.2	1128	10.2	660			Alc/H2O	
			4th rinse	1.7		1.7					
Feb 11-92	44.26	Q8A	Bkgd	1.5		1.5					
			Vectran beads	7.7	100	4	35			alc/H2O	
			3 & 4 rinse	3.8		2.4					
Feb 12-92	26.6	Q12	Bkgd								
			Spectra powe	2.2	50	1.4	<100				
			Bkgd 1 rinse?	0.5		2.1					
Feb 14-92	29.1	Q13A	Bkgd								
			Spectra powe	6.3	130	4.3	90				
			3 & 4 rinse	2.6		1.6					
Mar 4-92	32.27	1	Bkgd	0.12		0.24					
			Kev filament	3.4		5.2	148			no	run thru' a column
			double rinse	0.33		0.44					crystals not measure
Mar 5-92	27.33	V1	Bkgd	0.44		1.8					
			Spectra filam	31.2		20.8	630			no	
			double rinse	1.8		3.6					

Rope Mass Spect.

Date	Weight gms	Tube	ID	U ng	U ppt	Th ng	Th ppt	Th/U	Cut	Cleaned	Comments
Mar 10-92	32.2	1	Bkgd	0.2		0.6					
			Kev. filament	2.4		53.4	1633			no	lots of crystals
			double	0.6		0.8					run thru' a column
Mar 27-92	30	1	Bkgd	1.1		1.3					
			Vec. fib.(san)	5.3		8.9	230			no	10 mg sand left over
			double	1.5		1.9					
Mar 31-92	30.4	1	Bkgd	0.6		1.2					
			Vec. fil.(met)	5		8.3	230			no	10 mg sand/metal
			double	0.8		1.3					left over
Apr 21-92	31	1	Bkgd, A12	0.44		0.7				alc/H2O	still particles left
			Vec. fil. (met)	6.9		16.8				ultra	over and not measure
			double rinse	2.7		5				sound	
Apr 21-92	34.6	1	Bkgd, A12	0.7		1.5					
			Vec. fil.(sand)	7.2		12.9				ditto	ditto, rinsing is not
			double	3.1		4.6					removing everything