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## Rapid Determination of Radiostrontium in Large Soil Samples

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**Abstract**

29           A new method for the determination of radiostrontium in large soil samples has  
30 been developed at the Savannah River Environmental Laboratory (Aiken, SC, USA) that  
31 allows rapid preconcentration and separation of strontium in large soil samples for the  
32 measurement of strontium isotopes by gas flow proportional counting. The need for rapid  
33 analyses in the event of a Radiological Dispersive Device (RDD) or Improvised Nuclear  
34 Device (IND) event is well-known. In addition, the recent accident at Fukushima Nuclear  
35 Power Plant in March, 2011 reinforces the need to have rapid analyses for radionuclides  
36 in environmental samples in the event of a nuclear accident. The method employs a novel  
37 pre-concentration step that utilizes an iron hydroxide precipitation (enhanced with calcium  
38 phosphate) followed by a final calcium fluoride precipitation to remove silicates and other  
39 matrix components. The pre-concentration steps, in combination with a rapid Sr Resin  
40 separation using vacuum box technology, allow very large soil samples to be analyzed for  
41  $^{89,90}\text{Sr}$  using gas flow proportional counting with a lower method detection limit. The  
42 calcium fluoride precipitation eliminates column flow problems typically associated with  
43 large amounts of silicates in large soil samples.

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**Introduction**

46           There is an increasing need to develop faster analytical methods for emergency  
47 response, including emergency environmental samples [1-2]. There are a number of  
48 analytical methods reported that use ion exchange/extraction chromatography to  
49 determine radiostrontium in soil. Vajda and Kim provide a very good overview of recent  
50 radiostrontium separation and analytical measurement techniques. [3]

51 This review also included more classical methods using fuming nitric  
52 precipitation as reported by Bojanowski et al [4]. Fuming nitric acid presents handling  
53 difficulties and can be very tedious and time-consuming. Wang et al. [5] reported a  
54 sequential method to determine actinides and strontium in soil samples. A large anion  
55 resin column (Dowex 1x8) was used to collect and separate Pu and Th. The rinse  
56 fractions from the anion resin were treated further and processed individually for Am, U  
57 and Sr. Several sequential precipitations were carried out. An oxalate precipitation was  
58 performed at pH 4.2 on the anion resin rinse solution followed by a Sr Resin separation.  
59 Strontium was counted using Čerenkov counting, while all actinide fractions were  
60 electrodeposited for counting by alpha spectrometry. The chemical recoveries using this  
61 method on NRIP (National Institute of Standards and Technology [NIST] Radiochemistry  
62 Intercomparison Program) soil for strontium were 63-77%. A large number of sequential  
63 steps were required, but the accuracy of the results versus the NIST reference values was  
64 very good. Čerenkov counting, while it offers benefits regarding selectivity against low  
65 energy beta emitters and allows for rapid measurement of  $^{89}\text{Sr}$ , has a much higher  
66 detection limit than gas flow proportional counting.

67 Ageyev et al. [6] reported a sequential method for soil samples. After ashing the  
68 samples at 550°C the samples were leached with 8M nitric acid, followed by calcium  
69 oxalate precipitation, furnace heating of oxalates, redissolution in hydrochloric acid, iron  
70 hydroxide precipitation, and a lanthanum precipitation of plutonium, americium and  
71 curium. Carbonate, fuming nitric acid, chromate and iron hydroxide precipitations were  
72 performed to prepare strontium. Plutonium was separated using Dowex 1 anion resin  
73 loaded under reduced atmosphere. Am and Cm were precipitated as  $\text{LaOH}_3$ , redissolved  
74 in dilute hydrochloric acid, separated on Dowex 50 cation resin loaded under reduced  
75 pressure. A gradient elution separation of Am and Cm with rare earths was performed

76 using  $\alpha$ -hydroxy-iso-butyric acid. Chemical yields for Sr were 50-70%. The method is,  
77 however, relatively complex and would not be considered a rapid method.

78 Tavčar et al. [7] reported a method to determine actinides in soil. Soil and  
79 sediment samples up to 10g were leached using strong nitric acid, filtration, evaporation,  
80 and the residue was redissolved in 1M HNO<sub>3</sub>. The acid concentration was increased to  
81 8M HNO<sub>3</sub> and the samples were loaded onto Dowex 1x8 resin. Sr was collected from the  
82 anion exchange eluent solution using calcium oxalate and the Sr was then separated using  
83 Sr Resin. Very large elution volumes were used in this method, including 100 ml of water  
84 to elute Sr from Sr Resin. The Sr was precipitated as an oxalate, redissolved and  
85 measured using liquid scintillation counting. The average chemical yield for Sr was 67%.

86 Based on this survey of the literature, a more rapid method to determine  
87 radiostrontium in large soil samples is needed. The method would need simple, effective  
88 pre-concentration steps and good chemical yields.

89 Recently, the Savannah River Environmental Laboratory performed analyses on  
90 samples received from Japan in April, 2011 as part of a U.S. Department of Energy effort to  
91 provide assistance to the government of Japan. Of particular concern was whether it was safe  
92 to plant rice in certain areas (prefectures) near Fukushima. Two different analytical  
93 techniques were employed in the Savannah River Environmental Laboratory to determine  
94 <sup>89,90</sup>Sr in Japanese soil samples very rapidly.

95 A rapid fusion technique using 1.5 gram soil aliquots to enable a MDA (Minimum  
96 Detection Limit) of <1 pCi <sup>89,90</sup> Sr /g of soil was employed. This sequential technique has  
97 been published recently by this laboratory for actinides and radiostrontium in soil and  
98 vegetation [8, 9]. It consists of a rapid sodium hydroxide fusion, pre-concentration steps  
99 using iron hydroxide and calcium fluoride precipitations, followed by Sr-Resin separation  
100 and gas flow proportional counting. To achieve a lower detection limit for analysis of

101 certain soil samples, a 10 gram aliquot of soil was taken, acid-leached and processed with  
102 similar preconcentration chemistry. The MDA using this approach was  $\sim 0.03$  pCi/g (1.1  
103 mBq/g), which is less than the 0.05-0.10 pCi/g  $^{90}\text{Sr}$  levels found in soil as a result of  
104 global fallout. The large amounts of iron in Japanese soil limited the size of soil sample  
105 aliquots that could be easily handled to  $\sim 10$ -15g due to very large iron hydroxide  
106 precipitates. The chemical yields observed for the Japanese soil samples was typically 75-  
107 80% and the laboratory control sample (LCS) and matrix spike (MS) results looked very  
108 good for this work [10].

109 A newer version of this approach was developed for application to even larger  
110 sample aliquots (50 g) from soil samples taken at the Savannah River Site so that very  
111 low detection limits can be achieved. The method uses an acid leach, a rapid sample pre-  
112 concentration approach and vacuum-assisted column flow rates. The sample analyses  
113 required  $< 16$  hours to complete, with a significant portion (4 hours or more) of that time  
114 being the evaporation of the relatively large leachate solutions.

115

## 116 **Experimental**

### 117 **Reagents**

118 Sr Resin (4, 4', (5') di-t-butylcyclohexane-18-crown-6), was obtained from  
119 Eichrom Technologies, Inc., (Lyle, Illinois, USA). Nitric, hydrochloric and hydrofluoric  
120 acids were prepared from reagent-grade acids (Fisher Scientific, Inc., Pittsburgh, PA,  
121 USA). All water was obtained from a Milli-Q2™ water purification system. All other  
122 materials were ACS reagent grade and were used as received. Radiochemical isotopes  
123  $^{90}\text{Sr}$  were obtained from Eckert & Ziegler Analytics, Inc. (Atlanta, GA, USA) and diluted  
124 to the appropriate level.

125

126

127 Procedures

128 *Column preparation.* Sr Resin was obtained as cartridges containing 2 mL of each  
129 resin from Eichrom Technologies, Inc.. Small particle size (50-100 micron) resin was  
130 employed, along with a vacuum extraction system (Eichrom Technologies).

131 *Sample Preparation.* Soil samples obtained from a location near the Savannah  
132 River Site (Aiken, SC, USA) were dried at 110 °C and blended prior to taking sample  
133 aliquots. The soil was heated in a furnace at 550 °C to remove any organics present.  
134 Seven 50 g soil samples were aliquoted into 600 ml glass beakers. Sr carrier (6.09 mg Sr)  
135 was added to each sample to allow determination of chemical yield.

136 Known amounts of  $^{90}\text{Sr}$  were pipetted into each set of 50 g soil samples to  
137 demonstrate performance using this method.  $^{90}\text{Sr}$  was added to each set of soil samples  
138 to test at the following levels: 59.2 mBq/g, 11.84 mBq/g and 5.92 mBq/g respectively.  
139 The uncertainty associated with the known value of  $^{90}\text{Sr}$  standard added was ~3 % at the  
140 95% confidence level. Unspiked soil aliquots was analyzed to determine the native  
141 amount of  $^{90}\text{Sr}$  present in the soil. The stable strontium in the soil was found to be very  
142 low relative to the amount of stable strontium added so no correction had to be made for  
143 the native stable Sr content.

144 Figure 1 provides a flow chart of the soil sample preparation method. For 50 g soil  
145 samples, 50 ml concentrated nitric acid and 25 ml hydrochloric acid volumes were added.  
146 The samples were digested on medium heat to prevent splattering and taken to dryness on  
147 a hot plate. The solids were rinsed with 50 ml concentrated nitric acid, warmed on a hot  
148 plate and the leachate plus additional solids were transferred to a centrifuge tube. The  
149 centrifuge tubes were centrifuged at 3500 rpm for 10 minutes. The leachate was  
150 transferred to a 600 ml beaker and heated on a hot plate to evaporate the leachate to  
151 dryness.

152 The residual solids were rinsed two more times. For each rinse, twenty-five  
153 milliliters of concentrated nitric acid were added to each beaker, and the leachate plus  
154 additional solids were transferred to the centrifuge tube. The centrifuge tubes were  
155 centrifuged at 3500 rpm for 10 minutes. The leachate was transferred to a 600 ml beaker,  
156 heated on a hot plate to evaporate the leachate to dryness. The leachate solutions were  
157 evaporated to dryness on a hot plate on low to medium heat. If there were small solids  
158 still left in the leachate, the leachate was centrifuged again in a 50 ml tube to remove  
159 solids after the leachate volume reached ~40 ml, The residual solids were rinsed with ~10  
160 ml concentrated nitric acid, centrifuged, and the rinse was added to the remaining  
161 leachate, which was taken to dryness.

162 To each evaporated leachate, 15 to 20 ml 1M hydrochloric acid were added and  
163 warmed on a hot plate to easily dissolve the residue. This solution was transferred to 225  
164 ml centrifuge tube and 1 ml 1.25M calcium nitrate and 2 ml 3.2M ammonium hydrogen  
165 phosphate were added to each tube. Twenty-five milliliters of concentrated ammonium  
166 hydroxide was added to each tube and the strongly alkaline solution was diluted to 180 ml  
167 with water.

168 The tubes were centrifuged at 3500 rpm for 6 minutes and the supernatant was



169 discarded. The remaining precipitate was dissolved in 40 ml 1.5M HCl This solution was  
170 diluted to ~170 ml with 0.01M HCl and 25 ml 28M HF were added to each sample.  
171 More of the undissolved precipitate resulting from the iron hydroxide/calcium phosphate  
172 precipitate will redissolve at this point and a new, much smaller calcium fluoride  
173 precipitate will form upon addition of HF. The samples were centrifuged for 10 minutes  
174 at 3500 rpm. The CaF<sub>2</sub> precipitate is small and can be dissolved easily in a small volume  
175 column load solution. For laboratories that have restrictions regarding the use of  
176 hydrofluoric acid, the substitution of sodium fluoride may be possible.

177 The supernatant was removed and the residual solids containing the strontium  
178 were dissolved in 7 ml of concentrated nitric acid, 7 ml of 3M HNO<sub>3</sub>-0.25M boric acid,  
179 and 7 ml of 2 M aluminum nitrate. If any residual solids remained, these were rinsed  
180 with 5 ml 3M HNO<sub>3</sub>, centrifuged to remove the solids and this rinse was added to the  
181 load solution. Additional 3M HNO<sub>3</sub> may be needed to redissolve the precipitate with very  
182 high Ca soils.

183 *Column separation.* Figure 2 provides a flow chart of the rapid column  
184 separation method using two 2 ml Sr cartridges (~1.4 g Sr Resin total). Sr Resin columns  
185 were conditioned with 10 ml 8M HNO<sub>3</sub>. The sample solution was loaded onto the Sr  
186 Resin column at approximately ~1 drop per second. After the sample was loaded, a tube  
187 rinse of ~ 5 mL 8M HNO<sub>3</sub> was transferred to the Sr Resin column and allowed to pass  
188 through the resin at ~2 drops per second. The following column rinses were performed at  
189 ~2-3 drops per second: 15 ml 8M HNO<sub>3</sub>, 10 ml 3M HNO<sub>3</sub>- 0.05M oxalic acid, and 10 ml  
190 8M HNO<sub>3</sub>. Sr was eluted from the resin with 18 ml 0.05M HNO<sub>3</sub> at ~1 drop per second.

191 This solution was transferred to preweighed planchets and evaporated on a hot  
192 plate with medium heat to dryness. Two milliliters 0.05M HNO<sub>3</sub> were used to rinse each  
193 tube and then was transferred to each planchet, and evaporated to dryness on a hot plate.

194 The dried planchets were allowed to cool and then were weighed to determine  
195 gravimetric carrier recovery. The planchets were counted by simultaneous gas flow  
196 proportional counting (Tennelec LB 4100) for 90 minutes. The detectors were calibrated  
197 using NIST Traceable  $^{90}\text{Sr}/^{90}\text{Y}$  sources matching the sample geometry. Detector  
198 backgrounds are determined and subtracted from the sample counts. A mass attenuation  
199 correction factor was determined experimentally using prepared mounts containing  
200  $^{90}\text{Sr}/^{90}\text{Y}$  (>167 Bq) and a nominal amount of Sr carrier.

201

## 202 Apparatus

203 Polycarbonate vacuum boxes with 24 positions and a rack to hold 50 ml plastic  
204 tubes were used. Two boxes were connected to a single vacuum source by using a T-  
205 connector and individual valves on the tubing to each box.

206 Planchets were annealed for ~4 hours in a furnace at 550 °C prior to use. This  
207 provides chemical resistance to the planchets so that iron oxide does not form during  
208 evaporation of the nitric acid, which would cause error in the gravimetric weights.

209

## 210 Results and Discussion

211 Table 1 shows the measured values for  $^{90}\text{Sr}$  in a set of seven 50g soil samples spiked  
212 at the 59.2 mBq/g level. The average  $^{90}\text{Sr}$  result was 57.8 mBq/g  $\pm$  1.7 mBq (1SD,  
213 standard deviation) with an average bias of -2.36%. The average stable Sr carrier  
214 recovery was 89.3% (SD =4.7%), indicating very good chemical yield for the method  
215 even for 50g sample aliquots. The measured values were corrected for native content in  
216 the soil of 1.35 mBq  $^{90}\text{Sr}$  /g.

217 Table 2 shows the measured values for  $^{90}\text{Sr}$  in a set of seven 50 g soil samples spiked  
218 at the 11.84 mBq/g level. The average  $^{90}\text{Sr}$  result was 11.5 mBq/g  $\pm$  0.7 mBq/g (SD).

219 The average stable Sr carrier recovery was 89.6% (SD =2.7%) with an average bias of –  
 220 2.51%.

221 Table 3 shows the measured values for <sup>90</sup>Sr in a set of seven 50g soil samples spiked  
 222 at the 5.92 mBq/g level (0.16 pCi/g), which is not much greater than global fallout levels.  
 223 The average <sup>90</sup>Sr result was 5.95 mBq/g ± 0.22 mBq/g (SD), with an average bias of  
 224 0.43%. The average stable Sr carrier recovery was 94.0% (SD =2.6%), indicating very  
 225 good chemical yield.

226 The tests indicate that for three different spiked levels that <sup>90</sup>Sr can be measured very  
 227 well. The sample pre-concentration steps to remove the soil matrix worked very well.  
 228 Chemical yields were very good and no column flow issues were observed. The use of  
 229 iron hydroxide precipitation enhanced with a slight amount of calcium phosphate was  
 230 very effective, and the calcium fluoride removal of silicates ensured ease of column flow.  
 231 It has been the experience in this laboratory that blending combinations of different co-  
 232 precipitation steps can be a very effective way to maximize chemical yields from difficult  
 233 sample matrices.

234 The MDA (Minimum Detectable Activity) for the <sup>90</sup>Sr using this method with gas  
 235 flow proportional counting were calculated according to equations prescribed by Currie:  
 236 [11]

237

$$238 \quad \text{MDA} = [3 + 4.65\sqrt{B}] / (\text{CT} * \text{R} * \text{V} * \text{Eff} * 0.060)$$

239 Where B = Total Background counts, = BKG (rate) \* BKG Count time

240 CT = sample count time (min)

241 R = Chemical Recovery

242 V = Sample aliquot (g)

243 EFF = Detector Efficiency

244 0.060 = conversion from dpm to mBq

245 In low-level counting, where a zero background count is quite common, the constant 3 is  
246 used to prevent an excessively high false positive rate.

247 The MDA for the results can be adjusted as needed, depending on the sample  
248 aliquot and count time. For a 50 g sample aliquot, the method MDA for  $^{90}\text{Sr}$  with a 90  
249 minute count time is  $0.41 \text{ mBq g}^{-1}$ , typically below global fallout levels.

250 It should be noted that soil aliquots may have to be adjusted if very high levels of  
251 calcium are present in the soil. If very high levels of Ca are found, it may be necessary to  
252 reduce the soil sample aliquot or not add any additional Ca in the pre-concentration steps.  
253 A larger column load solution could also be tolerated with 4ml Sr Resin. Combining  
254 purified solutions from smaller replicate aliquots may also be employed to maintain a low  
255 MDA even with a more difficult sample matrix.

256 The test data in Tables 1-3 were obtained with nitric acid/ hydrochloric acid leaching,  
257 without aggressively attacking the soil silicate matrix. It is also possible to add  
258 hydrofluoric (HF) acid to the acid digestion step if smaller soil aliquots (25g) and large  
259 Teflon beakers are used. The HF can be removed via evaporation in the presence of  
260 concentrated nitric acid and boric acid. The same sample preconcentration steps may be  
261 applied but the chemical yields are not as high. Table 4 shows results using the digestion  
262 of 25g samples with hydrofluoric acid. The average  $^{90}\text{Sr}$  result was  $12.6 \text{ mBq/g} \pm 1.2$   
263  $\text{mBq/g}$  (SD), with an average bias of 6.1%. The chemical yields for the stable strontium  
264 carrier were reduced to an average yield of 73%. If acid digestion and leaching without  
265 HF provides sufficient ruggedness (often the case), a larger soil aliquot can be analyzed  
266 with a higher chemical yield. If individual  $^{89}\text{Sr}$  and  $^{90}\text{Sr}$  results are required, a second  
267 count measured after 7-10 days can be used to differentiate  $^{89}\text{Sr}$  and  $^{90}\text{Sr}$ . There are also

268 Čerenkov counting techniques for more rapid determination of  $^{89}\text{Sr}$  and  $^{90}\text{Sr}$ , however the  
269 MDA levels will be significantly higher using this approach. [12]

270

### 271 **Conclusions**

272 A new method to determine  $^{90}\text{Sr}$  has been developed that allows the rapid  
273 separation of radiostrontium in large soil samples with high chemical yields and  
274 effective removal of interferences. The simple matrix removal steps and rapid column  
275 separation steps resulted in reliable measurements of  $^{90}\text{Sr}$  at very low levels from 50 g  
276 soil aliquots. This approach allows large soil samples to be analyzed with a significant  
277 reduction in the detection limit.

278

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282

## References

- [1] D. Larivière, T. Cumming, S.Kiser, C. Li, and R. Cornett, Automated flow injection system using extraction chromatography for the determination of plutonium in urine by inductively coupled plasma mass spectrometry, *J. Anal. At. Spectrom.*, 23 (2008), 352
- [2] D.L. Stricklin, A. Tjarnhage, and U. Nygren, Application of low energy gamma-spectrometry in rapid actinide analysis for emergency preparedness, *J. Radioanal. Nucl.Chem.* 251 (2002) (1), 69
- [3] N. Vajda and C.K. Kim, Determination of radiostrontium isotopes: A review of analytical methodology, *Applied Radiation and Isotopes* 67 (2010), 2306
- [4] R. Bojanowski and D. Knapinska- Skiba, Determination of low-level  $^{90}\text{Sr}$  in environmental samples: a novel approach to the classical method, *J. Radioanal. Nucl.Chem.*, VoL 138, No. 2 (1990), 207
- [5] J. Wang, I. Chen, and J. Chiu, Sequential isotopic determination of plutonium, thorium, americium, strontium and uranium in environmental and bioassay samples, *Applied Radiation and Isotopes*, 61 (2004.), 299
- [6] Ageyev, V.A., Odintsov, O.O. and Sajeniouk, A.D., Routine radiochemical method for the determination of  $^{90}\text{Sr}$ ,  $^{238}\text{Pu}$ ,  $^{239+240}\text{Pu}$ ,  $^{241}\text{Am}$  and  $^{244}\text{Cm}$  in environmental samples, *J. Radioanal. Nucl.Chem.* 264 (2), (2005), 337
- [7] P. Tavčar, R. Jakopič, and L. Benedik,. Sequential Determination of  $^{241}\text{Am}$ ,  $^{237}\text{Np}$ , Pu Radioisotopes and  $^{90}\text{Sr}$  in Soil and Sediment Samples, *Acta. Chim.Slov.* 52 (2005), 60
- [8] S. Maxwell, B. Culligan, and G. Noyes, Rapid method for actinides in emergency soil samples, *Radiochimica Acta*, Vol. 98, No. 11, (2010), 793

- [9] S. Maxwell, B. Culligan, and G. Noyes, Rapid separation method for actinides and radiostrontium in vegetation samples, *J. Radioanal. Nucl.Chem.* Vol. 286 (2010), No. 1, 273
- [10] Rapid Radiochemical Methods in Support of Fukushima presentation at Radiobioassay and Radiochemical measurements Conference Eichrom User's group meeting, <http://www.eichrom.com/radiochem/meetings/2011/rrmc/pdf/4-Maxwell-Eichromworkshop2011.pdf>, November 2, 2011
- [11] L.A., Currie, Limits for qualitative and quantitative determination, *Anal. Chem.* 40 (1968) 586
- [12] J.P. Martin, and K.J. Odell, "The Development of Emergency Radioanalytical Techniques for the Determination of Radiostrontium and Transuranic Radioisotopes in Environmental Materials", *Radioactivity and Radiochemistry*, 1998, Vol. 9, No 3, 49-60.

**Table Captions**

Table 1  $^{90}\text{Sr}$  in Soil Results (59.2 mBq/g level) - 50 g samples

Table 2  $^{90}\text{Sr}$  in Soil Results (11.8 mBq/g level) - 50 g samples

Table 3  $^{90}\text{Sr}$  in Soil Results (5.92 mBq/g level) - 50 g samples

Table 4  $^{90}\text{Sr}$  in Soil Results (11.8 mBq/g) - 25g samples with HF Digest



Table 1  $^{90}\text{Sr}$  in Soil Results (59.2 mBq/g level) - 50 g samples

Sample ID	Sr carrier (%)	$^{90}\text{Sr}$ Reference Value (pCi g <sup>-1</sup> )	$^{90}\text{Sr}$ Reference Value (mBq g <sup>-1</sup> )	$^{90}\text{Sr}$ Measured Value (mBq g <sup>-1</sup> )	Difference (%)
1	86.4	1.60	59.2	60.6	2.36
2	93.9	1.60	59.2	54.9	-7.26
3	81.0	1.60	59.2	58.3	-1.52
4	92.5	1.60	59.2	57.7	-2.53
5	87.8	1.60	59.2	57.6	-2.70
6	93.9	1.60	59.2	58.3	-1.52
7	89.8	1.60	59.2	57.2	-3.38
Avg	89.3			57.8	-2.36
SD	4.7			1.7	
% RSD	5.3			2.9	
Measured values corrected for 1.35 mBq $^{90}\text{Sr}$ /g found in unpiked soil					

Table 2  $^{90}\text{Sr}$  in Soil Results (11.8 mBq/g level) - 50 g samples

Sample ID	Sr carrier (%)	$^{90}\text{Sr}$ Reference Value (pCi g $^{-1}$ )	$^{90}\text{Sr}$ Reference Value (mBq g $^{-1}$ )	$^{90}\text{Sr}$ Measured Value (mBq g $^{-1}$ )	Difference (%)
1	87.8	0.32	11.84	11.2	-5.41
2	88.4	0.32	11.84	11.9	0.51
3	87.1	0.32	11.84	12.2	3.04
4	93.9	0.32	11.84	12.7	7.26
5	92.5	0.32	11.84	11.2	-5.41
6	87.1	0.32	11.84	10.9	-7.94
7	90.5	0.32	11.84	10.7	-9.63
Avg	89.6			11.5	-2.51
SD	2.7			0.7	
% RSD	3.1			6.4	
Measured values corrected for 1.35 mBq $^{90}\text{Sr}$ /g found in unpiked soil					

Table 3  $^{90}\text{Sr}$  in Soil Results (5.92 mBq/g level) - 50 g samples

Sample ID	Sr carrier (%)	$^{90}\text{Sr}$ Reference Value (pCi g $^{-1}$ )	$^{90}\text{Sr}$ Reference Value (mBq g $^{-1}$ )	$^{90}\text{Sr}$ Measured Value (mBq g $^{-1}$ )	Difference (%)
1	95.9	0.160	5.92	6.05	2.20
2	98.6	0.160	5.92	6.02	1.69
3	94.6	0.160	5.92	5.82	-1.69
4	91.8	0.160	5.92	6.32	6.76
5	93.2	0.160	5.92	5.96	0.68
6	92.5	0.160	5.92	5.60	-5.41
7	91.2	0.160	5.92	5.85	-1.18
Avg	94.0			5.95	0.43
SD	2.6			0.22	
% RSD	2.8			3.77	
Measured values corrected for 1.35 mBq $^{90}\text{Sr}$ /g found in unpiked soil					

Table 4  $^{90}\text{Sr}$  in Soil Results (11.8 mBq/g) - 25g samples with HF Digest

Sample ID	Sr carrier (%)	$^{90}\text{Sr}$ Reference Value (pCi g $^{-1}$ )	$^{90}\text{Sr}$ Reference Value (mBq g $^{-1}$ )	$^{90}\text{Sr}$ Measured Value (mBq g $^{-1}$ )	Difference (%)
1	78.9	0.32	11.84	13.9	17.40
2	70.1	0.32	11.84	12.4	4.73
3	70.1	0.32	11.84	11.4	-3.72
Avg	73.0			12.6	6.14
SD	5.1			1.3	
% RSD	7.0			10.0	
Measured values corrected for 1.35 mBq $^{90}\text{Sr}$ /g found in unpiked soil					

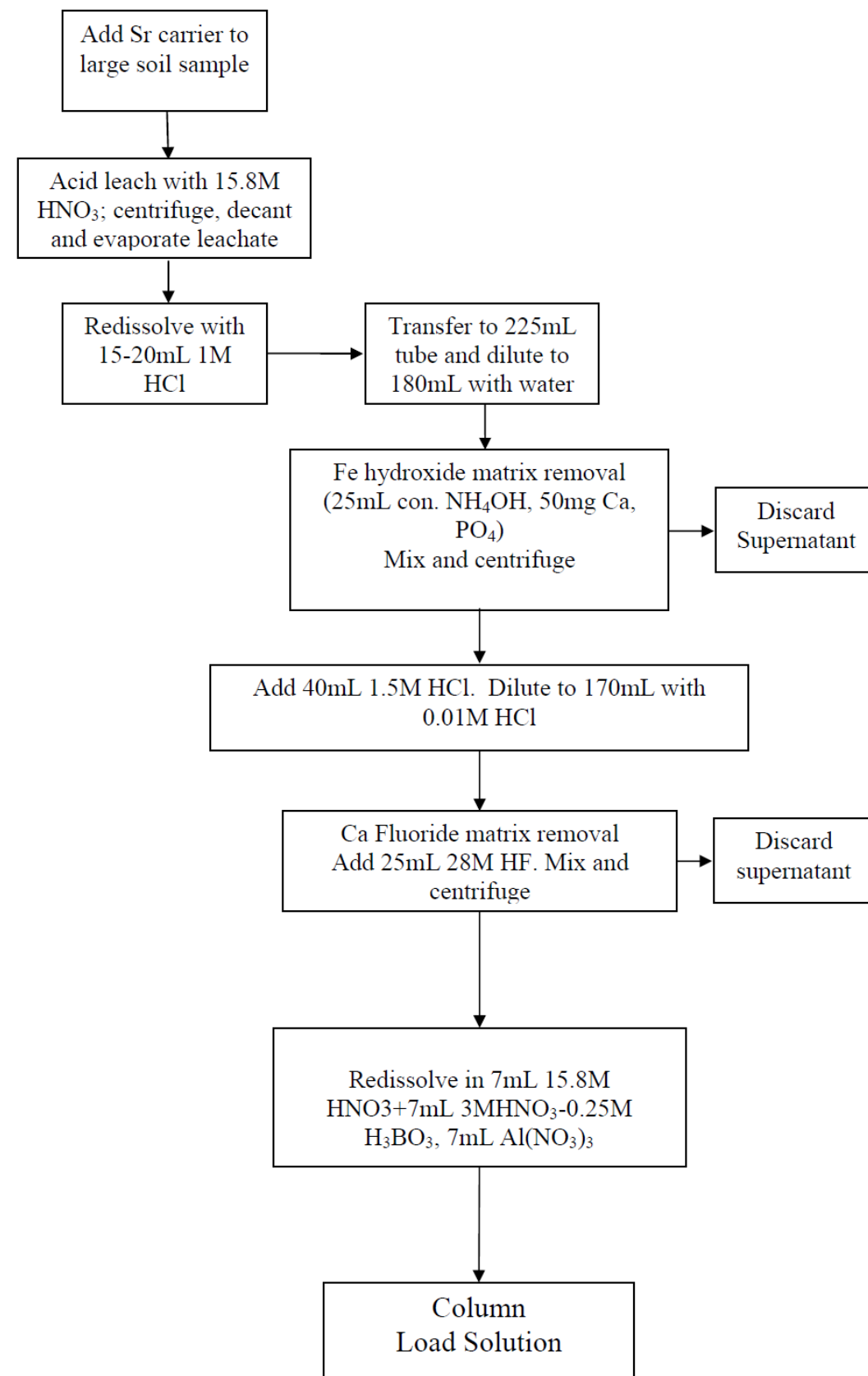
Figure 1 **Rapid Sample Preparation for Sr-89/90 in Large Soil Samples**

Figure 2 **Rapid Column Separation for Sr-89/90 in Large Soil Samples**