DRAFT # 1

November 19, 1979

A-150 EQUIVALENT GAS [1]

F. H. Attix
Medical Physics Division
University of Wisconsin
Madison, Wisconsin 53706

and

M. Awschalom
Fermi National Accelerator Laboratory
P.O.Box 500
Batavia, Illinois 60510

---

[1] This work was carried out with the support of US Department of Energy Contract # EY-76-S-02-1105 and National Institute Grant # 5PO1 CA18081-5

The so-called "tissue equivalent" ionization chamber first proposed for neutron dosimetry by Failla and Rossi (1950) is widely used for radiation protection and in neutron radiotherapy beam calibrations. The walls of such chambers are usually contructed of a conducting plastic developed by Shonka et al (1959), the characteristics of which have been documented by Smathers et al (1977). In particular, the atomic composition of that plastic known was "A-150" is shown in Table 1. This table also shows the compositions by weight of muscle, TE-gas, and one possible mixture of A-150 equivalent gas. It may be seen that the match is perfect between A-150 plastic and muscle with respect to hydrogen and nitrogen, but poor for carbon and oxygen where gross substitutions of carbon for oxygen have been made. The problem of making a more closely tissue-equivalent conducting plastic has never been mentioned in the open literature.

The gas generally employed in A-150 plastic chambers is usually a mixture proposed by Rossi (1956). This "tissue-equivalent" (TE) gas has a composition which matches neither muscle nor A-150 plastic with respect to carbon and oxygen.

Recently, at the Workshop on Ion Chambers for Neutron Dosimetry (September, 1979 at the Radiobiology Institute TNO, Rijswijk, The Netherlands) it was again suggested this time by J. W. Boag that a closer matching of the gas to the A-150 plastic would simplify the application of Bragg-Gray cavity theory to the interpretation of the collected charge in terms of dose absorbed by the gas in the ionization chamber. That is, if the atomic composition of the gas were made identical with that of the plastic wall, the production of charged particles by neutron interactions would then be the same per unit mass in the gas and wall. Moreover, the remaining stopping-power correction, wall/gas would be due only to the small polarization effect difference between solid and gas phases of the materials. This effect could probably be neglected. Finally, the charged particle types and spectra in the gas would no longer depend on the size of the gas volume, which would allow more accurate determination of the mean energy per ion pair ($\overline{W}$) in the gas (e.g., see Goodman and Mc Donald, 1979).

Three possible gas mixtures which might fill this requirement for an "A-150" equivalent gas are given in the appendix. Table I shows show closely the atomic composition of the A-150 plastic and these gases are matched, except for calcium being replaced by argonne. This minor discrepancy is not believed to be significant.

An experimental test of this gas is to be carried out soon.

Acknowledgement

We want to thank Mr. J. R. Wiley of Matheson (Joliet, IL plant) for discussions on practical considerations about gas mixtures.

References

Failla, G., and Rossi, H.H., 1950, Am. J. Roentgenology and Radium Therapy 64, 489.

Goodman, L. J., and Coyne, J. J., $\overline{W}_n$ for methane-based tissue-equivalent gas.

Goodman, L. and Mc Donald, J., 1979.

Myers, I. T., 1968, Chapter 7, Radiation Dosimetry, Vol. 1, 2nd Edition by F. H. Attix and W. C. Roesch, Academic Press, New York.

Rossi, H. H., 1956, Chapter 15, Radiation Dosimetry, 1st Edition, Ed. by G. J. Hine and G. L. Brownell, Academic Press, New York.

Shonka, F. R., Rose, J. E., and Failla, G., 1959, Paper p/753 in Geneva Conference on Progress in Nuclear Energy, Series XII, Vol. I, p. 160.

Smathers, J. B., Otte, V. A., Smith, A. R., Almond, P.R., Attix, F. H., Spokas, J. J., Quam, W. M., and Goodman, L. J., 1977, Med. Physics, 4, 74.

TABLE I

Atomic Compositions, Percentages by Weight

1 Element	2 Muscle	3 A-150	4 TE-Gas	5 A-150 Gas
H	10.2	10.2	10.2	10.20
C	12.3	76.8	45.6	76.80
O	72.9	5.9	40.7	5.90
N	3.5	3.6	3.5	3.60
F	---	1.7	---	1.70
Ca	---	1.8	---	1.80[5]
Other	1.1	---	---	---

1. NBS Handbook 85, ICRU Report 10b (1962).
2. Smathers, et al (1977)
3. 64.4% C_2H_4, 32.4% CO_2, and 3.2% N_2 by partial pressures. Rossi (1956).
4. See Text and Appendix
5. Calcium substituted for Argonne

(Replacement for Table II in "A-150 Plastic-Equivalent Gas" by Awschalom and Attix, in press, PMB).

TABLE II

Some A-150 Plastic-Equivalent Gas Mixtures

(percent by weight)

Gas	Molec. Wt.	Formula	Mix 1	Mix 2	Mix 3	Mix 4
Ethylene	28.05	C_2H_4	44.5	41.3	46.5	43.4
Propadiene	40.06	C_3H_4	37.8	28.9	32.0	25.3
1,3 Butadiene	54.09	C_4H_6	0	12.1	0	10.6
Acetylene	26.04	C_2H_2	0	0	3.8	3.0
Nitrogen	28.01	N_2	3.6	3.6	3.6	3.6
Carbon Monoxide	28.01	CO	10.3	10.3	10.3	10.3
Carbon-Tetrafluoride	88.00	CF_4	2.0	2.0	2.0	2.0
Argon	39.95	Ar	1.8	1.8	1.8	1.8
Maximum Practical Tank Pressure (Atm):			18.2	17.6	22.1	20.5
Nominal Gas Density (0°C., 760 torr, in g/ℓ):			1.442	1.496	1.408	1.461

APPENDIX

Formulation of A-150 Equivalent Gas Mixtures

The method followed to calculate the gas mixtures given below is described. The number of moles of gases needed to make 100g of A-150 equivalent gas are calculated in two steps. From column 3, in Table 1, the number of moles are calculated that give the proper masses of oxygen as carbon monoxide, nitrogen, fluorine as carbon tetrafluoride, and argonne replacing calcium. Then, the hydrogen and still unallocated carbon (total carbon less the carbon masses in CO and CF_4) are presumed to come from mixtures of ethylene, propadiene, and if desired 1,3 butadiene and acetylene. The gases, except for ethylene, are assumed to be mixed in proportion to their maximum practical vessel pressures (∿70% of their vapor pressure at $70^{o}F$), except for acetylene where a maximum pressure of only 15 lb/in^2 is allowed. This mixture is required to have a ratio of hydrogen to carbon atoms equal to 1.6855 (number hydrogen to number of unallocated carbon atoms). Solving the appropriate equation, the partial pressure of ethylene is found for the selected mixture of hydrocarbons. Partial pressures and partial volumes have the same ratios; therefore, the sum of the masses of the partial volumes may be related to the required mass of hydrogen plus unallocated carbon (82.302g). Thus, the actual masses of the gases are obtained. Finally, these masses are converted to number of moles and the partial pressures for all gases may finally be calculated as fractions of the gas pressure in the vessel.

There is no complete freedom in choosing partial pressures of gases having a formula C_mH_n where $(m/n)<2$. Acetylene in ordinary containers at pressures greater than $15 lb/in^2$ may dissociate spontaneously and exoergically! Also, when two gases which are close to their liquid phases are mixed together, their behavior becomes impredictable. Therefore, their partial pressures must be kept even below the 70% of their vapor pressures at a nominal room temperature such as $70^{o}F$ ($21^{o}C$) mentioned above. A practial rule is to use the maximum absolute pressure of the gas with the highest absolute practial vapor pressure and divide this pressure by the sum of the partial pressures of the gases involved. For example, in mixture # 1, the only critical gas is propadiene, then the vessel pressure becomes (81.7/0.305) lb/in^2

In mixture # 2, this pressure becomes 81.7/(0.242 + 0.075) or 258 lb/in^2. In mixture # 3, the practial absolute pressure becomes 81.7/(0.207 + 0.064) or 301 lb/in^2 In mixture # 3, the acetylene is limited in pressure by its chemical instability and not its vapor pressure.

Finally, caution must be exercised when using these gas mixtures. The vessel must be well above 70°F and any cooling due to the Joule-Kelvin effect must keep the gas mixture at a temperature above 70°F to avoid partial condensation of one or both of the critical hydrocarbons.

Table II Possible A-150 Gas Mixtures

% Partial Pressures

Gas	Formula	Mix #1	Mix #2	Mix #3
ethylene	C_2H_4	51.24%	49.42%	50.61%
propadiene	C_3H_4	30.51%	24.17%	20.70%
1,3 butadiene	C_4H_6	0	7.48%	6.41%
acetylene	C_2H_2	0	0	3.80%
nitrogen	N_2	4.15%	4.31%	4.21%
carbon monoxide	CO	11.92%	12.36%	12.07%
carbon tetrofluoride	CF_4	0.72%	0.75%	0.73%
argonne	Ar	1.45%	1.51%	1.48%
theoretical vessel pressure	(lb/in^2	267	338	394
practical vessel pressure	(lb/ in^2	257	258	301