Introduction
There are four stable isotopes of strontium with different isotopic abundances: $^{88}$Sr (0.56%), $^{87}$Sr (88.9%), $^{86}$Sr (7.0%) and $^{84}$Sr (0.2%). In some environments, such as those that have experienced radioactive contamination from nuclear accidents or weapons testing, radioactive strontium ($^{90}$Sr) can be found, with a half-life of 28.8 years. The monitoring of $^{90}$Sr is important from a human perspective because contaminated food or water is ingested. When the filament temperature is increased to 1790°C, a filament interference, which appears at higher filament temperatures. The filament temperature is modulated to keep the $^{90}$Zr signal within 20%. The collector configuration for both $^{88}$Sr and $^{90}$Sr signals is the same, with a $^{89}$Sr signal at 20%. The collector configuration for both $^{88}$Sr and $^{90}$Sr signals is the same, with a $^{89}$Sr signal at 20%

Results
The effect of the RPQ on peak tailing from $^{90}$Sr
Samples of the non-radioactive NIST strontium carbonate standard SRM-897 were measured with the Triton XT TIMS equipped with an RPQ. The effect of the RPQ on peak tailing was observed by scanning across the mass range 88-90.56 amu of a non-radioactive strontium SRM-897 (Figure 6). It is clear that the tailing from the $^{90}$Sr is effectively removed by the RPQ feature of the Triton Series TIMS equipped with an RPQ.

Environmental samples
A number of different radioactive environmental samples of known activity were measured to determine the $^{90}$Sr/$^{88}$Sr ratio (Figure 7). These measurements were made on both the Bremen and Fukushima instruments across 3 analytical sessions (2 years apart).

Abundance sensitivity
The abundance sensitivity ($^{90}$Sr/$^{88}$Sr) achieved by the Triton Series TIMS equipped with an RPQ during static measurements of SRM 897 at 20 V 90Sr was $5 \times 10^{-10}$ (2 SD, m=3) (Figure 5). Note that this value is not dark noise corrected.

Limits of detection
The limit of detection (LOD) is determined as 3$\sigma$ ($^{90}$Sr/$^{88}$Sr) ratio (dark noise corrected ratio) = 2.9x10$^{-12}$. Using this LOD, it is possible to determine the minimum activity for environmental samples with varying concentrations of stable strontium (Figure 6).

Conclusions
The RPQ feature of the Triton Series TIMS improves the abundance sensitivity by reducing peak tailing on both the high and the low mass side of the peak. Replicate measurements of non-radioactive Sr demonstrate that an abundance sensitivity of $^{90}$Sr/$^{88}$Sr = 5.5x10$^{-11}$ can be achieved. This theoretically enables samples with a low $^{90}$Sr activity to be measured with a detection limit of 2.3x10$^{-11}$ (2SD/LOD).

The ability of the Triton Series TIMS coupled with the RPQ to measure low levels of $^{90}$Sr has been demonstrated through measurements of a range of environmental samples. These experiments show that the $^{90}$Sr can be accurately and precisely determined, with precisions close to the limit of counting statistics.

References

Materials and methods
Instrumentation
Two thermal ionization mass spectrometers were used, the Triton XT TIMS at Thermo Fisher Scientific, Bremen, Germany, and the Thermo Scientific™ Triton™ Plus TIMS at Fukushima University, Japan. Both instruments were equipped with a Retarding Potential Quadrupole lens (RPQ) in front of the central secondary electron multiplier (SEM) to reduce peak tailing from more abundant masses.

Sample preparation
The IAEA reference material’s certified $^{90}$Sr activity values were calculated using their dry weight. Concentrated $^{90}$Sr and $^{88}$Sr acids were used to digest IAEA 156 and IAEA 330. The dried sample was smelted and the low mass samples were digested and degassed successively using 2.4 M HCl and concentrated HNO$_3$. All the samples were dissolved in 3 M HNO$_3$. Strontium was separated from the other elements, including Zr, using a combination of chromatography with Sr resin (Eichrom Technologies, Inc., USA) using a homemade PTFE column of 12 mL volume (5). The total yield of the Sr separation chemistry was approximately 94% (4). After the Sr separation chemistry, the 2Sr ratio was reduced to 1.2 x 10$^{-11}$ times the original ratio of the sample.

Figure 3. Glowing filament in the TIMS source.

Figure 4. Effect of the RPQ on peak tailing from $^{90}$Sr

Figure 5. Abundance sensitivity of non-radioactive Sr (SRM 897) across three different analytical sessions. Each data point represents a 1 hour measurement at 20 and 25 V on the different electronic blocks show internal precision of 20%.

Figure 6. Determination of the minimum activity resolvable with a Triton XT TIMS with RPQ (black line) for varying strontium concentrations. The $^{90}$Sr/$^{88}$Sr detection limit of the previous TIMS studies (grey dashed line) and typical environmental samples data (decay corrected to January 2009) are shown for comparison.

Figure 7. Determination of the $^{90}$Sr/$^{88}$Sr ratio for a range of environmental samples. The decay corrected reference value (corrected to the measurement date) is shown in green. Different analytical sessions are separated here due to the difference in the $^{90}$Sr/$^{88}$Sr owing to radioactive decay over time.