Dissolution and solvent extraction for the purification of Sr-89 from irradiated yttria target in Hot cells


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*89 Sr*: pure $\beta$- emitter, $t_\frac{1}{2} = 50.5$ days: Energy $\sim 1.5$ MeV

- Pain palliative medicine for bone metastases.
- Strontium biological analogue to calcium & high affinity for metabolically active bone.

- Normal dose 40 – 60 $\mu$Ci / kg of body weight
- Biological $t_\frac{1}{2} = 14$ days in normal bone: Exceeds 50 d in osteoblastic metastases.

- As IV injection 4 mCi /4 ml per injection as ($^{89}\text{SrCl}_2$ in 0.1 N HCl, pH: 6-7)

- US FDA approved $^{89}$Sr, $^{32}$P & $^{153}$Sm as candidates: $^{32}$P & $^{153}$Sm found to result in mild to severe bone marrow suppression
Production Principle

Fast Reactor route: $^{89}\text{Y}(n,p)^{89}\text{Sr}$

Advantage: Product with very high specific activity possible: 19 kCi $^{89}\text{Sr}/g$ of Sr. Sr produced is easily separated from Y target as product.

Present Study: $^{89}\text{Y}(n,p)^{89}\text{Sr}$ in FBTR

Other products: $^{90}\text{Sr}$ $\frac{1}{2} = 29$ years and Yttrium 88 - $\frac{1}{2}$ 106 days

Yield (Ci/g of Y) for 30 days at flux : $2.4 \times 10^{15}n \text{ cm}^{-2}\text{s}^{-1}$

$^{89}\text{Sr}: 0.011 :: ^{88}\text{Y}: 0.005 :: ^{90}\text{Sr}: 1.98 \times 10^{-19}$ (Based on computed cross section)
Yttria target preparation: Sintered Yttria Y$_2$O$_3$: 1g/pellet prepared and characterized for bulk density and Na compatibility test.

Irradiation in FBTR:

<table>
<thead>
<tr>
<th>Campaign No.</th>
<th>Position of irradiation</th>
<th>No. of days of irradiation (days)</th>
<th>Material of Pellet encapsulation tube</th>
<th>Solvent extraction route followed</th>
<th>Activity of Sr$^{89}$ obtained (mCi/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Centre Core</td>
<td>72</td>
<td>SS</td>
<td>TBP</td>
<td>19</td>
</tr>
<tr>
<td>II</td>
<td>4$^{th}$ Ring</td>
<td>118</td>
<td>Quartz</td>
<td>CE</td>
<td>2</td>
</tr>
<tr>
<td>III</td>
<td>5$^{th}$ Ring</td>
<td>30</td>
<td>Quartz</td>
<td>TBP</td>
<td>0.9</td>
</tr>
<tr>
<td>IV</td>
<td>5$^{th}$ Ring</td>
<td>45</td>
<td>SS</td>
<td>CE</td>
<td>In process</td>
</tr>
</tbody>
</table>
Transportation of irradiated yttira

La-Calhene loaded in to lead cask

Unloading the lead cask

HP checking the dose level

$Y_2O_3$ pellets were posting in to Hot cell through EXTP.
Quartz tube cutting device

Developed in-house for cutting QT in Hot cell with MSM

In case of SS casing, the laser cutting carried out in Radio Metalurgical Laboratory of IGCAR and capped before transportation
Dissolution

\[ \text{Y}_2\text{O}_3 + 6\text{HNO}_3 \rightarrow 2\text{Y(NO}_3)_3 + 3\text{H}_2\text{O} \]

Dissolver: Titanium vessel of 350 ml inner volume.
25 nos of irradiated yttria pellets dissolved in 150 ml of 9 M /11 M \( \text{HNO}_3 \) under reflux condition for 24 hrs at 120°C

- Vessel Dim: 70mm OD: 35mm ID & 300 mm height:
  Thickness 6 mm

“O” rings used: EPDM or Viton

Base heater with cylindrical heat insulator and silicone insulated RTD outputs inside the cell.
Multi-tasking table

- Vice
- Dissolver holder
- Lid open cum closure arrangement
- Solution transfer system
- Separation fixture
Temperature calibration of the vessel

Δ T (outer – inner) = 25°

For heating up to 150 °C pressure raised up to 5.203 kg/cm²
The bulk yttrium was separated by 100% TBP
Bulk Yttrium to organic phase and strontium in aqueous phase.

The bulk yttrium was separated by 0.2M CE in octonal
Strontium to organic phase and Yttrium in aqueous phase.

\[ \text{Y(NO}_3\text{)}_3 + 3 \text{TBP} \rightarrow [\text{Y(NO}_3\text{)}_3 \cdot 3 \text{TBP}] \]

\[ \text{Y(NO}_3\text{)}_3 + 3 \text{TBP} \rightarrow [\text{Y(TBP)}_3 \cdot \text{HNO}_3] \]

\[ \text{Sr}^{2+} (\text{NO}_3\text{)}_2 + \text{C.E.}(\text{Dt.BuCh18C6}) \rightarrow \text{Sr}(\text{Dt.BuCh18C6}) (\text{NO}_3\text{)}_2 \]
Flowchart for separation of strontium (TBP Route)

Irradiated $\text{Y}_2\text{O}_3$ pellets were transported from RML

Dissolution with nitric acid

Yttrium and Strontium separated by TBP

Sr 89 in $\text{HNO}_3$ (Aqs.)

Further purification

Y 88 gamma active in TBP (org.)

TBP stripped with water

TBP free from Yttrium

Yttrium in water (Stored in hot cell in SS Container)
Flowchart for separation of strontium (CE Route)

- Irradiated $\text{Y}_2\text{O}_3$ pellets were transported from RML to RCL
- Dissolution with nitric acid
- Strontium extracted by C.E.
- Sr 89 in C.E. (org.)
- Yttrium in HNO$_3$ (Aqs.)
- C.E. (Organic phase) for further purification steps
Transfer of Dissolver Solution

- Dissolver solution transferred to a beaker & volume measured.
- No evaporation loss
- No residue inside the dissolver vessel.
Solvent Extraction Steps

Organic transferred in to the bottle

Stirring unit

Solution transferred in to separating funnel

Interface position

Phase separation

Collection of Aqueous and Organic

Strontium phase
List of radioactive impurities formed during irradiation

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Route</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-88</td>
<td>89Y(n,2n)88Y</td>
<td>Target material</td>
</tr>
<tr>
<td>Rb-86</td>
<td>89Y(n,\alpha)86Rb</td>
<td></td>
</tr>
<tr>
<td>Tb-160</td>
<td>159Tb(n,\gamma)160Tb</td>
<td>Rare Earth impurities in the target material</td>
</tr>
<tr>
<td>Ce-139</td>
<td>138Ce(n,\gamma)139Ce</td>
<td></td>
</tr>
<tr>
<td>Ce-141</td>
<td>140Ce(n,\gamma)141Ce</td>
<td></td>
</tr>
<tr>
<td>Eu-154</td>
<td>153Eu(n,\gamma)154Eu</td>
<td></td>
</tr>
<tr>
<td>Zn-65</td>
<td>64Zn(n,\gamma)65Zn</td>
<td>Binder used in pellet preparation</td>
</tr>
<tr>
<td>Co-58</td>
<td>58Ni(n, p)58Co</td>
<td></td>
</tr>
<tr>
<td>Mn-54</td>
<td>54Fe(n, p)54Mn</td>
<td>Activation products of S.S</td>
</tr>
</tbody>
</table>
Further Purification Steps (NRCS)

Impurities in Strontium after SE separation (TBP Route)

Aq. Soln. after TBP extraction with impurities in 0.1M HNO₃

Loaded on to Cation Exchange Column: DOWEX 50W X 8 resin (100-200 Mesh size) Conditioned to 0.1M HNO₃ (FR: 0.3 ml/min)

Elution with 1 M HNO₃ for selective removal of Sr

Elution with 3 M HNO₃ for removal of Y from the column

CE Route:
CE being highly selective to Sr, the purification steps involved are less.

Calcination:

\[ \text{Sr}^{2+} \quad \text{(NO}_3\text{)}_2 \xrightarrow{\Delta} \text{SrO} \xrightarrow{\text{HCl}} \text{SrCl}_2 \]

\[ \text{Calcination:} \quad \text{Sr}^{2+} \quad \text{(NO}_3\text{)}_2 \xrightarrow{800 \text{°C}} \text{SrO} \xrightarrow{\text{HCl}} \text{SrCl}_2 \]
Qualification for medical application

Specifications for $^{89}$SrCl$_2$ for use as bone pain palliation

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>Transparent colourless solution</td>
</tr>
<tr>
<td>pH</td>
<td>4.0 – 7.0</td>
</tr>
<tr>
<td>Radionuclides purity (% $^{89}$Sr)</td>
<td>$&gt;$ 99.6</td>
</tr>
<tr>
<td>Total beta impurities (%$^{89}$Sr)</td>
<td>$&lt;$ 0.2</td>
</tr>
<tr>
<td>Gamma emitting radionuclides (%$^{89}$Sr)</td>
<td>$&lt;$ 0.4</td>
</tr>
<tr>
<td>$^{90}$Sr activity relative to $^{89}$Sr activity (%$^{89}$Sr)</td>
<td>$&lt;$ 2.3 x 10$^{-4}$</td>
</tr>
<tr>
<td>Specific activity (MBq/mg Sr)</td>
<td>3.5 – 3.6</td>
</tr>
<tr>
<td>Radioactive concentration (MBq/mL)</td>
<td>37.5</td>
</tr>
<tr>
<td>Chemical Purity, overall (%)</td>
<td>$\geq$ 99.8%</td>
</tr>
<tr>
<td>Al</td>
<td>$&lt;$ 2.0</td>
</tr>
<tr>
<td>Fe</td>
<td>$&lt;$ 5.0</td>
</tr>
<tr>
<td>Pb</td>
<td>$&lt;$ 5.0</td>
</tr>
<tr>
<td>Assay of strontium chloride (mg/mL)</td>
<td>10.8 – 19.4</td>
</tr>
<tr>
<td>Sterility</td>
<td>Sterile</td>
</tr>
</tbody>
</table>

$^{89}$SrCl$_2$ Solution obtained using the above procedure has qualified the requirements.
Thank you!