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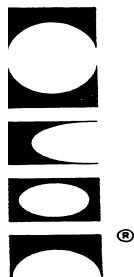
NUCON Technical Bulletin No. 11B10
Noble Gas Delay Carbons
Rev. October 2010)
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NUCON[®] NUSORB[®] NOBLE GAS DELAY CARBONS

NUCON Technical Bulletin 11B10

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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 not the best choice for optimum noble gas delay (USAEC CONF-720823 Vol 1 p. 71).

2.0 PRODUCTS

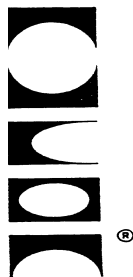
Activated carbons offered by NUCON for noble gas delay are the NUSORB® G30™ series. These are typically used in the 6x12 and 8x16 U.S. mesh sizes. The attached data sheets show typical properties of these products.

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 (H₂O, CO₂, etc.)
- 4) Packing density
- 5) Bed geometry



4.0 DESIGN PARAMETERS FOR NUSORB G30 SERIES

- Bed void fraction: 0.40 - 0.44
- Carbon thermal conductivity: 3.1×10^{-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:

<u>Velocity</u>	<u>G30-6X12</u>	<u>G30-8X16</u>
0.1 fpm	0.001	0.0012
1.0 fpm	0.021	0.026
10.0 fpm	0.500	0.605

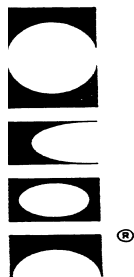
In typical noble gas control systems the more critical dose effect is from Xenon and not from Krypton. However, the very critical moisture effect on Xenon adsorption has been rarely evaluated in the past. Radon adsorption is of concern for mining air purification, where relative humidity is also variable. 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 micro pore volume. The relationship between relative humidity and weight percent water adsorbed is non-linear.

TEST PARAMETERS:

Adsorbent Wt., (g):	1052.6
Bed Depth, (cm):	95.25 (37.5 in)
Adsorbent Volume, (cc):	1870
Face Velocity, (ft/min):	8-40
Relative Humidity, (%):	5-90
Temperature, (°C):	18.3 (65°F)
Tracer:	^{133}Xe

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



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, cm³/g

F = flow, cm³/sec

TABLE 1

Noble Gas Dynamic K vs. Relative Humidity NUCON Grade G-30

Flow l/min	Face Vel. ft/min	R.H. %	H2O Wt %	Kr Dynamic K cc/g	Xe Dynamic K cc/g	Rn Dynamic K cc/g
4.94	8.0	5	0.9	60	1,390	4,000
4.94	8.0	10	2.0	57	1,340	3,850
4.94	8.0	20	2.4	47	1,085	3,125
4.94	8.0	30	3.6	40	929	2,670
4.94	8.0	40	4.9	33	767	2,200
4.94	8.0	50	10.0	26	612	1,775
4.94	8.0	60	19.2	17	387	1,115
4.94	8.0	70	19.6	9	211	610
4.94	8.0	80	20.9	4	84	245
4.94	8.0	90	21.6	1	28	82

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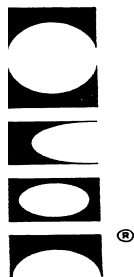


TABLE 2

Xenon Dynamic K vs. Velocity NUCON Grade G-30

Flow l/min	Face Vel. ft/min	R.H. %	Mean Delay (min.)	Dynamic K cc/g
4.94	8.0	28	210	985
9.9	16.0	28	105	989
14.9	24.1	28	69	974
19.8	32.1	28	54	1017
24.8	40.1	28	42	991

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

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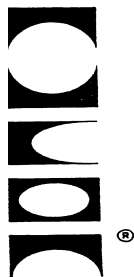
TABLE 3

Xenon Dynamic K vs. Relative Humidity NUCON Grade G-30

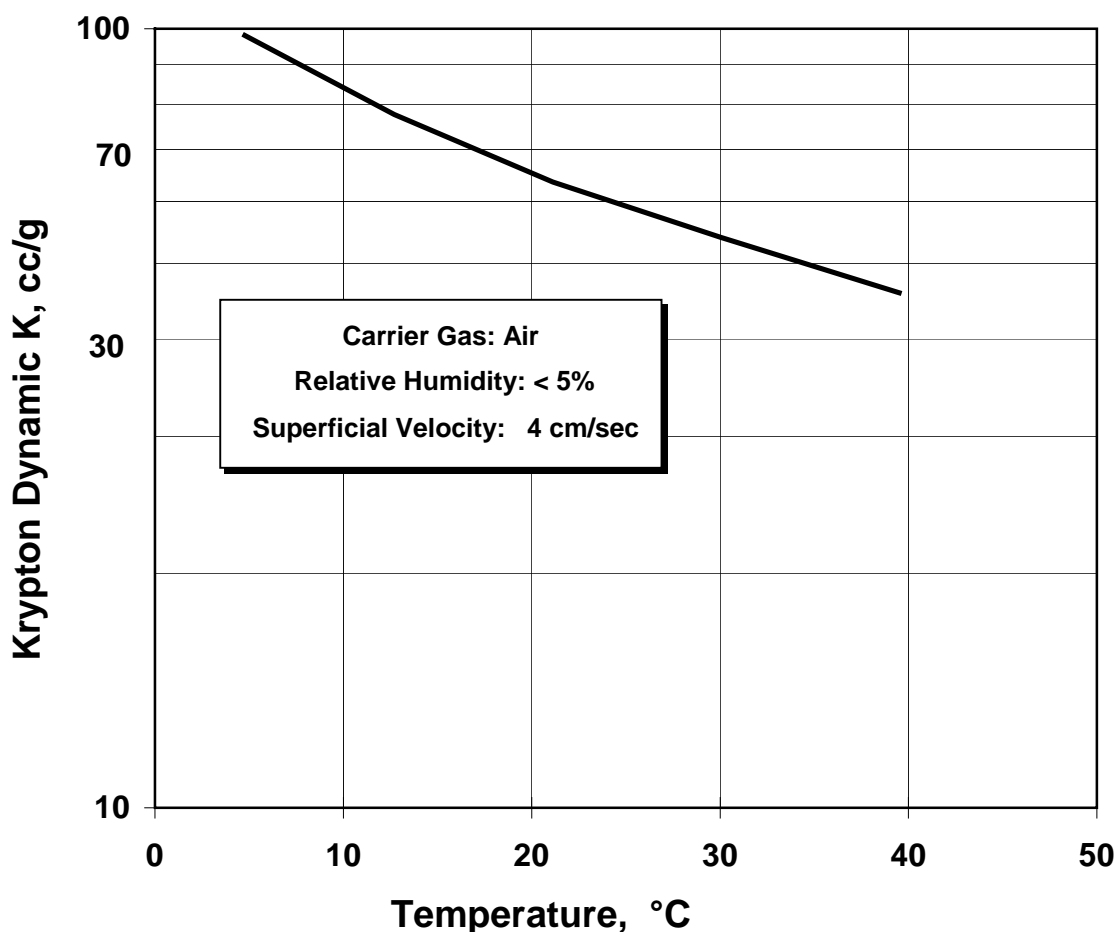
R.H. (%)	Weight H ₂ O Adsorbed (%)	Volume H ₂ O Adsorbed (ml per g carbon)	Xe Dynamic K cc/g	Available Pore Vol (%)
90	21.6	0.216	28	1.9
80	20.9	0.209	84	5.8
70	19.6	0.196	211	14.6
60	19.2	0.196	387	26.7
50	10.0	0.100	612	42.2
40	4.9	0.049	767	52.9
30	3.6	0.036	929	64.1
20	2.4	0.024	1085	74.8
10	2.0	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.

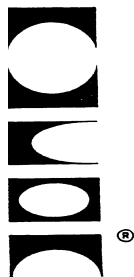
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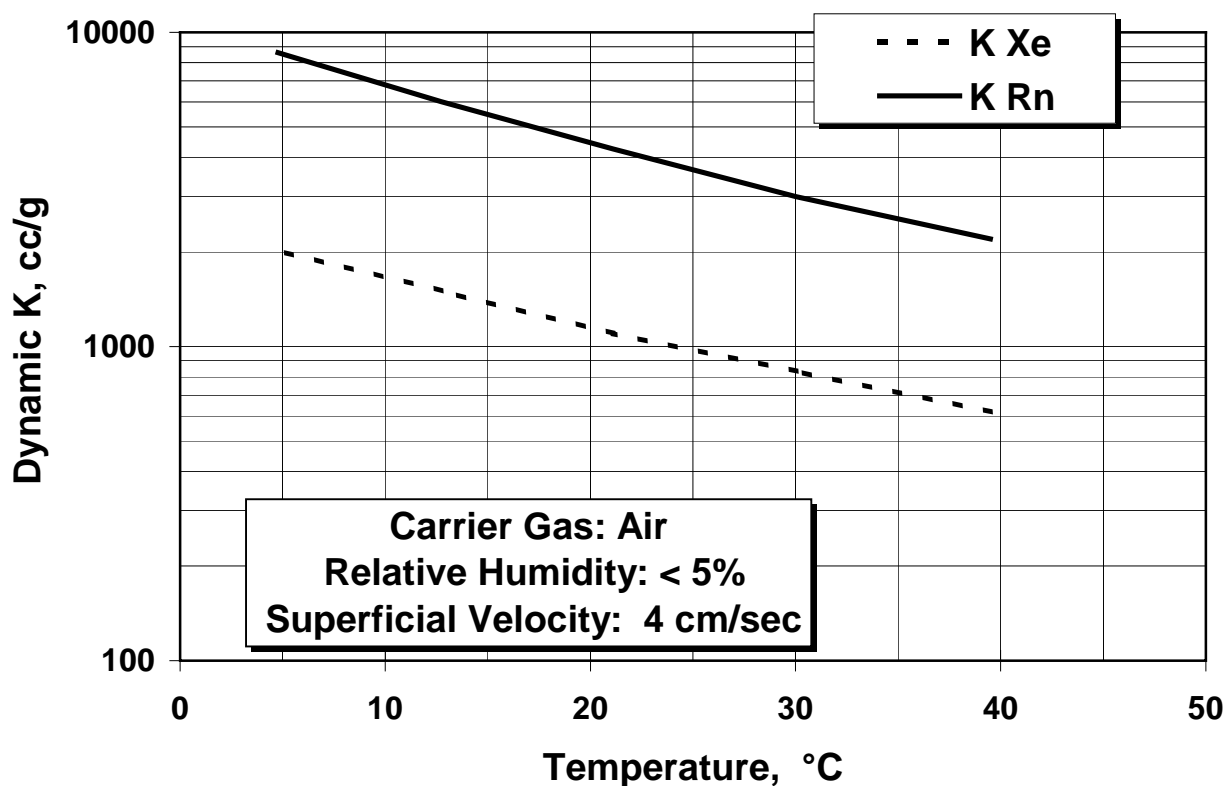
**Figure 1:
Temperature vs Krypton Dynamic K
NUCON Grade G-30**



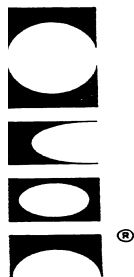
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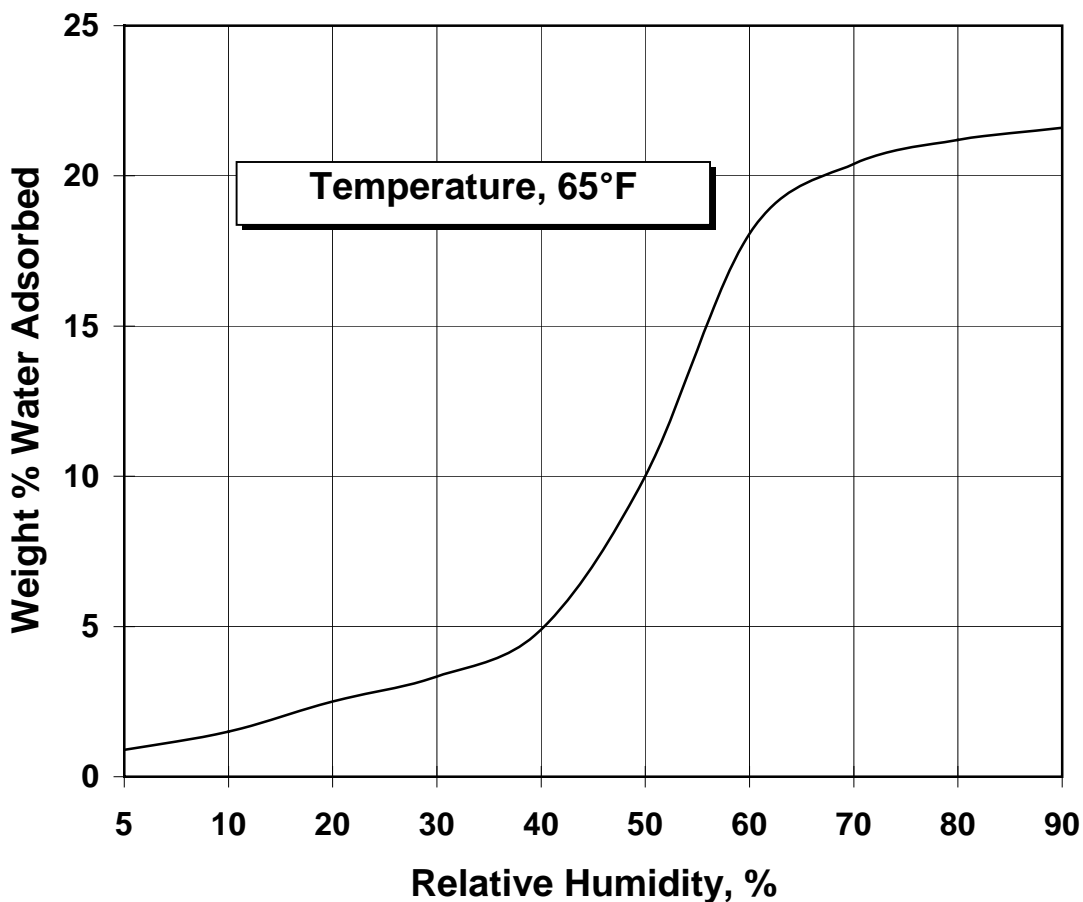
**Figure 2:
Temperature vs Xenon and Radon Dynamic K
NUCON Grade G-30**



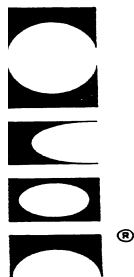
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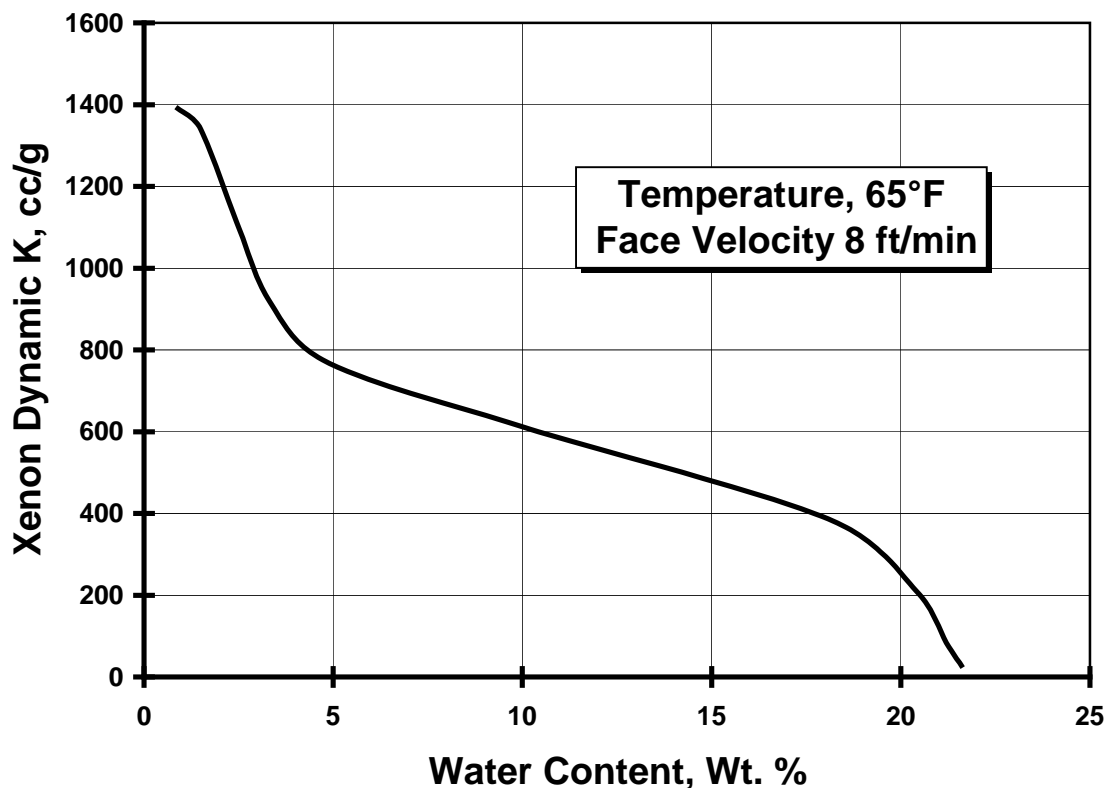
**Figure 3:
Equilibrium Adsorption
of Water Vapor
NUCON Grade G-30**



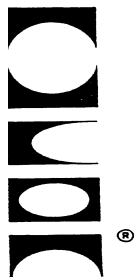
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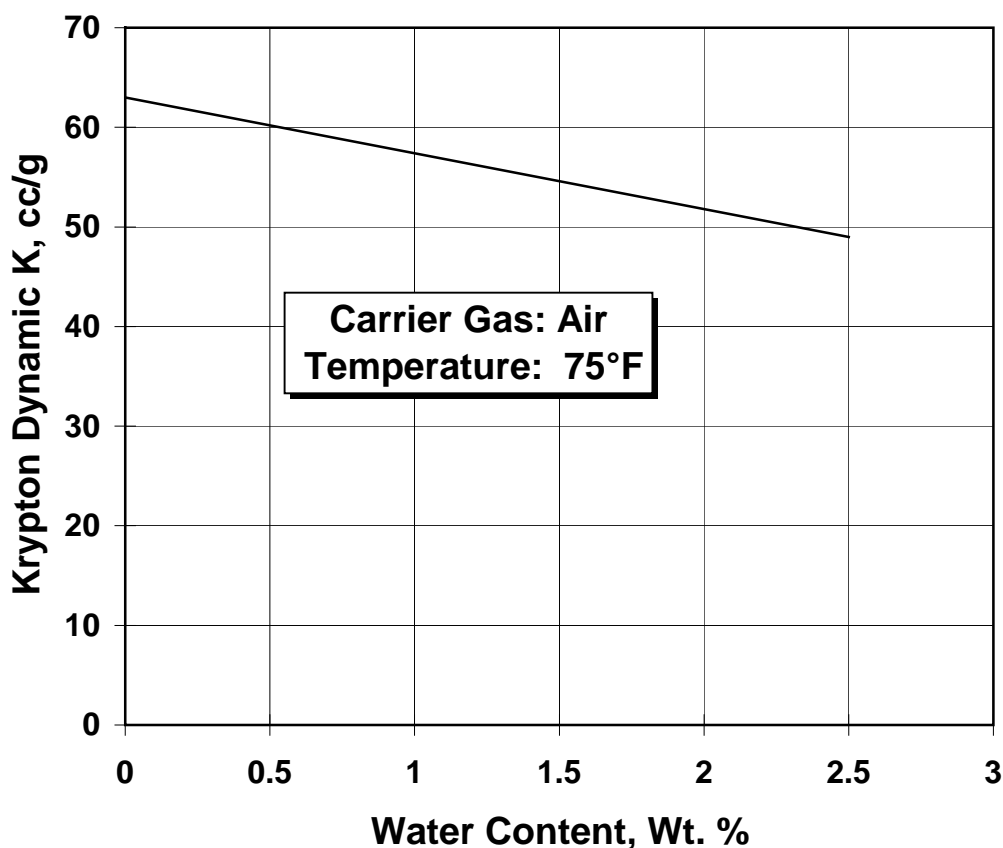
**Figure 4:
Impact of Water Content on
Xenon Dynamic K
NUCON Grade G-30**



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**Figure 5:
Impact of Water Content on
Krypton Dynamic K
NUCON Grade G-30**



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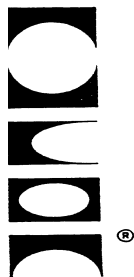
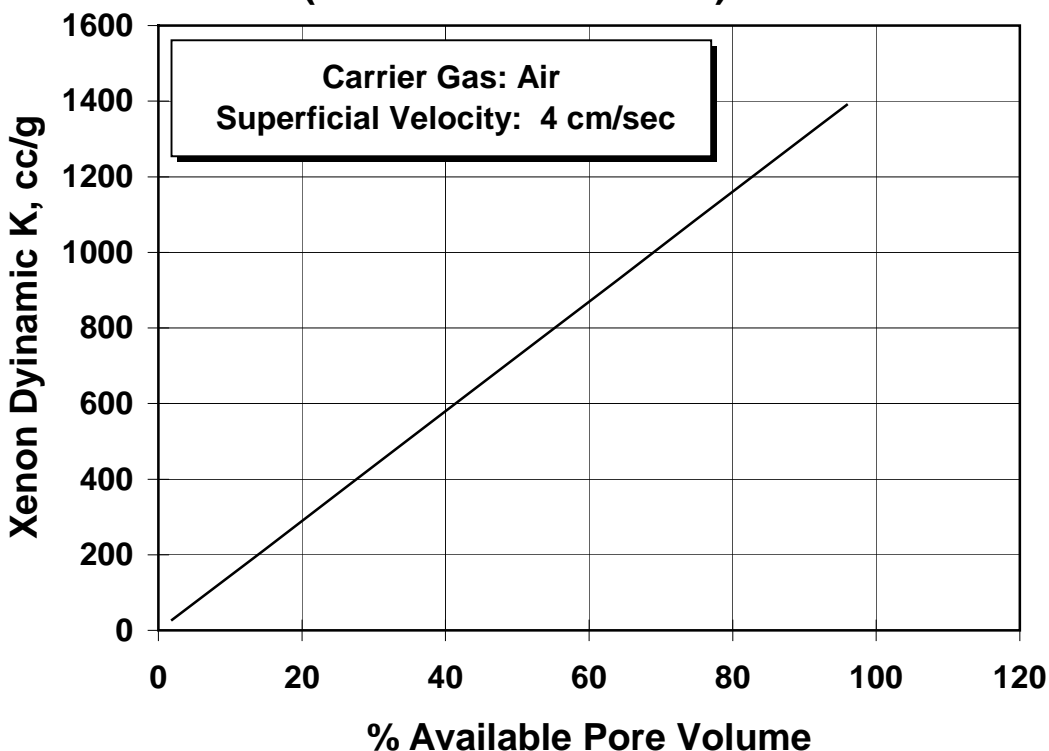


Figure 6
Xenon Dynamic K vs
% Available Pore Volume for NUCON Grade
G-30
(not filled with water)



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

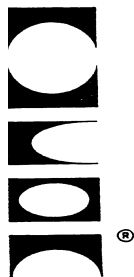
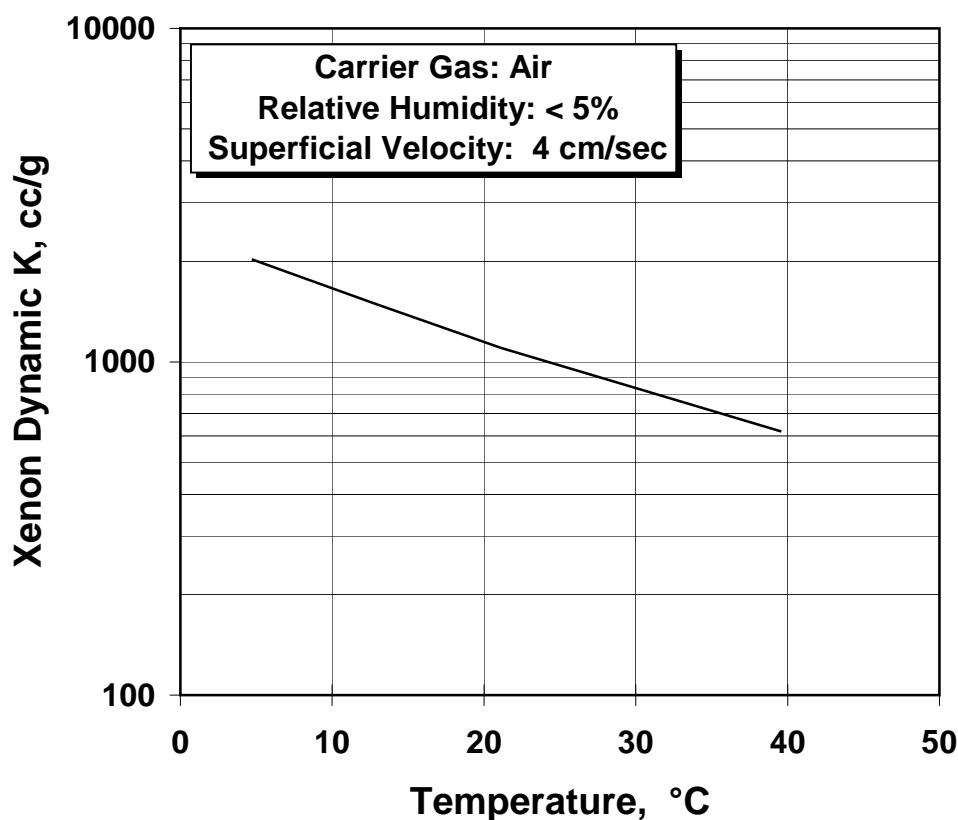
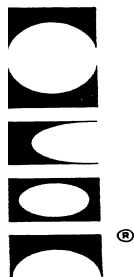


Figure 7
Temperature vs Xenon Dynamic K
NUCON Grade G-30



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



NUSORB[®] / G30-6X12[™] TECHNICAL DATA SHEET

RAW MATERIAL: Coconut Shell
ACTIVATION METHOD: High Temperature Steam
PARTICLE TYPE: Natural Grain
APPLICATION: Noble Gas Holdup

PHYSICAL PROPERTIES:

Particle Size, US Sieves (ASTM D2862)
5% Maximum Retention on 6
90-100% Thru 6 on 12
5% Maximum Thru 12

Apparent Density: 0.55-0.60 g/ml
(ASTM D2854)

Hardness: 97.0% Minimum
(ASTM D3802)

Moisture (as packaged) 5.0% Maximum
(ASTM D2867)

Ash Content: 4.0% Maximum
(ASTM D2866)

DYNAMIC ADSORPTION PROPERTIES:

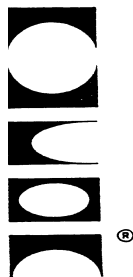
Moisture content: 5.0% max
Test Temperature: 70°F

Dynamic K, Xenon (cc/g) 1400 minimum
Dynamic K, Krypton (cc/g) 60 minimum

IMPORTANT SAFETY INFORMATION

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).



NUSORB[®] / G30-8X16[™] TECHNICAL DATA SHEET

RAW MATERIAL: Coconut Shell
ACTIVATION METHOD: High Temperature Steam
PARTICLE TYPE: Natural Grain
APPLICATION: Noble Gas Holdup

PHYSICAL PROPERTIES:

Particle Size, US Sieves (ASTM D2862)
5% Maximum Retention on 8
90-100% Thru 6 on 16
5% Maximum Thru 16

Apparent Density: 0.55-0.60 g/ml
(ASTM D2854)

Hardness: 97.0% Minimum
(ASTM D3802)

Moisture (as packaged) 5.0% Maximum
(ASTM D2867)

Ash Content: 4.0% Maximum
(ASTM D2866)

DYNAMIC ADSORPTION PROPERTIES:

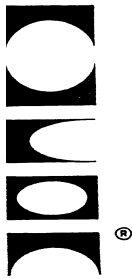
Moisture content: 5.0 % max
Test Temperature: 70°F

Dynamic K, Xenon (cc/g) 1400 minimum
Dynamic K, Krypton (cc/g) 60 minimum

IMPORTANT SAFETY INFORMATION

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

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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.

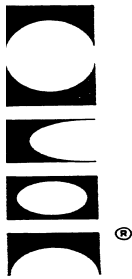
Upon selection of the technology (Ambient Carbon) NUCON developed the P&ID and technical specifications of system, performed vendor evaluation and start-up testing, and participated in the licensing process.

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 35°F
- Refrigerated dryer operating at -40°F (with defrost cycle)
- Pumping system for explosive mixture
- 2 horizontal buried 30" X 150 ft. carbon beds (at 55°F)
- 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 (60°F) and refrigerated (0°F) 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.

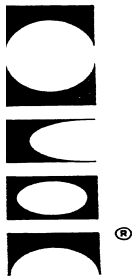
5. Oyster Creek (1974)

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.



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.

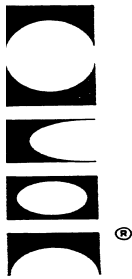
10. **USEPA** (1979)

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 and 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.

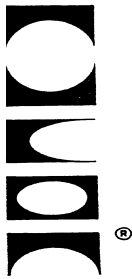
14. **Montalto di Castro** (1984)

Licenser 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)

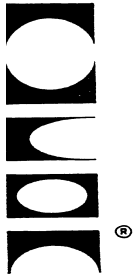
Engineering design of PWR Gaseous Radwaste System and Carbon Supply.

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