

Options for ^{89}Sr and ^{90}Sr Determination

Summary There are many methods (Table 1) available for the measurement of radiostrontium (Table 2) from environmental, building materials, or biological samples. Typically, analysts are interested in the measurement of the fission products ^{89}Sr and ^{90}Sr . Stable strontium or ^{85}Sr may also be used as a chemical yield tracer. Methods typically begin with a concentration or matrix removal step, followed by the separation of strontium from interfering nuclides (Figure 1). Methods may also incorporate steps to discriminate between ^{89}Sr and ^{90}Sr , including multiple counts, nuclide selective counting techniques and ingrowth and secondary separations of ^{90}Y (daughter of ^{90}Sr). Measurement instrumentation includes low background gas flow proportional counting (GFPC), liquid scintillation (LSC), Cerenkov counting, and inductively coupled plasma-mass spectrometry (ICP-MS).

This application note will offer guidance in choosing an appropriate method, taking into account process knowledge, available measurement equipment and data quality objectives (required detection limits, urgency of measurement, age of sample, and need for $^{89/90}\text{Sr}$ discrimination). The measurement methods are meant to be used in concert with the appropriate sample preparation method for the matrix being analyzed. For a more comprehensive treatment of sample preparation methods, see the application notes available at <http://www.eichrom.com/eichrom/appnotes/applications/index.aspx>. A detailed discussion of interferences can also be found in references [2] and [5].

Table 1. Summary of $^{89/90}\text{Sr}$ Method Options

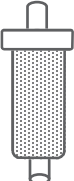
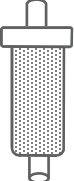
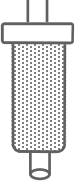
Method	Primary Separation	Primary Count	Secondary Separation	Secondary Count	Sr Yield Monitor	Ref.
ICP-MS	1A	^{90}Sr by ICP-MS	None	None	Stable Sr	1
Total $^{89/90}\text{Sr}$	1A	$^{89/90}\text{Sr}$ by GFPC/LSC	None	None	Stable Sr	4,5
^{90}Y Direct	1C	^{90}Y by GFPC/LSC/Cerenkov	None	None	Stable Sr	6
Two Count ^{89}Sr and ^{90}Sr	1A	$^{89/90}\text{Sr}$ by GFPC/LSC	None	$^{89/90}\text{Sr}$ by GFPC/LSC*	Stable Sr	2
Rapid ^{89}Sr and ^{90}Sr	1A	^{89}Sr by Cerenkov	None	$^{89/90}\text{Sr}$ by LSC	Stable Sr	3,5
Cerenkov ^{89}Sr and ^{90}Sr (^{90}Y)	1A	^{89}Sr by Cerenkov	1B or 1C	^{90}Y by Cerenkov	Stable Sr/ ^{85}Sr	3,5
Gas Flow Porportional	1A	$^{89/90}\text{Sr}$ by GFPC	1B or 1C	^{90}Y by GFPC	Stable Sr/ ^{85}Sr	4,5

* $^{89}\text{Sr}/^{90}\text{Sr}$ discrimination by solving equations for ^{89}Sr decay and ^{90}Y ingrowth during time between 2 counts

Table 2. Properties of Selected Nuclides

Nuclide	Half-Life	Decay Mode	Energy	Detector Suitable for Measurement				
				GFPC	LSC	Cerenkov	MS/AES	Gamma
^{85}Sr	64.849 days	ϵ/γ	$\gamma = 514 \text{ keV}$ (96%)	No	Yes	No	No	Yes
^{88}Sr	Stable			No	No	No	Yes	No
^{89}Sr	50.563 days	β^-	$\beta_{\text{max}} = 1500 \text{ keV}$ $\beta_{\text{mean}} = 587 \text{ keV}$	Yes	Yes	Yes	No	No
^{90}Sr	28.79 years	β^-	$\beta_{\text{max}} = 546 \text{ keV}$ $\beta_{\text{mean}} = 196 \text{ keV}$	Yes	Yes	No	Yes	No
^{90}Y	64 hours	β^-	$\beta_{\text{max}} = 2280 \text{ keV}$ $\beta_{\text{mean}} = 934 \text{ keV}$	Yes	Yes	Yes	No	No

Figure 1. Strontium Separation Options

<p>A. Sr separation (Sr Resin)</p>	<p>B. Sr/⁹⁰Y (Sr Resin)</p>	<p>C. Sr/⁹⁰Y (DGA Resin)</p>
<p>Sr Resin 2-4 mL in cartridges</p> 	<p>Sr Resin 2 mL cartridge</p> 	<p>DGA Resin, Normal 2 mL cartridge</p> 
<ol style="list-style-type: none"> (1) Precondition Sr Resin with 3 bed volumes 8M HNO₃. (2) Load sample at 1-2 mL/min. (3) Rinse sample tube with 5 mL 8M HNO₃. (4) Add tube rinse to Sr Resin. Elute at 1-2 mL/min. (5) Rinse Sr Resin sequentially with* <ul style="list-style-type: none"> - 3 bed volumes 8M HNO₃. - 3 bed volumes 3M HNO₃- 0.05M oxalic acid. - 3 bed volumes 8M HNO₃. (6) Dispose of (1) to (5) as waste. (7) Strip Sr with 5 bed volumes 0.05M HNO₃ at 1 mL/min. <p>*Rinse solutions and volumes listed are general guidelines. See detailed app. notes for recommended rinsing for each matrix.</p>	<ol style="list-style-type: none"> (1) Dissolve Sr Residue from planchet used for total ^{89/90}Sr measurement with 5 mL 8M HNO₃. (Or acidify Cerenkov sample to 8M HNO₃.) (2) Using transfer pipet, transfer dissolved residue to 15mL c-tube. (3) Rinse planchet with 5 mL 8M HNO₃. Add to 15 mL c-tube. (4) Precondition 2 mL Sr Resin cartridge with 5 mL 8M HNO₃. (5) Load sample at 1-2 mL/min, collecting eluate (⁹⁰Y-fraction). (6) Rinse c-tube with 5 mL 8M HNO₃. (7) Add tube rinse to column. Elute 1-2 mL/min, collecting eluate (⁹⁰Y fraction) 	<ol style="list-style-type: none"> (1) Dissolve Sr Residue from planchet used for total ^{89/90}Sr measurement with 5 mL 8M HNO₃. (Or acidify Cerenkov sample to 8M HNO₃.) (2) Using transfer pipet, transfer dissolved residue to 15mL c-tube. (3) Rinse planchet with 5 mL 8M HNO₃. Add to 15 mL c-tube. (4) Precondition 2 mL DGA Resin cartridge with 5 mL 8M HNO₃. (5) Load sample at 1-2 mL/min. (6) Rinse c-tube with 5 mL 8M HNO₃. (7) Add tube rinse to cartridge. (8) Rinse DGA with 15 mL 0.1M HNO₃. (9) Save (4) to (8) as Sr fraction. (10) Strip ⁹⁰Y with 10 mL 0.1M HCl.

ICP-MS (⁹⁰Sr only) ⁹⁰Sr may be determined by inductively coupled plasma-mass spectrometry (ICP-MS) following separation on Sr Resin (Figure 1A). However, due to the relatively short half-life of ⁹⁰Sr, **application to low level environmental analyses will be limited** by the available mass spectrometry technology and concentration chemistries. Recent publications suggest detection limits of ~1Bq/g are possible. However the achievable detection limit will depend on several factors, including sample type, sample size, and the age and type of MS instrument available [1].

Radiometric techniques will allow lower detection limits for ⁹⁰Sr and the ability to also determine ⁸⁹Sr.

Accurate measurement of strontium chemical yield as ⁸⁸Sr by ICP-MS has very little chance for impact by **isobaric interferences** (⁸⁷Rb-H⁺, which should be effectively removed by Sr Resin Separation). ⁹⁰Zr is the only significant isobaric interference for ⁹⁰Sr measurement. Separation chemistries should be tailored to ensure complete removal of zirconium (rinsing with 3M HNO₃-0.05M oxalic acid for Sr Resin separations). Determination of ⁹⁰Sr by ICP-MS **greatly simplifies the calculation of ⁹⁰Sr activity**, which can be complicated in radiometric detection techniques by the ingrowth of ⁹⁰Y and the decay of ⁸⁹Sr.

ICP-MS and **ICP-AES** (atomic emission spectrometry) are also very effective tools for the determination of **strontium chemical yield** when using radiometric detection methods for ⁸⁹Sr and ⁹⁰Sr. ICP-MS and ICP-AES will often give more precise chemical yield data than gravimetric techniques, while also allowing the use of **less Sr carrier** (<1mg vs 4-6 mg stable Sr). Many environmental samples (soils, brines, sea water and some ground waters) may contain significant levels of stable strontium. Pre-analysis of these samples by ICP-MS or ICP-AES for **native Sr** content may be necessary to adjust the amount of stable Sr yield monitor added and to ensure accurate measurement of the Sr yield throughout the separation process.

Total ^{89/90}Sr In instances where ⁹⁰Sr is the only radiostrontium isotope likely to be present or where total ⁸⁹Sr + ⁹⁰Sr determination is desired, radiostrontium may be determined by liquid scintillation counting or gas flow proportional counting following separation on Sr Resin (Figure 1A). **Confirmation of ⁹⁰Sr activity will require discrimination from ⁸⁹Sr through two count methods and calculations [2], ingrowth and separation of ⁹⁰Y (Figure 1B or 1C) [4,5] or selective ⁸⁹Sr/⁹⁰Y measurement(s) using Cerenkov counting [3].**

⁹⁰Sr by Direct Recovery of ⁹⁰Y In the analysis of debris from decommissioning of older facilities or other instances where ⁹⁰Sr is likely to be present in the absence of short-lived fission products (⁹¹Y, ⁸⁹Sr, etc.) and where ⁹⁰Y is in equilibrium with ⁹⁰Sr, ⁹⁰Sr may be determined by liquid scintillation, gas flow proportional counting, or Cerenkov counting following the direct separation of ⁹⁰Y on DGA Resin (Figure 1C) [6]. The very high retention of ⁹⁰Y on DGA resin allows recovery of ⁹⁰Y from difficult matrices, large sample volumes, and/or samples with high native Sr content that may prove problematic using the isolation of Sr on Sr Resin. However, the presence of fresh fission products, such as ⁹¹Y and rare earth radionuclides, will cause significant positive bias in the ⁹⁰Sr determination performed using this method. Stable yttrium yield can be measured by ICP-MS or ICP-AES.

Two Count Method ⁹⁰Sr and/or ⁸⁹Sr can be measured in an initial count using GFPC or LSC following separation on Sr Resin (Figure 1A). Following a period of ingrowth for ⁹⁰Y, the samples can be counted again, and individual ⁸⁹Sr and ⁹⁰Sr activities calculated by solving a series of equations related to the decay of ⁸⁹Sr and the ingrowth of ⁹⁰Y (two count method) [2]. Ideally, the initial count is performed as quickly as possible following the separation on Sr Resin to minimize ⁹⁰Y ingrowth. The second count is ideally performed after 1-2 weeks of ⁹⁰Y ingrowth. Computational methods for resolving the ⁸⁹Sr and ⁹⁰Sr activities are outlined in Appendix B of reference [2].

Cerenkov vs LSC The beta emission of ⁹⁰Sr is below the threshold for efficient measurement by Cerenkov counting (LSC without addition of cocktail). ⁸⁹Sr may be determined by Cerenkov counting immediately following separation of radiostrontium on Sr Resin (Figure 1A). ⁹⁰Y will also be efficiently measured by Cerenkov counting.

Counting of ⁸⁹Sr by Cerenkov counting is less efficient than by liquid scintillation (LSC). However, the lower counting efficiency is partially offset by the lower background observed in Cerenkov counting. Furthermore, Cerenkov counting eliminates interferences from many low energy beta emitters that may cause bias in measurements made by LSC or GFPC. Additionally, Cerenkov counting does not require the addition of cocktail, offering cost savings in waste disposal and reagent costs. Cerenkov counting does not suffer from quenching which can occur in liquid scintillation.

Counting ⁸⁹Sr by Cerenkov or total ^{89/90}Sr by GFPC as a first measurement leaves open the option to separate ⁹⁰Y from the strontium fraction for further confirmation of ⁹⁰Sr or discrimination of ⁸⁹Sr/⁹⁰Sr. Counting the strontium fraction by LSC limits any further separation on the sample due to the addition of the LSC cocktail, leaving the two count method as the only viable ⁸⁹Sr/⁹⁰Sr discrimination option after LSC.

⁸⁹Sr by Cerenkov, ^{89/90}Sr by LSC Counting (Rapid ^{89/90}Sr) ⁸⁹Sr is determined by Cerenkov counting immediately following separation of radiostrontium on Sr Resin (Figure 1A) [3]. After the addition of LSC cocktail, ⁹⁰Sr may then be determined by measuring total radiostrontium (⁸⁹Sr + ⁹⁰Sr) by standard liquid scintillation counting and calculating the difference (total radiostrontium - ⁸⁹Sr), taking into account ingrowth of ⁹⁰Y and decay of ⁸⁹Sr during counting.

This approach may not be appropriate for samples that require long count times to meet data quality objectives or for samples with low ratios of ⁸⁹Sr/⁹⁰Sr, due to interference from ⁹⁰Y ingrowth. However, this method can be used very effectively to rapidly determine ⁸⁹Sr and ⁹⁰Sr in samples containing relatively high amounts of radiostrontium in the immediate aftermath of a release of fresh fission products.

When utilizing Cerenkov and/or liquid scintillation counting, chemical yield of Sr throughout the separation process is most effectively measured via stable strontium carrier by taking a small aliquot of the separated strontium fraction for analysis by ICP-MS or ICP-AES. Recovery by ⁸⁵Sr gamma emission is not recommended, due to interference with the measurement of total radiostrontium by liquid scintillation counting.

DGA vs Sr Resin for ^{90}Y Separation For samples with expected high ratios of $^{89}\text{Sr}/^{90}\text{Sr}$, using DGA to selectively retain ^{90}Y is recommended, as the Sr can be effectively rinsed from the column, while ^{90}Y recovery remains essentially 100% ($k' \text{ Y on DGA} \gg 1000$). In high $^{89}\text{Sr}/^{90}\text{Sr}$ samples, small breakthrough of strontium from separation on Sr Resin into the ^{90}Y fraction ($k' \text{ Sr only} \sim 100$ on Sr Resin) can lead to high bias of the ^{90}Sr measurement and a corresponding low bias of the ^{89}Sr .

^{89}Sr by Cerenkov, ^{90}Y by Cerenkov Following Ingrowth and Separation ^{89}Sr is measured by Cerenkov counting following separation of strontium on Sr Resin (Figure 1A). ^{90}Sr may then be determined by waiting 1-14 days for ^{90}Y ingrowth, acidifying the Cerenkov counted sample with HNO_3 , separating the ^{90}Y using Sr Resin (Figure 1B) or DGA Resin (Figure 1C), and measuring ^{90}Y by Cerenkov counting.

This method is **not as rapid as the Cerenkov/LSC rapid $^{89/90}\text{Sr}$ method**, due to the ^{90}Y ingrowth period. However, due to the separation of pure ^{90}Y from strontium and other beta emitting nuclides with high decontamination factors, this method **may provide more accurate and sensitive measurements** for samples with **high $^{89}\text{Sr}/^{90}\text{Sr}$ or $^{90}\text{Sr}/^{89}\text{Sr}$ ratios**. The chemical yield of Sr may be measured via stable strontium carrier by taking a small aliquot of the separated strontium fraction for analysis by ICP-MS or ICP-AES or by ^{85}Sr gamma emission. Yttrium yields may also be tracked using stable Y and measurement by ICP-MS or ICP-AES.

$^{89/90}\text{Sr}$ by GFPC, ^{90}Y by GFPC Following Ingrowth and Separation ^{90}Sr and/or ^{89}Sr can be measured effectively using low background gas flow proportional counting (GFPC) following separation of strontium on Sr Resin (Figure 1A) [4,5]. Prior to measurement by GFPC, purified strontium fractions are dried onto cupped planchets or precipitated as carbonates or phosphates and collected on filter paper (and dried). Immediate counts of the purified strontium fractions yield the total radiostrontium ($^{89}\text{Sr} + ^{90}\text{Sr}$). Following the initial count for total radiostrontium and a period of ^{90}Y ingrowth, the dried sample can be dissolved from the planchet or filter using HNO_3 , and additional separations performed to isolate ^{90}Y from the strontium fraction using Sr Resin (Figure 1B) or DGA Resin (Figure 1C). ^{90}Y can then be measured by GFPC after evaporation on a stainless steel planchet or collection of an YF_3 precipitate on a filter. ^{90}Sr activity can be calculated using the measured ^{90}Y activity and the period of ingrowth from the initial separation. ^{89}Sr activity can be calculating by difference (total radiostrontium - ^{90}Sr).

When using GFPC, strontium chemical yield may be determined via stable strontium using ICP-MS, ICP-AES or gravimetric methods. GFPC offers relatively **high detection efficiency** and **very low instrument background** and, therefore, normally the **lowest detection limits** of the available counting techniques. Additionally, multiple drawer GFPC systems allow for the **simultaneous counting** of multiple samples, an option which is normally not available for Cerenkov or LSC.

References

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