NUCON® NUSORB® NOBLE GAS DELAY CARBONS

NUCON Technical Bulletin 11B10
Revised December 2019

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1.0 INTRODUCTION

In 1973 Nuclear Consulting Services, Inc. (NUCON) established the first pilot plant capable of testing adsorbents under dynamic conditions using radioactive noble gas isotopes. This enabled us to evaluate and optimize selection of activated carbons for reactor off-gas use. NUCON also developed procedures for laboratory quality control under dynamic conditions, again using noble gas isotopes.

Today, NUCON International, Inc (NUCON is the successor to Nuclear Consulting Services, Inc) has one of the most sophisticated laboratory and pilot facilities available for noble gas delay studies. NUCON personnel have studied the optimization of adsorbents for this use. We were the first to point out that high surface area large pore carbons are <u>not</u> the best choice for optimum noble gas delay (USAEC CONF-720823 Vol 1 p. 71).

2.0 PRODUCTS

Activated carbons offered by NUCON for noble gas delay are the NUSORB® G30™ series. These are typically used in the 6x12 and 8x16 U.S. mesh sizes. The attached data sheets show typical properties of these products.

3.0 GENERAL TECHNICAL INFORMATION

Noble gas delay beds should be protected by HEPA inlet and outlet filters.

During detailed evaluation of specific applications, it must be noted that actual performance is also affected by:

1) Type of carrier gas
2) System absolute pressure
3) Presence of other impurities (H_2O, CO_2, etc.)
4) Packing density
5) Bed geometry

4.0 DESIGN PARAMETERS FOR NUSORB GXK™ SERIES

- Bed void fraction: 0.40 - 0.44
- Carbon thermal conductivity: 3.1 X 10-4 cal/(cm) (sec) (°C)
- Carbon heat capacity: 0.20 cal/(g) (°C)

- Pressure drop at low velocities expressed as inch of water/foot carbon at maximum (free fall) packing density:

Velocity		GXK-6x12™		GXK-8x16™	
fpm	m/min	inch water/foot of carbon	mm water/meter of carbon	inch water/foot of carbon	mm water/meter of carbon
0.1	0.03048	0.001	0.0833	0.0012	0.100
1.0	0.3048	0.021	1.750	0.026	2.170
10.0	3.048	0.500	41.7	0.605	50.400

In typical noble gas control systems the more critical dose effect is from Xenon and not from Krypton. However, the very critical moisture effect on Xenon adsorption has been rarely evaluated in the past. Radon adsorption is of concern for mining air purification, where relative humidity is also variable. NUCON has performed a series of experiments to evaluate this design parameter.

It was found that the adsorbed water under equilibrium conditions has a linear effect on noble gas delay by blocking available micropore volume. The relationship between relative humidity and weight percent water adsorbed is non-linear.

Test Parameters

Adsorbent Wt. (g)	1052.6	(2.32 lbs)
Bed Depth (cm)	95.25	(37.5 in)
Adsorbent Volume (cc)	1879	(114.11 in^3)
Face Velocity (m/min)	2.438-12.192	(8-40 ft/min)
Temperature (^{o}C)	20	(68^{o}F)
Relative Humidity (%)	5-90	
Tracer	^{133}Xe	

All data developed in the NUCON International, Inc. Radioisotope Laboratory and is the property of NUCON.

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Calculation of Noble Gas Delay Time

The noble gas delay time in a bed of activated carbon is determined by the carbon weight, the gas flow rate and the dynamic coefficient (K) for the specific carbon that is installed, according to the following formula.

T=MK/F

T = Delay time, seconds
M = Carbon weight, g
K= dynamic K, cm^3/g
F = flow, cm^3/sec

TABLE 1

Noble Gas Dynamic K vs. Relative Humidity NUCON Grade GXK™

Flow l/min	Face Vel. m/min	R.H. %	H2O Wt %	Kr Dynamic K cc/g	Xe Dynamic K cc/g	Rn Dynamic K cc/g
4.94	2.438	5	0.9	60	1,390	4,000
4.94	2.438	10	2.0	57	1,340	3,850
4.94	2.438	20	2.4	47	1,085	3,125
4.94	2.438	30	3.6	40	929	2,670
4.94	2.438	40	4.9	33	767	2,200
4.94	2.438	50	10.0	26	612	1,775
4.94	2.438	60	19.2	17	387	1,115
4.94	2.438	70	19.6	9	211	610
4.94	2.438	80	20.9	4	84	245
4.94	2.438	90	21.6	1	28	82

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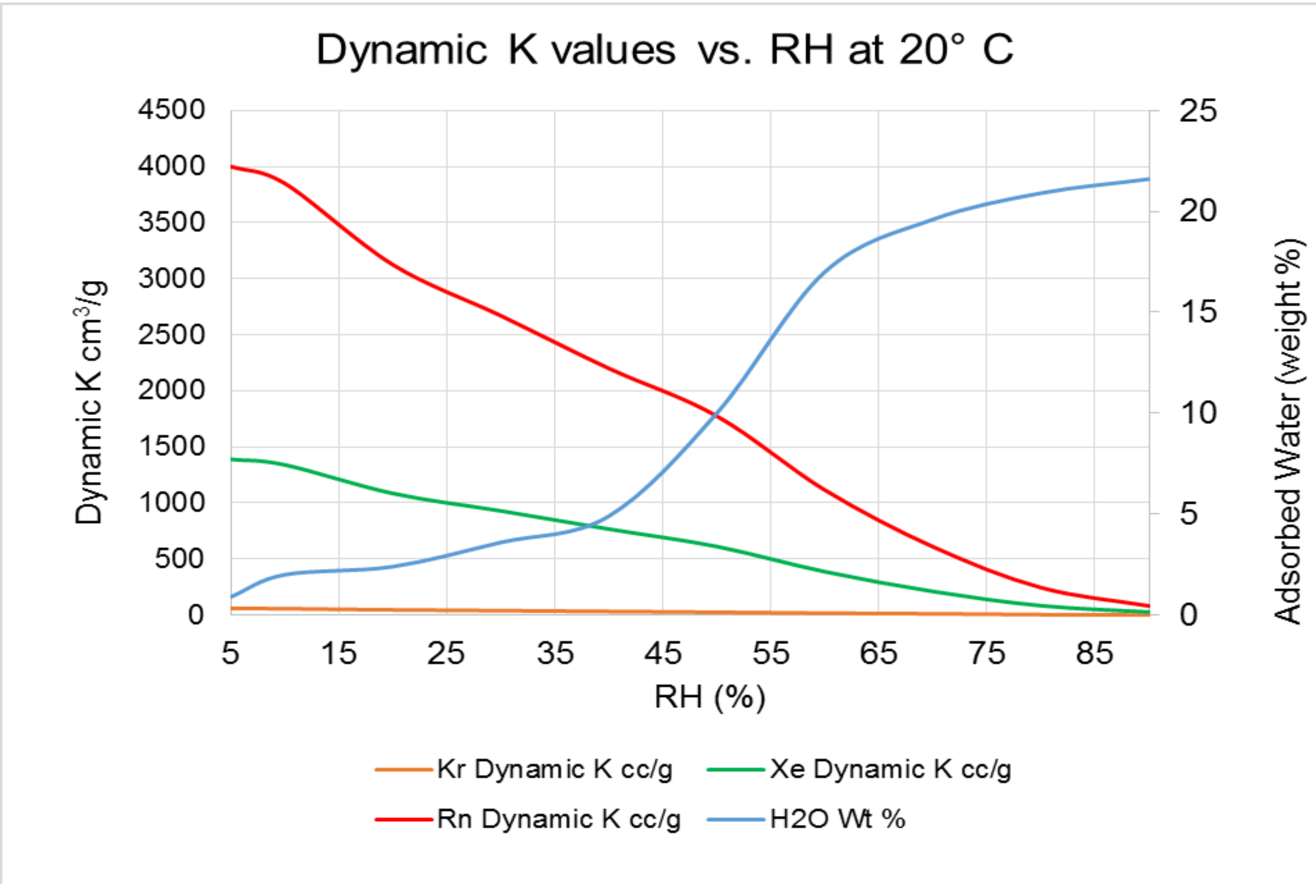
FIGURE 1



Since the "delay" of Noble gases, relative to other components in the gas phase is based purely on physical adsorption, for any given adsorbent, under identical relative humidity values, the Dynamic K values will be proportional (see Table 2). From a practical standpoint, it is generally much easier to use krypton 85 to determine a Dynamic K value for a given adsorbent. For that adsorbent, at the same temperature, the Dynamic K value for xenon will be ≈ 22 times that measured for krypton, and the Dynamic K value for radon will be ≈ 67 times the krypton value. Experiments carried out by NUCON International, Inc. using krypton, xenon and radon tracer gases show that this relationship holds over relative humidity values ranging from 0 to 60%.

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Table 2

Proportionality constants for extrapolation of Dynamic K values for xenon and radon based on determinations of K_{Kr} over an RH range of 5 to 60 %

R.H. %	Kr Dynamic K cc/g	Xe Dynamic K cc/g	K_{Xe}/K_{Kr}	Rn Dynamic K cc/g	K_{Rn}/K_{Kr}
5	60	1390	23.17	4000	66.67
10	57	1340	23.51	3850	67.54
20	47	1085	23.09	3125	66.49
30	40	929	23.23	2670	66.75
40	33	767	23.24	2200	66.67
50	26	612	23.54	1775	68.27
60	17	387	22.76	1115	65.59
Average multiplier value			23.22		66.85
Standard Deviation			0.26		0.85

TABLE 3

Xenon Dynamic K vs. Velocity NUCON Grade GXK™

Flow l/min	Face Vel. m/min	R.H. %	Mean Delay (min.)	Dynamic K cc/g
4.94	2.438	28	210	985
9.9	4.876	28	105	989
14.9	7.344	28	69	974
19.8	9.782	28	54	1017
24.8	12.145	28	42	991

The indication is that there is no velocity effect in down-flow mode.

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TABLE 4

Xenon Dynamic K vs. Relative Humidity NUCON Grade GXK™

R.H. (%)	Weight H_2O Adsorbed (%)	Volume H_2O Adsorbed (ml per g carbon)	Xe Dynamic K cc/g	Available Pore Vol (%)
90	21.6	0.216	28	1.9
80	20.9	0.209	84	5.8
70	19.6	0.196	211	14.6
60	19.2	0.196	387	26.7
50	10.0	0.100	612	42.2
40	4.9	0.049	767	52.9
30	3.6	0.036	929	64.1
20	2.4	0.024	1085	74.8
10	2.0	0.020	1340	92.4
5	0.9	0.009	1390	95.9

The indication is that the moisture caused dynamic K deterioration is linear with the pore volume filling of the adsorbed water.

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TABLE 5

Xenon and Krypton Dynamic K vs. Temperature NUCON Grade GXK™

T °C	Krypton Dynamic K (cc/g)	Xenon Dynamic K (cc/g)
40	45.8	619
30	54.0	834
21	63.5	1100
13	77.6	1500
5	98.0	2020
-5	130.0	2805
-15	166.3	3750
-25	203.2	4920
-35	241.0	5957

Figure 2

Xenon and Krypton Dynamic K vs. Temperature NUCON Grade GXK™

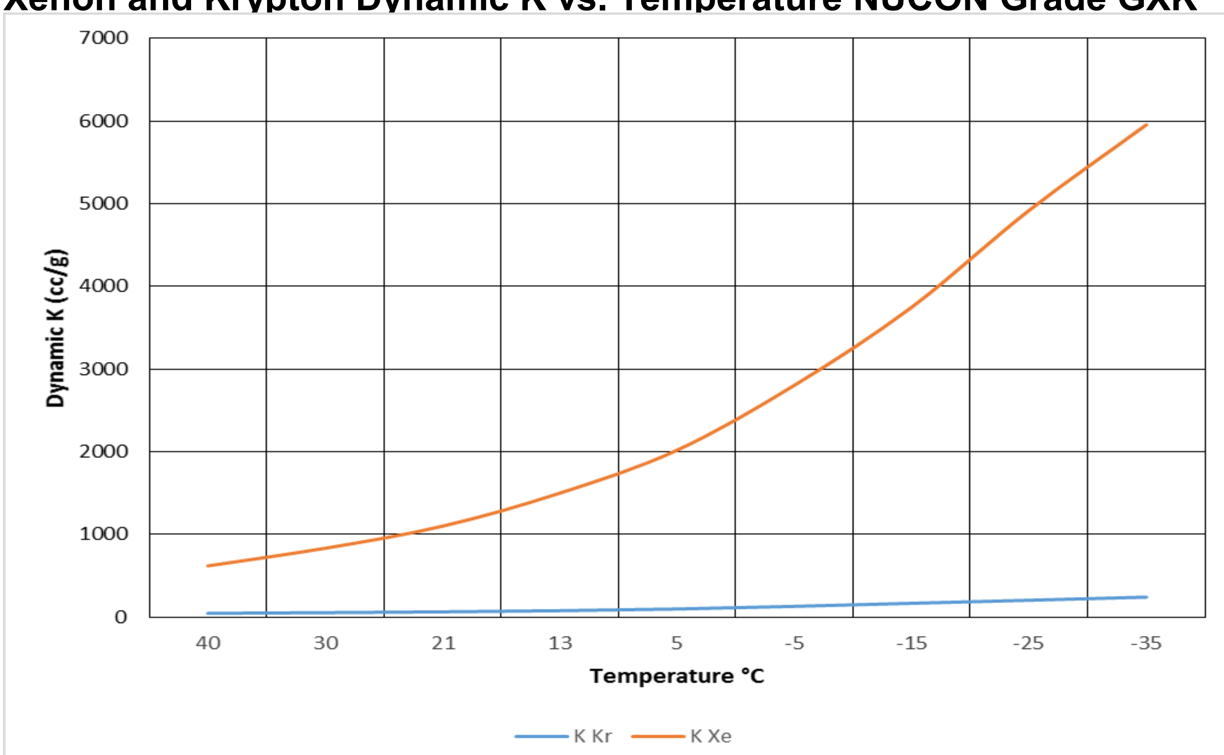

**Figure 3:
Equilibrium Adsorption
of Water Vapor
NUCON Grade GXK™**

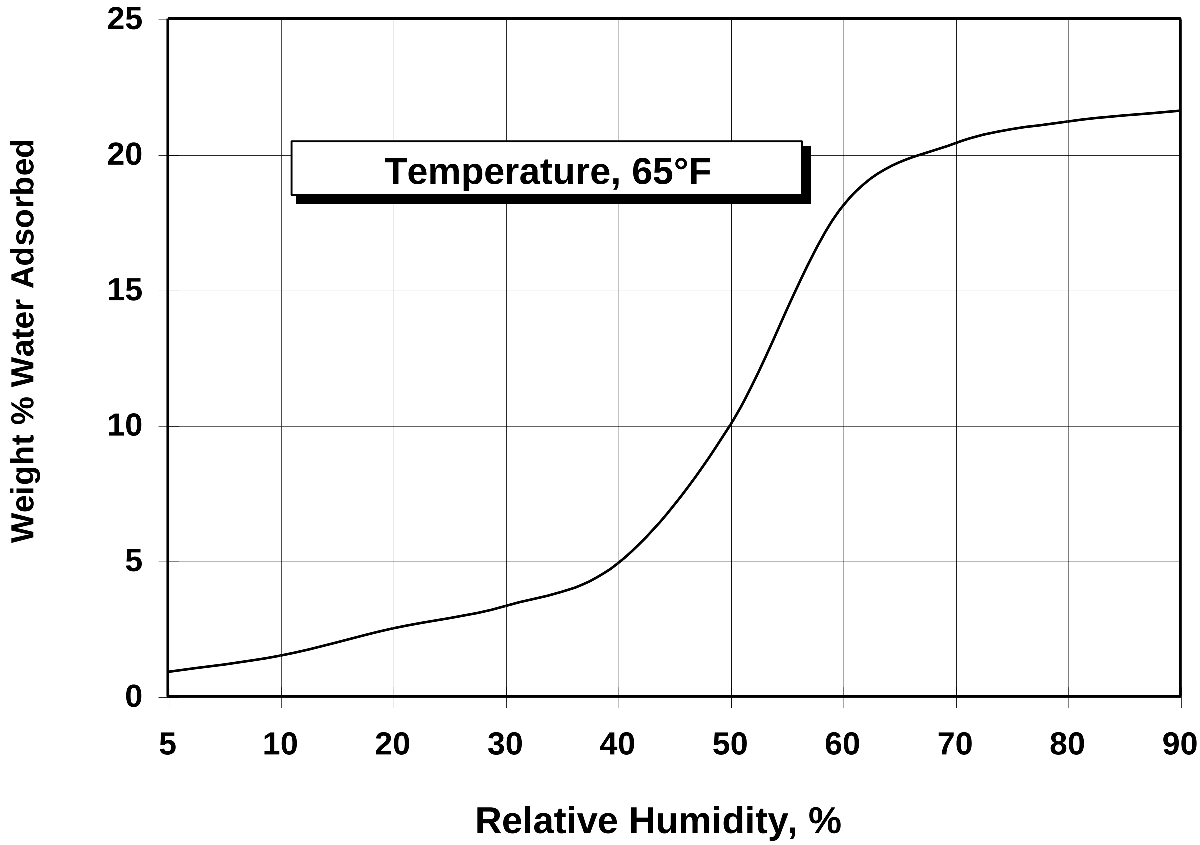

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Figure 4:
Impact of Water Content on
Xenon Dynamic K
NUCON Grade GXK™

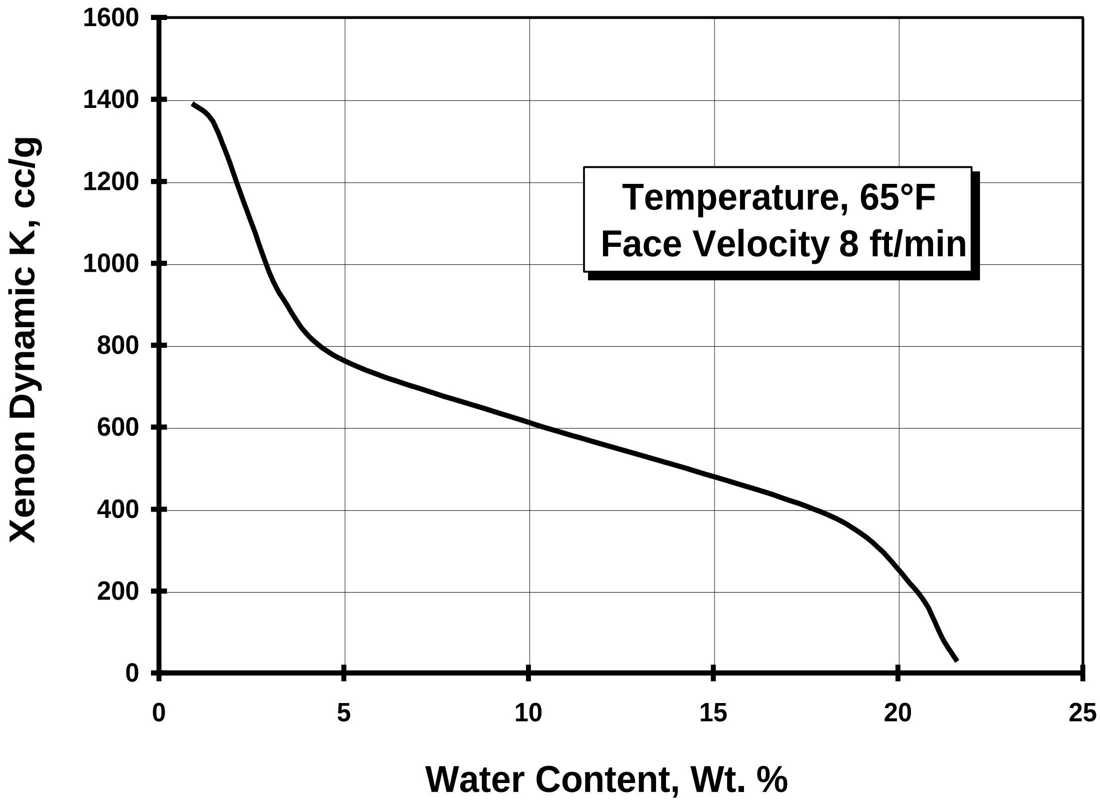

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Figure 5:
Impact of Water Content on Krypton Dynamic K NUCON Grade GXK™

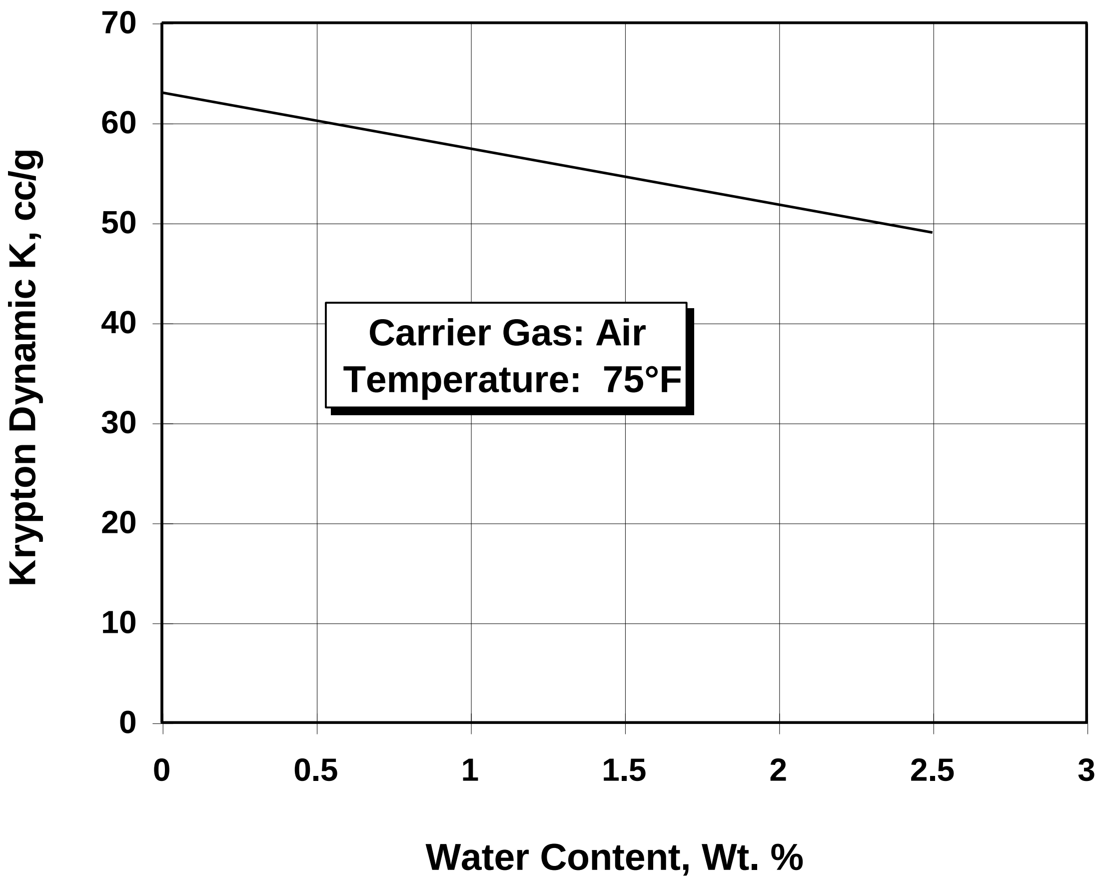

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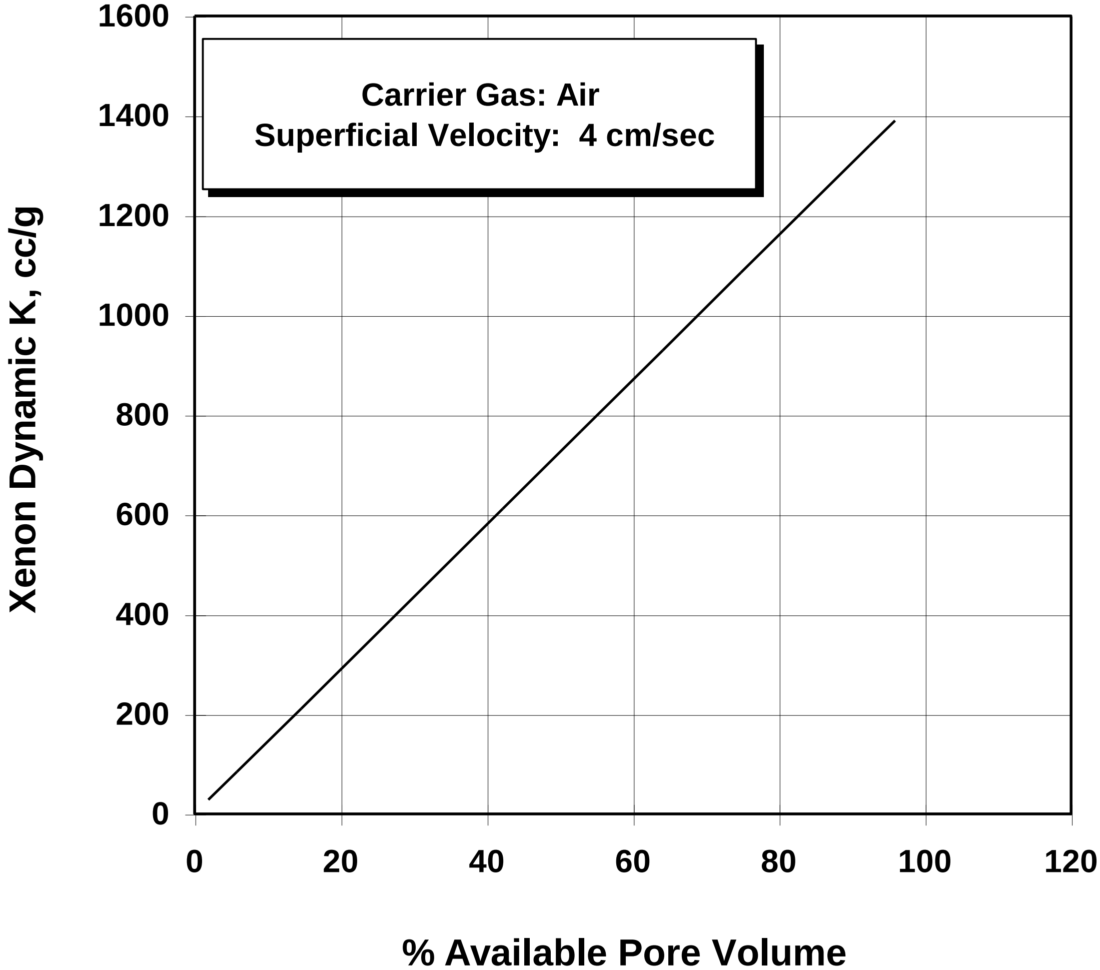
Figure 6
Xenon Dynamic K vs
% Available Pore Volume for
NUCON Grade GXK™
(not filled with water)



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NUSORB® / GXK-6X12™ Product Data Sheet

General Information:

Raw Material:	Coconut Shell
Activation Method:	High Temperature Steam
Particle Type:	Natural Grain
Application:	Noble Gas Holdup

Typical Physical Properties:

Particle Size, US Sieves	(ASTM D2862)	5% Maximum Retention on 6 (3.35 mm) 90-100% Thru 6 on 12 (3.35 mm x 1.70 mm) 5% Maximum Thru 12 (1.70 mm)
Apparent Density:	(ASTM D2854)	0.50-0.60 g/mL
Hardness:	(ASTM D3802)	99.0 wt. % Minimum
Ash Content:	(ASTM D2866)	4.0 wt. % Maximum
Moisture (as packaged)	(ASTM D2867)	5.0 wt. % Maximum

(Note: After installation, the moisture content of the carbon will equilibrate with the relative humidity of the gas stream)

Dynamic Adsorption Properties:

Relative Humidity of Test Gas Stream:	5% max
Test Temperature:	70°F
Dynamic K, Xenon (cc/g)	1400 minimum
Dynamic K, Krypton (cc/g)	60 minimum

CAUTION: OXYGEN IS REMOVED FROM AIR BY WET ACTIVATED CARBON.

Oxygen may be rapidly reduced to a hazardous level in closed or partially closed tanks, receptacles or other enclosed spaces containing carbon. When entering any enclosed space regardless of its contents, follow recommended safety procedures (See MCA Safety Guide SG-10, "Recommended Safe Practices and Procedures, Entering Tanks and Other Enclosed Spaces," Mfg. Chem. Assoc., 1825 Connecticut Ave., N.W., Washington, D.C., 20009).

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Noble Gas Delay Carbons
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NUSORB® / GXK-8X16™ Product Data Sheet

General Information:

Raw Material:	Coconut Shell
Activation Method:	High Temperature Steam
Particle Type:	Natural Grain
Application:	Noble Gas Holdup

Typical Physical Properties:

Particle Size, US Sieves	(ASTM D2862)	5% Maximum Retention on 8 (2.36 mm) 90-100% Thru 8 on 16 (2.36 mm x 1.18 mm) 5% Maximum Thru 16 (1.18 mm)
Apparent Density:	(ASTM D2854)	0.50-0.60 g/mL
Hardness:	(ASTM D3802)	99.0 wt. % Minimum
Ash Content:	(ASTM D2866)	4.0 wt. % Maximum
Moisture (as packaged)	(ASTM D2867)	5.0 wt. % Maximum

(Note: After installation, the moisture content of the carbon will equilibrate with the relative humidity of the gas stream.)

Dynamic Adsorption Properties:

Relative Humidity of Test Gas Stream:	5% max
Test Temperature:	70°F
Dynamic K, Xenon (cc/g)	1400 minimum
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NUCON Experience List
Gaseous Radwaste Off-Gas Systems

1. Vermont Yankee AOG (1972)

Consultant to Utility.

Project responsibility included evaluation of potential technologies for BWR Off-Gas Treatment, including, cryogenic distillation, compressed gas delay pipe, ambient carbon, and refrigerated carbon.

Upon selection of the technology (Ambient Carbon) NUCON developed the P&ID and technical specifications of system, performed vendor evaluation and start-up testing, and participated in the licensing process.

2. Vermont Yankee IOG (1973)

Engineering and Equipment Supplier to Utility.

Designed, built and installed an interim BWR off-gas system processing un-recombined off-gas. Design criteria:

- 30 minute time delay pipe
- Refrigerated dryer operating at 35ºF
- Refrigerated dryer operating at –40ºF (with defrost cycle)
- Pumping system for explosive mixture
- 2 horizontal (buried) carbon beds buried 30" X 150 ft. @ 55ºF (0.762 m x 45.72 m carbon beds 12.78ºC)
- Full control instrumentation
- Supervision of on-site fabrication
- Start-up and turn over
- Participation in licensing process

NUCON Experience List
Gaseous Radwaste Off-Gas Systems
(continued)

3. Peach Bottom II & III (1972-1973)

Consultant to Bechtel Corp.

Performed proof tests on installed pressurized delay pipe for a BWR. Evaluated test results. Recommended interim system configuration changes to meet desired delay time. Recommended long-term permanent changes. Performed proof tests on rebuilt system.

4. CTI, Inc. (Now called Koch Processing, Inc.) (1973)

Consultant to Equipment Supplier.

Evaluated designs for ambient, cooled (60ºF) and refrigerated (0ºF) carbon adsorption system operation. Performed scale testing of adsorption system noble gas delay using various adsorbents, for both BWR and PWR application. Reviewed proposal prepared by vendor.

5. Oyster Creek (1974)

Contractor to Utility.

Loaded adsorbent beds to assure uniform pressure drop in vessels. Provided start-up assistance for BWR.

6. Cooper Nuclear (1974)

Loaded adsorbent beds to assure uniform pressure drop in vessels. Provided start-up assistance for BWR.

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NUCON Experience List
Gaseous Radwaste Off-Gas Systems
(continued)

7. AMINCO (1975)

Consultant to Prime Contractor.

Prepared P&ID and major component specifications for PWR waste gas processing systems.

8. AMETEK (1976)

Consultant to Prime Contractor.

Prepared process design, P&ID, layout drawings and equipment specifications for both BWR off-gas systems, PWR waste gas processing systems and HWR tritium recovery off-gas systems using Kr-85 rejection with hydrogen membrane diffusion.

9. Bechtel Corp. (1972-1977)

Consultant in general gaseous waste processing and HVAC for projects where Bechtel was prime contractor.

10. USEPA (1979)

Consultant to review technology of noble gas control in the fuel cycle with primary importance on the Kr-85 control from fuel reprocessing plants.

11. Shoreham

Contractor to Utility.

Supplied carbon adsorbent <u>and</u> loaded adsorbent beds to assure uniform pressure drop in vessels. Provided start-up assistance for BWR.

NUCON Experience List
Gaseous Radwaste Off-Gas Systems
(continued)

12. Seabrook NPP (1974 and 1986)

Consulting Engineer to Utility.

Developed waste gas processing system without storage tanks for PWR. Developed process prepared P&ID for process design, developed process cost estimates and prepared system and component specifications. Prepared component bidder lists, evaluated bidders and assisted with completion. Provided carbon and loaded vessels.

13. Browns Ferry

Performed tests subsequent to off-gas system fire at a BWR and provided consulting assistance regarding recovery from fire.

14. Montalto di Castro (1984)

Licensor of detailed process for turnkey design construction and installation of off-gas system for twin BWR's. Prepare sizing documents, licensing and construction data.

15. Perry NPP (1987 and 1988)

Consultant to Utility.

Consulting provided regarding fire, subsequent hydrogen detonation and extinguishing of fire. Reviewed damage assessment, participated in preparation of recovery plan, participated in licensing discussions and recommended modifications prior to start-up. Also supplied adsorbent and supervised vessel loading.

NUCON Experience List
Gaseous Radwaste Off-Gas Systems
(continued)

16. Susquehanna NPP (1987)

Consultant to Utility.

Performed consulting and test work subsequent to hydrogen detonation at a BWR plant.

17. KEPCO Yonggwang 3 & 4 (1991)

Engineering and equipment supplier to utility.

Design and build PWR Gaseous Radwaste Systems. NUCON designed system (KOPEC/Sargent & Lundy specification) and supplied skid-mounted equipment for delay of noble gases under ambient temperature.

18. KEPCO Ulchin 3 & 4 (2000)

Engineering design of PWR Gaseous Radwaste System and Carbon Supply.

19. Finetec Century, Korea (2006)

Technology transfer training for GRS design and fabrication

20. CFE, Laguna Verde (2007 & 2008)

Preliminary engineering study of process improvements in their off-gas system to enable them to achieve required performance. Supply carbon based on recommendation.

NUCON Experience List
Gaseous Radwaste Off-Gas Systems
(continued)

21. Korea Hydro Nuclear Power (KHNP) (2008)

Supply of activated carbon (NUSORB G30-6x12) for GRS system

22. KHNP Shin Kori (2009)

Supply of activated carbon (NUSORB G30-6x12) for GRS system

23. KHNP Shin Wolsong (2009)

Supply of activated carbon (NUSORB G30-6x12) for GRS system

24. Nine Mile Point Nuclear Generating Station (2014, 2016, 2018)

Contractor to Utility.

Supply of activated carbon (NUSORB G30-6x12) for GRS system

Supervised the unloading of degraded adsorbent and the loading of new adsorbent to assure uniform pressure drop in vessels.