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ESSENTIALS OF A RUBIDIUM-82 GENERATOR FOR NUCLEAR MEDICINE

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DISCLAIMER

Essentials of a Rubidium-82 Generator for Nuclear Medicine

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The use of generator-produced ^{82}Rb for positron emission tomography studies in clinical nuclear medicine requires a number of factors to be considered. These include ^{82}Sr availability, methods of recharging the generator with fresh ^{82}Sr, adequate elution yield of ^{82}Rb, low breakthrough of $^{82-85}Sr$, simple and reliable operation of the generator, and delivery of a sterile and pyrogen free eluate of ^{82}Rb.

Acknowledgement

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Introduction

Quantitative studies of flow and metabolism can be obtained noninvasively by positron emission tomography (PET). These studies require a high flux of photons from short-lived positron emitters which provide adequate statistical sampling in the reconstructed cross-sectional image while minimizing the radiation dose to the patient.

Radionuclide generators provide an inexpensive alternative to on-site dedicated cyclotrons for the production of short-lived positron-emitting radionuclides. Table 1 lists some generators for positron emitters. The short half life of the daughter radionuclide permits the intravenous administration of 5-50 mCi of radioactivity. When the half life is < 3.8 m the rapid decay of activity within the subject and the rapid regeneration of the daughter radionuclide permits serial studies to be done on the same patient every 5-30 minutes. The essentials of one these generators, the $^{82}Sr/^{82}Rb$ system, will be discussed for the application of 76 second ^{82}Rb to PET studies of myocardial perfusion in patients with heart disease and to the changes in the permeability of the blood-brain barrier in patients with brain tumors or radiation therapy necrosis[1-4].

Essentials for a ^{82}Rb Generator

The essential requirements for a clinically-useful ^{82}Rb generator are the following: 1) Adequate and reasonably priced supply of ^{82}Sr, 2) Replaceable inorganic ion exchange columns charged with 100-200 mCi of ^{82}Sr, 3) 60-70% yields of ^{82}Rb per rapid bolus elution, 4) Low breakthroughs of ^{82},^{85}Sr per elution, 5) Simple and reliable operation of the generator over extended elution volumes and long term use, and 6) Maintaining a sterile and pyrogen

free eluate for safe intravenous injection. Each of these requirements will be discussed in the light of our operational experience and in the prospects of continuing developments.

^{82}Sr Supply:

Presently the two major suppliers are linear accelerators at the Los Alamos National Laboratory (LANL) and the Brookhaven National Laboratories (BNL). At LANL the ^{82}Sr is produced by the spallation of a molybdenum target with 800-MeV protons at the Los Alamos Meson Physics Facility (LAMPF). The target is processed by the LANL radiochemistry group[5]. Curie quantities of ^{82}Sr are produced with a major radiocontaminant ^{85}Sr and lesser amounts of other radionuclides. The LANL process is discussed in detail by K. Thomas (this volume). At BNL the ^{82}Sr is produced by the irradiation of a RbCl target with protons at the Brookhaven Linac Isotope Producer (BLIP). The production yield of ^{82}Sr is less by this method because of lower beam current and less target material; but there are fewer radiostrontium contaminants and the ratio of ^{85}Sr to ^{82}Sr is smaller at the end of processing[6]. The BLIP process is discussed by L. Mausner (this volume).

Although these two suppliers produce relatively large quantities of ^{82}Sr, because of the long down times (up to 6 months) at both of these facilities, there are periods when it is not possible to recharge the ^{82}Rb generator with a new loading of ^{82}Sr. Present efforts to alleviate this problem have resulted in closer coordination of the down times at LAMPF and at BLIP to maintain one of the two units in operation while the other is down. However, even under these conditions it will be difficult to maintain an adequate supply of ^{82}Sr for the continuous demand of clinical nuclear medicine. Other possible suppliers and cross-sections for nuclear reactions are being investigated to expand the production capability for ^{82}Sr[7] using other accelerators.

Replaceable Ion Exchange Columns Containing New ^{82}Sr Loadings.

The versatility of the ^{82}Rb generator to provide positron emitters for the clinical setting is dependent upon the method of either reloading the generator with a new batch of ^{82}Sr every 2-3 months or upon the commercial availability of an ion exchange column freshly loaded with ^{82}Sr for replacement in the lead shielded compartment of the ^{82}Rb generator. If the user reloads the ^{82}Sr on the column, he will need a "hot cell" with 2 inches of lead shielding which is adequate to handle the 200 mCi ^{82}Sr solution, and a remotely operated pumping system. When an alumina column is used the same column can be reloaded at least 3 times without a significant increase in $^{82/85}Sr$ breakthrough[8] as has been done at Lawrence Berkeley Laboratory for the past 5 years. However, the preferred option would be to have a commercially available supplier of preloaded ^{82}Sr columns contained in primary lead shielding for shipment and placement in a secondary lead shield that is an integral part of the ^{82}Rb generator pumping and flow-control system at the PET imaging site. Such a system has been described which utilizes "quick connects" to connect the 1/8 inch o.d. stainless steel tubing from the column to the pumping and delivery system of the ^{82}Rb generator, Fig. 1[8]. This method would preclude the need for a "hot cell" by the user and simplify the daily operation of the ^{82}Rb generator on a long-term basis. Additionally, quality control of the ^{82}Sr column elution characteristics could be determined by the supplier before shipment to the user, and thus maintain uniform generator performance with respect to elution yield and breakthrough. However, the user should conduct yield and breakthrough measurements on a daily basis.

Elution Yields of ^{82}Rb.

The elution yields of ^{82}Rb are dependent upon the type and volume of ion exchange adsorber, the type and concentration of the eluent, and the flow-rate

of the eluent [9,10]. Various combinations of adsorber materials and eluent have been investigated by several researchers as shown in Table 2. Of these various combinations for a ^{82}Rb generator, the SnO_2 and the Al_2O_3 columns have shown the most promise in combination with 1% and 2% saline eluent respectively[10,9]. For rapid bolus elutions at 0.5 to 1.0 ml per second, the ^{82}Rb yields range from 40-90%. The SnO_2 column using isotonic 1% saline eluent gave about 70% yield at a flow rate of 50 ml/min. The Al_2O_3 with 2% saline eluent gave >80% yields ^{82}Rb at a flow rate of 60 ml/min[11]. The latter system has been used in over one hundred patient studies over the past 5 years without any adverse effects to the patients, even in cases of very ill patients with heart disease or brain tumors that were undergoing therapy.

Breakthrough of $^{82,85}Sr$.

The breakthrough of radioactive Sr is a function of the type and volume of adsorber matrix, the concentration of the saline eluent, and the flow-rate of the eluent[9,10]. A study was made to compare the breakthrough of Sr from SnO_2 and from Al_2O_3 using both the batch method and column separation. In the batch method, equal weights of the two adsorbers were mixed with equal volumes of $^{82,85}Sr$ at pH 7.0-8.5, the supernatant was removed, and the radioactivity in the two phases was determined by sample counting in a gamma well counter. The breakthrough was calculated to be the activity per gram in the solution divided by the activity per gram left on the adsorber after each separation. Similar measurements were made on eluates from identical columns of the two adsorbers. In the column experiments, SnO_2 and Al_2O_3 were packed in 2 ml bed volumes. The eluent for SnO_2 was normal saline, pH 7.0, and for Al_2O_3 the eluent was 2% saline, pH 8.5. The flow rate was 60 ml/min. The eluates from the column were collected and the ^{82}Rb allowed to decay away. Four ml aliquots of each

elution volume were counted by either a NaI(Tl) or Ge(Li) gamma-ray detector. Calculations of breakthrough were made against a $^{82,85}Sr$ standard with the same ^{82}Sr: ^{85}Sr ratio as the column radiostrontium. The breakthrough of $^{82,85}Sr$ from both SnO_2 and Al_2O_3 is a function of the rate of elution. At higher elution rates the breakthrough increases by 30% at 70 ml/min compared to elutions at 60 ml/min. These results are shown in Figs. 2 and 3 for the batch and column separations respectively. Under the conditions of the experiment, both SnO_2 and Al_2O_3 showed very similar breakthroughs at the early separation times, but the Al_2O_3 maintains a lower breakthrough of Sr over extended elution volumes. The breakthrough continues to slowly decrease with continued elution on the Al_2O_3 column, while the SnO_2 column begins to increase in Sr breakthrough with extended elution volumes.

An explanation for these results could be the highly pH dependent nature of the distribution coefficients (K_D's) for Sr on Al_2O_3 as reported by Brihaye[12]. His work shows the log K_D for Sr on Al_2O_3 to be about 3.2 at pH 7.0 and 4.8 at pH 8.0 while the log K_D for Sr on SnO_2 is 4.2 at pH 7.0 and about 4.0 at pH 8.0. These results were from the low temperature form of SnO_2, the so-called alpha or ortho form[13] and supplied by Applied Research, Belgium, under the trade name (OXTAIN). At pH 7.0 SnO_2 has the better retention properties for Sr, but at pH 7.5-8.0 Al_2O_3 improves its retention of Sr dramatically, and the continued elution of ^{82}Rb at this pH decreases the breakthrough of Sr. However, the K_D for Rb increases on SnO_2 as the pH goes from 7.0 to 8.0, while on Al_2O_3 the K_D for Rb does not increase significantly with the change in pH from 7.0 to 8.0[12]. Thus the Al_2O_3 column functions optimally for the separation of Rb from Sr at pH>8.0 while the SnO_2 functions most efficiently for the separation of Rb from Sr at pH 7.0.

A Reliable and Easily Operated ^{82}Rb Generator.

For the routine clinical application of generator produced ^{82}Rb to PET studies, it is necessary that the generator delivers the desired levels of radioactivity in reproducible rapid bolus elutions or at constant infusion rates for equilibrium and washout measurements. Another requirement is low breakthrough of $^{82,85}Sr$ (nCi amounts) per elution for many elutions over an extended generator life of 2-3 months.

The generator should be simple to operate and yet provide precise control of the elution parameters such as rate of flow, total volume delivered, and radioactive dose delivered. Several generators have been described which meet these requirements[8,10]. One of these systems is completely automated and provides push-button control for the entire operation of the ^{82}Rb generator, as shown in Fig. 1 [11]. This system has been in use at LBL for patient studies with PET for the past 5 years. For precise flow-control, the generator pump is driven by a stepping motor and microprocessor controller which permits reproducible delivery of the desired radioactive dose of ^{82}Rb as calculated from the amount of the ^{82}Sr on the column and the flow-rate and ml delivered values set on the thumb-wheel switches, Fig. 4.

An alternative approach in a commercial ^{82}Rb generator, is to use a radioactive detector to integrate the dose of ^{82}Rb delivered and to electronically trigger a shut-off or bypass valve to stop the infusion of radioactivity at the desired level[10].

Controlling the injected dose of ^{82}Rb is readily attainable by either of the two methods described. However, the breakthrough of $^{82,85}Sr$ is determined before and after the study by collecting elutions from the generator, allowing the ^{82}Rb activity to decay away, and counting the elution fraction and a standard $^{82,85}Sr$ sample with the same ratio of ^{85}Sr to ^{82}Sr as the Sr

activities on the generator column. Normally this standard is an aliquot of an elution fraction from the generator, and in which the concentration of ^{82}Sr and ^{85}Sr have been determined by Ge(Li)/gamma ray measurements. The breakthrough of Sr can then be determined for any subsequent elution of ^{82}Rb by using the same standard for the life of that particular loading of Sr, since the ^{85}Sr:^{82}Sr ratio is changing at the same rate for both the column and the standard.

Selected samples of ^{82}Rb eluates were analyzed for radionuclidic breakthrough by Ge(Li) analysis. These results are shown in Table 2-A. The smaller sample numbers indicate samples taken relatively soon after loading the column with ^{82}Sr when the breakthroughs values are higher. With continued elutions the breakthroughs of $^{82,85}Sr$ and other contaminating radionuclides decreased to a few nCi or less for a 20 ml elution from a 3 ml volume alumina column. For all of the samples except 63, 75, and 76, the column loading was 100 - 200 mCi of ^{82}Sr and 200 - 400 mCi of ^{85}Sr. The column loading for samples 63, 75, and 76 was 150 mCi of ^{82}Sr and 2.0 Ci of ^{85}Sr from an aged production batch at LASL and represents an extreme separation requirement for the alumina column.

In our experience with a large number of patient studies, we have not encountered any adverse or unexpected breakthroughs of $^{82,85}Sr$ during any of these studies. The reliability of an Al_2O_3 column to effectively retain the Sr activity over periods of up to 9 months with three loadings of ^{82}Sr and through nearly 200 separate elutions of ^{82}Rb has been demonstrated[8].

Maintaining Sterility and Apyrogenicity of the Eluate.
All of the components of the generator column and pumping system that contact the eluent are thoroughly cleaned and autoclaved before assembly. The eluent is prepared with sterile components in a sterile laminar flow hood.

The $^{82,85}Sr$ is shipped in a few ml of dilute HCl from LASL. The shipping shield is opened remotely and the contents of the vial are transferred to a flask. The $^{82,85}Sr$ solution is diluted with about 100 ml sterile pyrogen-free H_2O to maintain a low salt concentration and the pH is adjusted to 8-9 with dilute base. A remotely operated pumping system pumps the $^{82,85}Sr$ solution through the alumina column at a flow rate of about 1-2 ml/min. After the $^{82,85}Sr$ has been placed on the column, the flask and pumping syringe are washed two times with about 40 ml of pH 8-9 sterile water. Usually the column is left undisturbed overnight to allow the $^{82,85}Sr$ to become more firmly fixed to the alumina matrix. The column is then purged with 500 ml of 2% saline at pH 8-9 at a moderate flow rate of about 0.5 ml/second. Washing the generator column with a large volume of sterile eluent effectively removes any contaminating material in the $^{82,85}Sr$ shipment from the generator and reestablishes sterility of the system.

Although the system is sterile and pyrogen-free, a sterile membrane filter is placed in the outflow line from the ^{82}Rb generator before direct i.v. infusion into the patient. This is an added precaution to eliminate any uncertainties about the sterility of the eluate.

Periodically samples of the eluate, which are representative elution samples, are sent to a private laboratory for sterility and pyrogen testing. Within the past 6 years we have prepared 8 newly packed alumina (Al_2O_3) columns, which were loaded 3 times each or a total of 24 loadings with ^{82}Sr solution. In that time we did not encounter any sterility or pyrogen problems from many hundreds of elutions from the generator. By maintaining a closed system for the eluent and the pump and by inserting a new in-line membrane filter before each day of patient studies, it has been possible to safely operate the generator for direct intravenous infusion of the eluate.

Summary

The development of the ^{82}Rb generator has progressed to the stage where it has been safely applied to PET studies in clinical nuclear medicine. The completely automated system was used to provide a readily available supply of the 76-seconds positron emitter for studies of myocardial perfusion defects and changes in the permeability of the blood-brain barrier in patients with brain tumors or in conjunction with ^{18}F-fluorodeoxyglucose (FDG) to differentiate radiation therapy necrosis from recurrence of the tumor(4). Another possible application for ^{82}Rb is the assessment of kidney function. Table 3 summarizes the patient studies done with PET in our Research Medicine Group over the past 5 years.

With the commercial availabilty of the ^{82}Rb generator[10] and PET imaging systems, the advantages of quantitative and dynamic studies provided by PET become economically feasible without the need for an on-site cyclotron.

Since many studies can be performed each day with an inexhaustible supply of ^{82}Rb, to maintain the PET system in operation, then regional cyclotron centers can produce and ship other radiopharmaceuticals such as ^{18}F-FDG on a weekly schedule for glucose metabolic studies with PET. The ^{82}Rb generator would make a PET center cost effective because without a dedicated medical cyclotron radiopharmaceuticals such as ^{18}FDG could not be supplied more than 1-2 times a week from a regional cyclotron such as the Crocker Nuclear 76-inch cyclotron at University of California, Davis.

References

1. Budinger T.F., Yano Y., Moyer B.R., Twitchell J.A., and Huesman, R.H. Circulation **68**, III-81 (1983).

2. Budinger T.F., Yano Y., Twitchell J.A., Huesman R.H., Derenzo S.E., Brennan K.A., Botvinick E. and Dae M. J. Nucl. Med. **27**, in press (1986).

3. Yen C-K., Yano Y., Budinger T.F., Friedland R.P., Derenzo S.E., Huesman R.H. J. Nucl. Med. **23**, 532 (1982).

4. Budinger T.F., Doyle W.K., Levin V.A. and Gutin P.H. J. Nucl. Med. **26**, P24 (1985).

5. Grant P.M., O'Brien H.A.,Jr. and Kahn M. J. Inorg. Nucl. Chem. **37**, 413 (1975).

6. Mausner L.F. personal communication.

7. O'Brien H.A.,Jr. personal communication.

8. Yano Y. In: Radionuclide Generators New Systems for Nuclear Medicine Applications (Eds. Knapp F.F.and Butler T.A.) p.97 (ACS Symp. Series No. 241, Am. Chem. Soc. Washington, 1984).

9. Yano Y., Budinger T.F., Chiang G., O'Brien H.A., Jr. and Grant P.M. J. Nucl. Med. **20**, 961 (1979).

10. Gennaro G.P., Neirinckx R.D., Bergner B., Muller W.R., Waranis A., Haney T.A., Barker S.L., Loberg M.D. and Yarnis A. In: Radionuclide Generators New Systems for Nuclear Medicine Applications (Eds. Knapp F.F. and Butler T.A.) p. 136 (ACS Symp Series No. 241, Am. Chem. Soc. Washington, 1984).

11. Yano Y., Cahoon J.L. and Budinger T.F. J. Nucl. Med. **22**, 1006 (1981).

12. Brihaye C., Guillaume M. and Cogneau M. Radiochem. Radioanal. Lett. **48**, 157 (1981).

13. Waters S.L., Horlock P.L. and Kensett M.J. Int. J. Appl. Radiat. Isot. **34**, 1023(1983).

14. Neirinckx R.D., Kronauge J.F., and Loberg M.D. Int. J. Appl. Radiat. Isot. **34**, 721, 1983.

15. Neirinckx R.D., Kronauge J.F., Grennaro G.P., and Loberg M.D. J. Nucl. Med. **23**, 245, 1982.

Table Captions

Table 1. Generators for Positron Emitters.

Table 2. Rubidium-82 Generators.

Table 2A. Radionuclides in ^{82}Rb Eluates.

Table 3. Summary of Patients Studied with Rb-82 and PET.

Figure Captions

Fig. 1. Rubidium-82 generator with quick connects, primary and secondary lead shielding, and automated controls.

Fig. 2. Breakthrough of Sr from SnO_2 and Al_2O_3 by batch method.

Fig. 3. Breakthrough of Sr from SnO_2 and Al_2O_3 by column elution with saline eluent.

Fig. 4. Schematic of microprocessor controller for automated operation of the ^{82}Rb generator.

Table 1. GENERATORS FOR POSITRON EMITTERS

Parent	Half-life	Decay Mode (%)	Daughter	Half-life	Decay Mode (%)	Gammas MeV (%)
Fe-52	8.3 h	β^+(56),EC(44)	Mn-52m	21.1 m	β^+(98),EC(2)	1.43(100)
Zn-62	9.1 h	β^+(18),EC(82)	Cu-62	9.8 m	β^+(100)	0.59(22)
Ge-68	275. d	EC(100)	Ga-68	68. m	β^+(88),EC(12)	l.08(3.5)
Sr-82	25. d	EC(100)	Rb-82	76. s	β^+(96),EC(4)	0.78(9)
Te-118	6.0 d	EC(100)	Sb-118	3.5 m	β^+(75),EC(22)	1.23(3)
Xe-122	20.1 h	EC(100)	I-122	3.6 m	β^+(77)	0.56(14)
Ba-128	2.4 d	EC(l00)	Cs-128	3.8 m	β^+(51),EC(49)	0.44(27)

Table 2. Rubidium-82 Generators				
Column	Eluent	Rb-82 Yield (%)	Sr-82/85 Breakthrough/ml	Reference
Bio-Rex 70	NH_4Ac	72	10^{-5}	Yano 1968
Chelex 100	NH_4Cl	90	10^{-7}	Grant 1975
Bio-Rex 70	NaCl	72	10^{-7}	Yano 1979
Al_2O_3	NaCl	76	10^{-7}	Yano 1979
ZrO_2	NaCl	60-70	10^{-8}	Kulprathipanja 1979
Al_2O_3 + Chelex 100	NaCl	14-66	10^{-9}	Horlock 1981
Al_2O_3	NaCl	80-90	10^{-8}	Yano 1981
SnO_2	NaCl	70	10^{-9}	Neirinckx 1981
Al_2O_3 + Chelex 100	NaCl	40	10^{-9}	Vallabhajousla 1981
Al_2O_3	NaCl		10^{-8}	Neirinckx 1982
SnO_2	NaCl	65	$< 10^{-9}$	Neirinckx 1983

Table 2A - Radionuclides in ^{82}Rb Eluates (nCi/20 ml Elution)									
Date	Sample	^{48}V	^{51}Cr	^{54}Mn	^{57}Co	^{58}Co	^{82}Sr/ ^{82}Rb	^{83}Rb	^{85}Sr
04/24/81	16	0.03	77.0	0.20		0.04	0.40	44.0	1.20
09/24/81	66		0.90	0.01	0.01	0.01	0.45	0.04	0.90
02/26/82	63			0.05	0.08	0.08	1.30	0.20	22.7
03/01/82	75			0.08	0.08	0.08	1.70	0.95	34.3
03/02/82	76			0.07	0.09	0.14	2.10	0.49	34.1
10/25/82	8	0.01	1.0	0.10			5.50	22.0	13.6

Table 3. Summary of ^{82}Rb Patient Studies (1981-1985)							
	BRAIN STUDIES					HEART STUDIES	
Year	Alzheimer	Dementia	Stroke	Tumor	^{82}Rb Dose Total(mCi)	Patient #	^{82}Rb Dose Total(mCi)
1981	1			22	920		
1982	1	19		8	940	2	120
1983	3	17		4	600		
1984	1	6	7	11	700	1	45
1985		1	8	16	580	4	225
1986[1]				6	190		
TOTAL	6	43	15	67	3930	7	490

[1] 1st Quarter 1986.

Total all patients = 138
Total ^{82}Rb dose = 4420 mCi
Avg. ^{82}Rb dose/study = 32 mCi

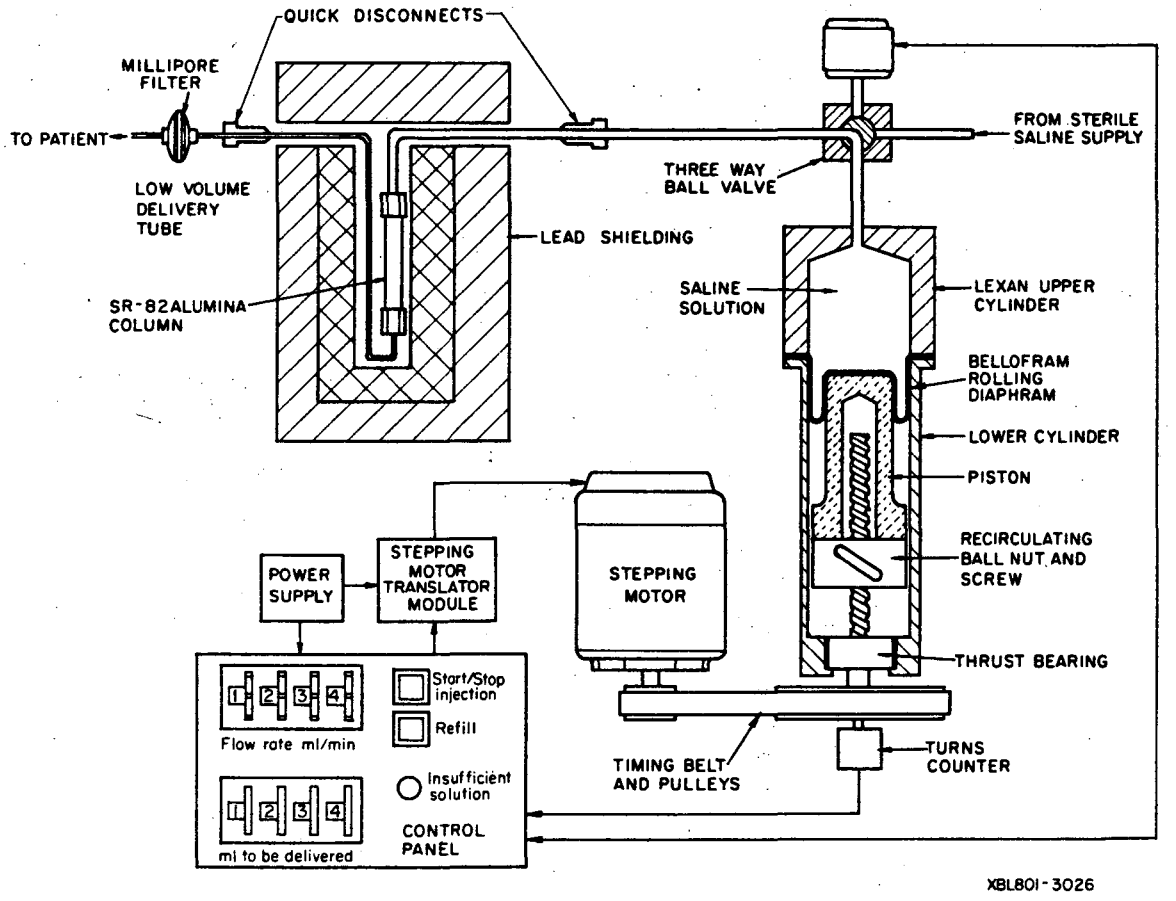
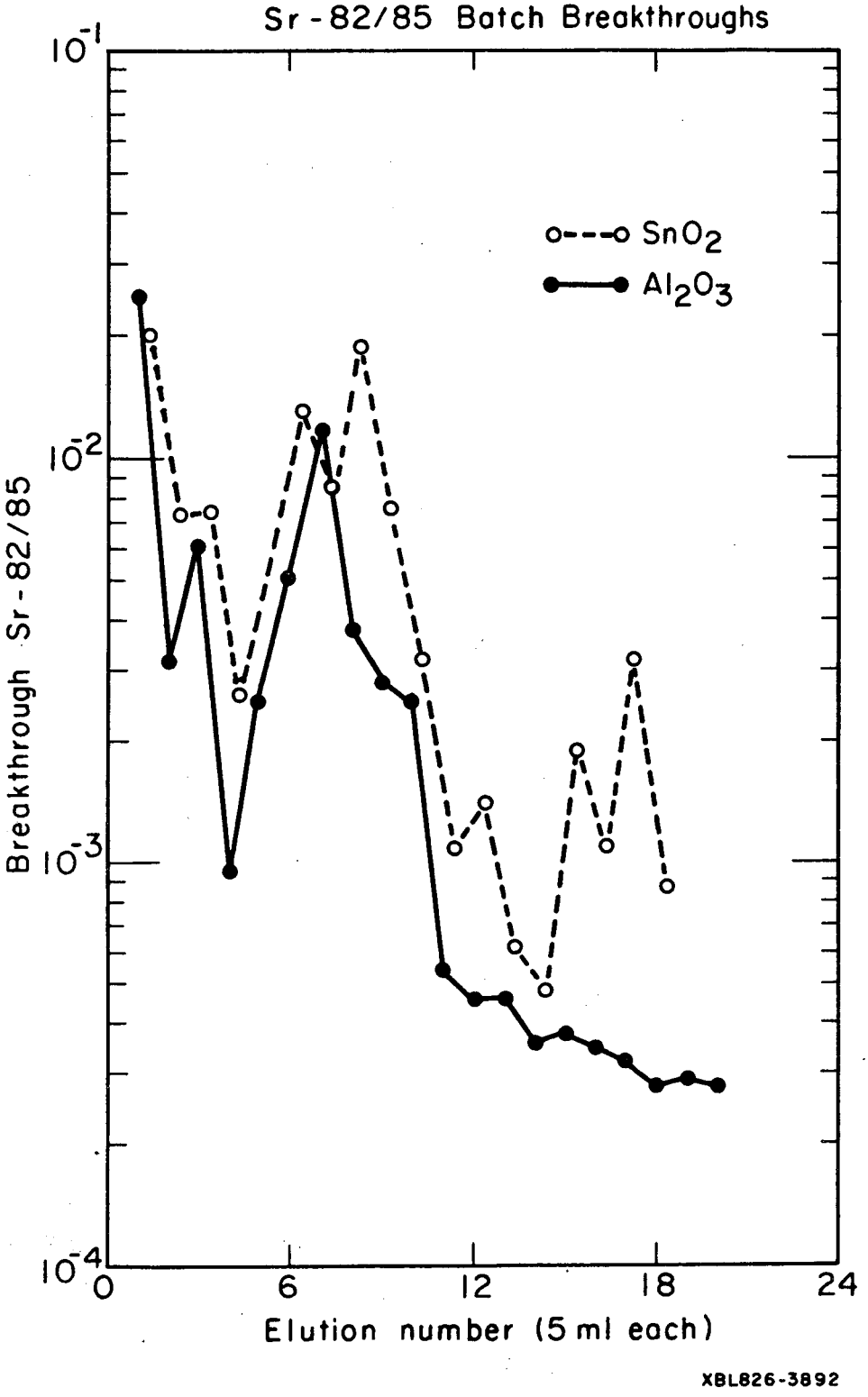

QUICK DISCONNECTS
MILLIPORE FILTER
TO PATIENT
LOW VOLUME DELIVERY TUBE
SR-82 ALUMINA COLUMN
LEAD SHIELDING
FROM STERILE SALINE SUPPLY
THREE WAY BALL VALVE
SALINE SOLUTION
LEXAN UPPER CYLINDER
BELLOFRAM ROLLING DIAPHRAM
LOWER CYLINDER
PISTON
RECIRCULATING BALL NUT AND SCREW
THRUST BEARING
STEPPING MOTOR
POWER SUPPLY
STEPPING MOTOR TRANSLATOR MODULE
Start/Stop injection
Refill
Insufficient solution
Flow rate ml/min
ml to be delivered
CONTROL PANEL
TIMING BELT AND PULLEYS
TURNS COUNTER
XBL801-3026

Fig. 1


Sr - 82/85 Batch Breakthroughs
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Breakthrough Sr - 82/85
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Al_2O_3
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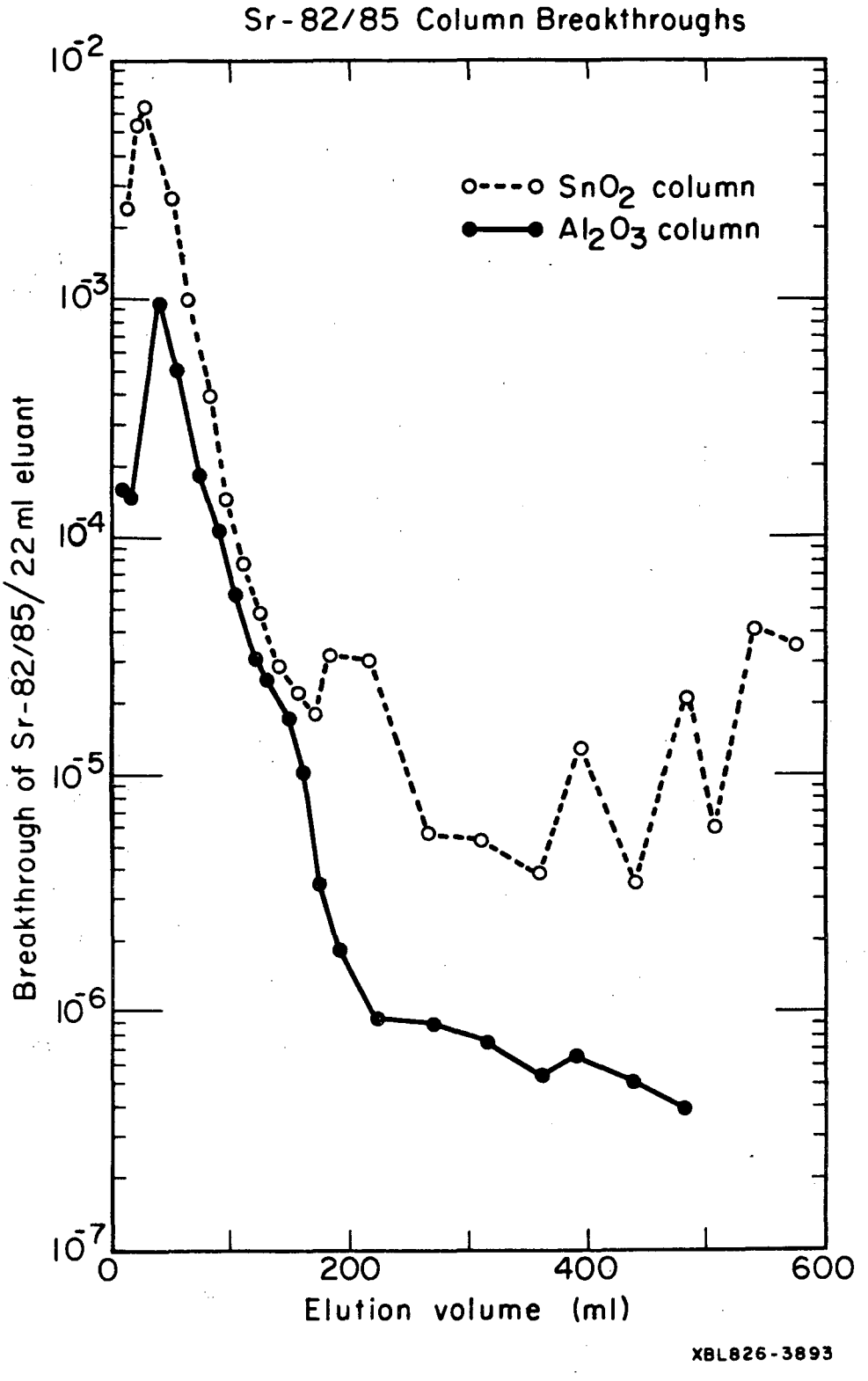
6
12
18
24
Elution number (5 ml each)
XBL826-3892

Fig. 2


Sr-82/85 Column Breakthroughs
SnO_2 column
Al_2O_3 column
Breakthrough of Sr-82/85/22 ml eluant
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10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0
200
400
600
Elution volume (ml)
XBL826-3893

Fig. 3

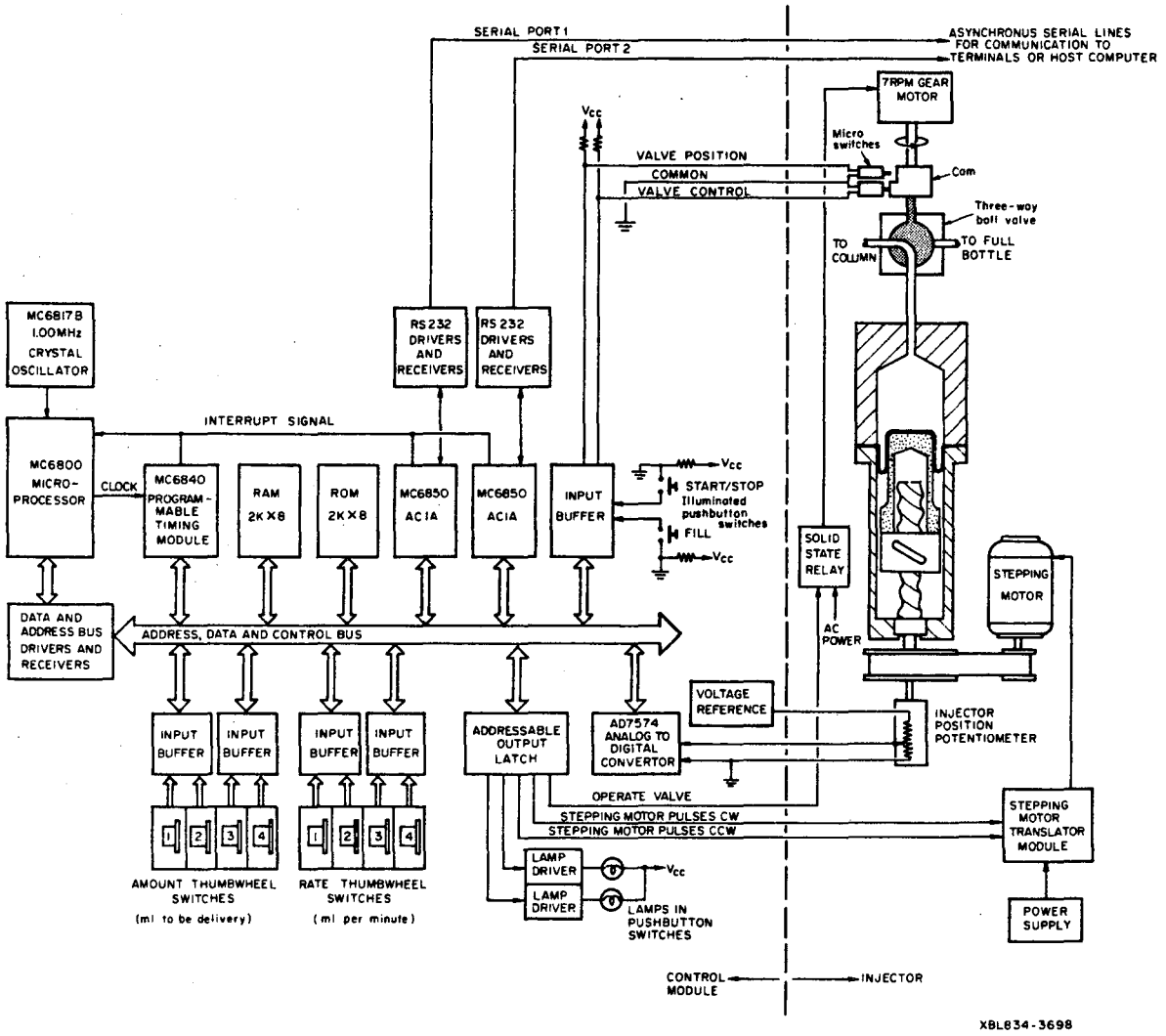
SERIAL PORT 1
SERIAL PORT 2
ASYNCHRONUS SERIAL LINES FOR COMMUNICATION TO TERMINALS OR HOST COMPUTER
7RPM GEAR MOTOR
Micro switches
Cam
Vcc
VALVE POSITION
COMMON
VALVE CONTROL
Three-way ball valve
TO COLUMN
TO FULL BOTTLE
MC68B17B 1.00MHz CRYSTAL OSCILLATOR
RS232 DRIVERS AND RECEIVERS
RS232 DRIVERS AND RECEIVERS
INTERRUPT SIGNAL
MC6800 MICRO-PROCESSOR
CLOCK
MC6840 PROGRAM-MABLE TIMING MODULE
RAM 2K X 8
ROM 2K X 8
MC6850 ACIA
MC6850 ACIA
INPUT BUFFER
START/STOP Illuminated pushbutton switches
FILL
SOLID STATE RELAY
STEPPING MOTOR
AC POWER
DATA AND ADDRESS BUS DRIVERS AND RECEIVERS
ADDRESS, DATA AND CONTROL BUS
VOLTAGE REFERENCE
INJECTOR POSITION POTENTIOMETER
INPUT BUFFER
INPUT BUFFER
INPUT BUFFER
INPUT BUFFER
ADDRESSABLE OUTPUT LATCH
AD7574 ANALOG TO DIGITAL CONVERTOR
OPERATE VALVE
STEPPING MOTOR PULSES CW
STEPPING MOTOR PULSES CCW
STEPPING MOTOR TRANSLATOR MODULE
LAMP DRIVER
LAMP DRIVER
LAMPS IN PUSHBUTTON SWITCHES
POWER SUPPLY
AMOUNT THUMBWHEEL SWITCHES
(ml to be delivery)
RATE THUMBWHEEL SWITCHES
(ml per minute)
CONTROL MODULE
INJECTOR
XBL834-3698

Fig. 4

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