Spacecraft Environment Interaction

R7004R

SPENVIS Report

Analysis of the Cluster-II FM-8 (Tango) Mission

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Abstract

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Contents

1 Introduction

Since space applications become more and more important for our everyday life, be it direct-broadcast services, environmental monitoring or even space travel, the understanding of the environment those applications operate in is crucial to ensure proper and smooth functioning.

To improve the understanding of the space environment and to examine different effects of the space environment on a spacecraft, this report will give an in-depth analysis of the Cluster-II Mission, a mission carried out by the European Space Agency (ESA) to study the interaction between the solar wind and the earth's magnetosphere and provide an unprecedented 3D-model of those interactions [**?**].

This report is focused especially on the space radiation environment of the Cluster-II FM8 (Tango) satellite, one of the four satellites of the Cluster-II mission, and on the radiation effects on solar arrays and different electronic devices. For analysing the space environment a tool called SPENVIS (Space Environment Information System) developed by ESA is used. SPENVIS is a Web-interface with a powerful backend that provides access to numerical calculations and evaluations of a user-defined orbit or mission. It also provides data on different effects as "[...] cosmic rays, natural radiation belts, solar energetic particles, plasmas, gases, and "micro-particles" [...]" [**?**].

To provide an overview over the FM8 Tango Mission, the next chapter will introduce the mission objectives as well as the basic space environment this specific satellite faces. After, different radiation effects are examined and numerical calculations for solar arrays and memory devices are performed, followed by an analysis of their results. [**?**].

2 Mission Overview

2.1 Mission Definition

The Cluster-II Mission is planned and executed by the European Space Agency and was launched on 16th of July 2016. The whole mission consists of four identical spacecrafts flying in a tetrahedral formation in a highly elliptical orbit, where each spacecraft is collecting various data on the space environment with its 11 scientific payload instruments. These in-situ measurements are done to build a very accurate 3D-Model of the earth's magnetosphere and thus to observe the magnetosphere interaction with the solar wind not only in a spatial but also in a temporal resolution.

The main goal of this mission is to examine and gather data especially on the plasma structures in the bow shock region, the magnetopause, polar cusps, the earth's magnetotail and the auroral zone, all of them regions with very interesting properties when it comes to the interaction with solar wind [**?**].

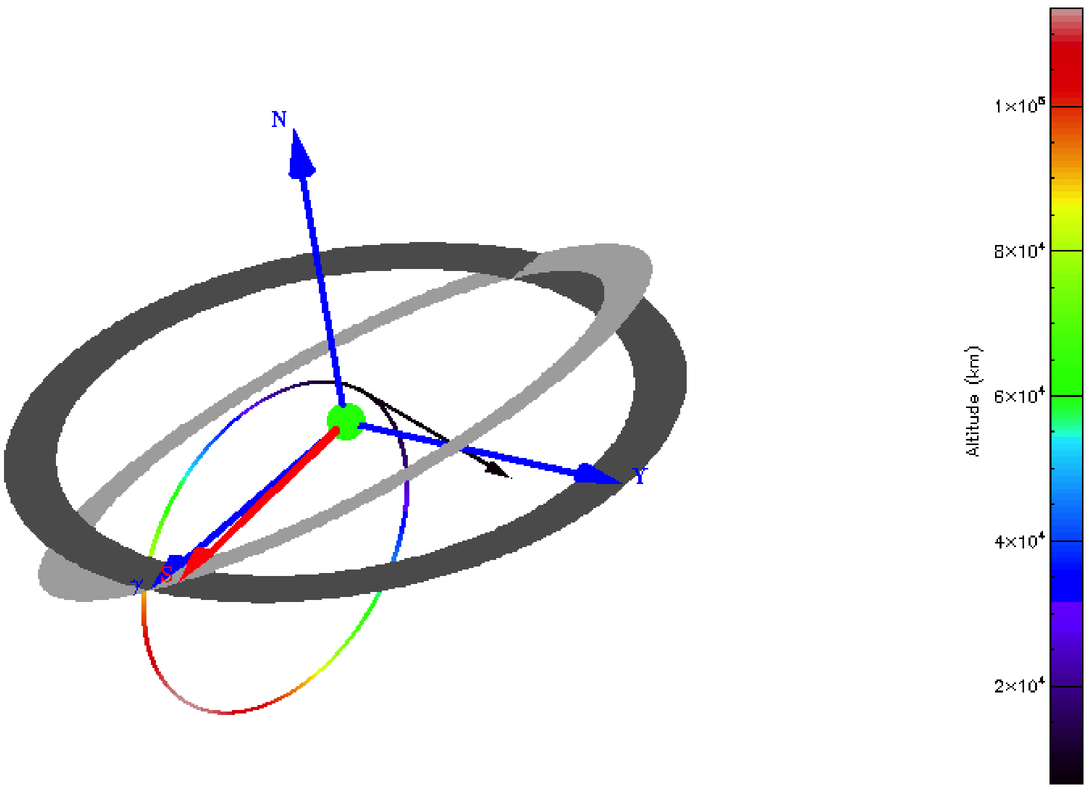

Figure 1: One Orbit of FM-8 Tango, the color bar shows the altitude

To model the Orbit of FM-8 Tango a set of TLE[1] data provided by CelesTrak was used [**?**].
Figure 1 shows one orbit of FM-8 Tango and indicates the altitude of the orbit. The orbit

[1]Two Line Element

itself is a retrograde orbit with an inclination of 131.6 degrees. A complete set of TLE data describing all important orbit parameters can be found in the Appendix A.1.

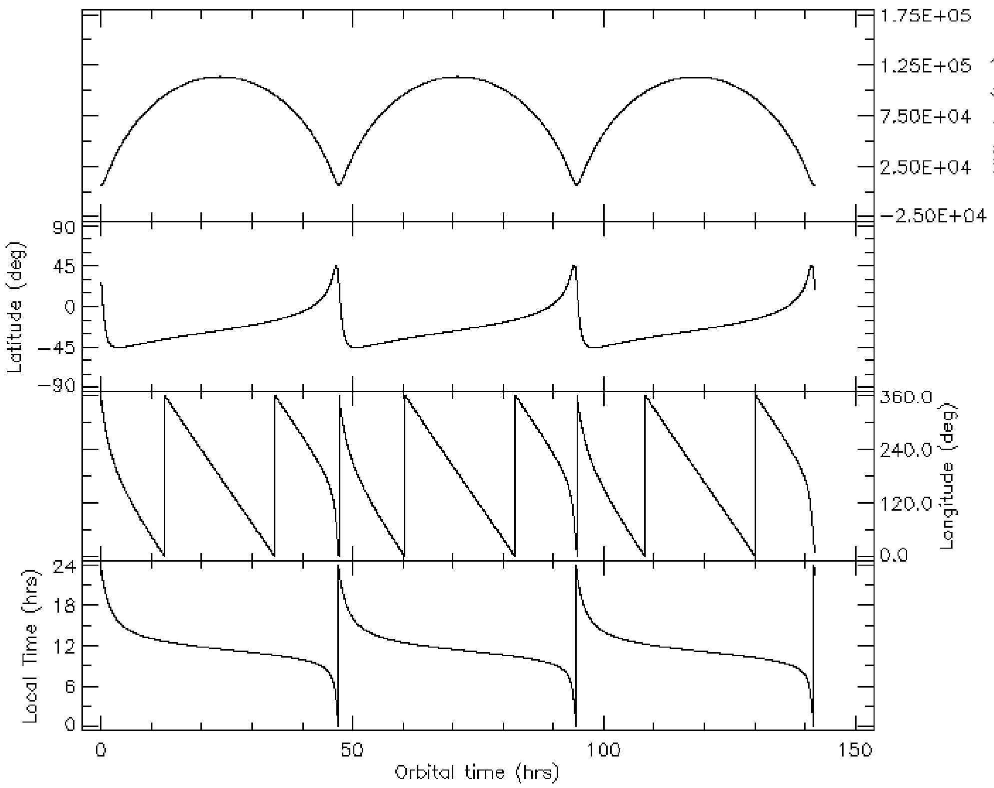

Figure 2: Various Data on 3 orbits of FM8 Tango

2.2 Space Environment

The Space Environment of the FM8 Tango Orbit itself is very interesting in terms of radiation and magnetic fields. Due to its highly elliptical orbit, with a perigee at about 28000km and an apogee at about 104000km it crosses the Van Allen radiation belts, which extend from 100km to 65000km, the inner one from 100km up to 1 Earth radius and the outer one from two to six earth radii [**?**].

2.3 Radiation Environment

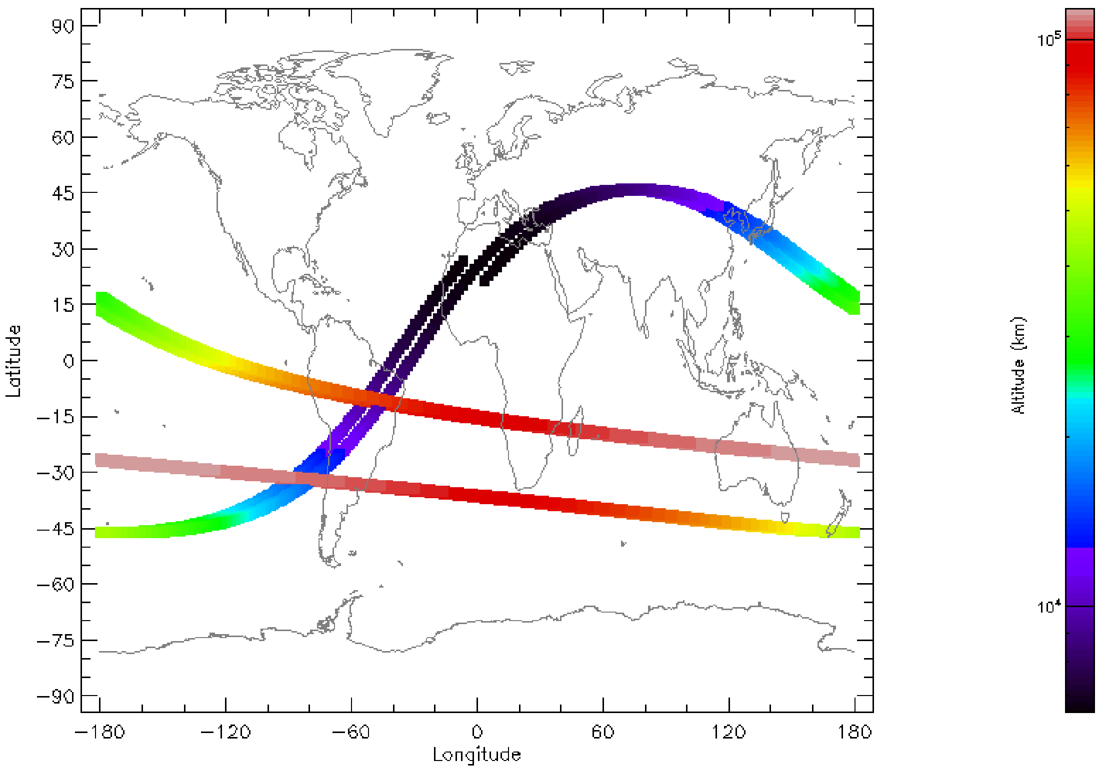

Figure 3: Groundtrack of 2 FM8 Tango Orbits

3 Numerical Simulations

3.1 Environmental flux

SPENVIS uses the AP-8/AE-8 model to simulate the trapped proton and electron models, which can simulate the fluxes during solar maximum and minimum.

For the worst-case simulation the solar maximum is considered.

For the protons the number of trapped protons is higher during solar minimum due to the increased scale height caused by the increased UV radiation from the sun, but only for lower altitudes, for this orbit the difference between solar minimum and maximum for the proton flux is negligible, which is not the case for the electrons.

In figures 7 and 6 the integrated fluxes are displayed over the orbit in GEI mode.

The highes proton fluxes are expected at perigee, while for the electron flux the highes flux is expected during crossing of the radiation belts (c.f. fig. 8).

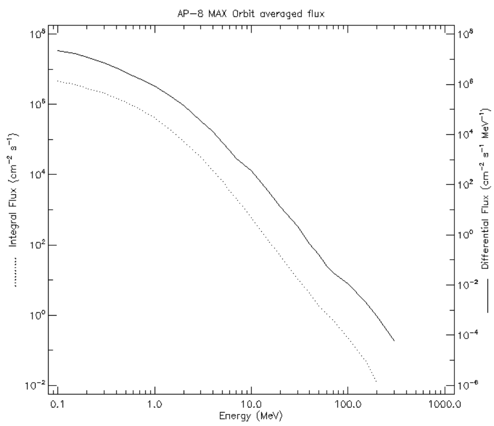

Figure 4: Proton Flux

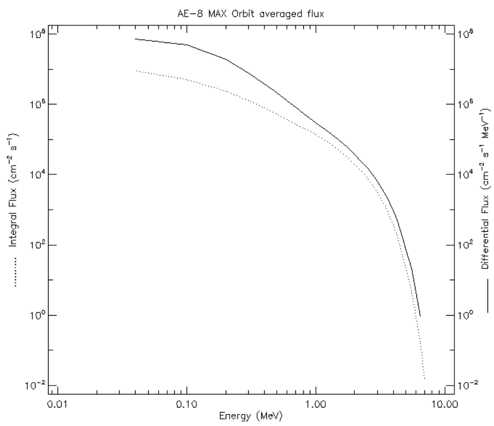

Figure 5: Electron Flux

3.2 Lifetime and Performance Degradation

The satellite is using Azur 3G28 solar cells, with an EOL power of 95% of the BOL power [**?**].

Using SPENVIS' MC-SCREAM for solar cells, it was determined that the shielding thickness should be around 230 µm which leaves an EOL powerloss of 3.3%.

3.3 Total Dose and Shielding

The satellite is using a memory device which can withstand a total radiation dose of 25 Krad before failure.

With 1mm of shielding the memory device exceeds its maximum radiation dose with a total dose of 1.5 Mrad, which is about 62 times the maximum allowed dose.

To achieve a maximum dose of 25 Krad or less the shielding has to be increased to a minimum of 5.1mm, which will lead to a maximum dose of 26 Krad.

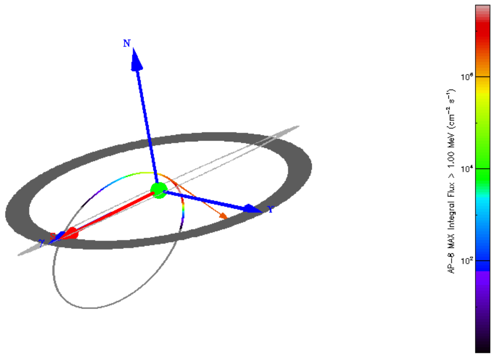

Figure 6: Proton Flux greater than 1 MeV

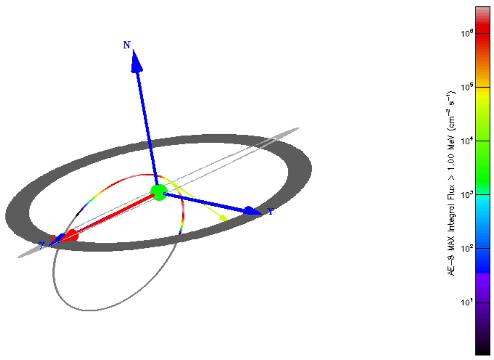

Figure 7: Electron Flux greater than 1 MeV

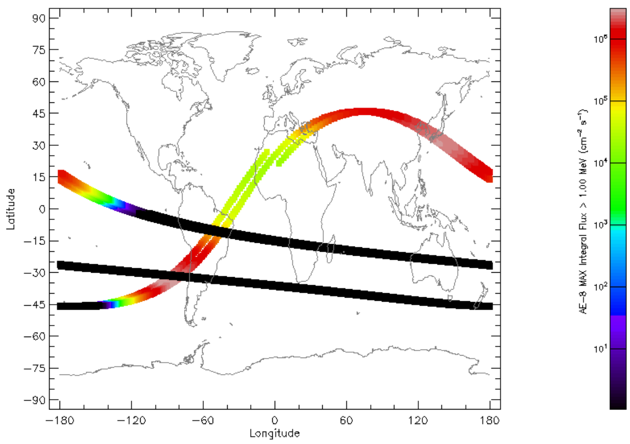

Figure 8: Electron Flux World map

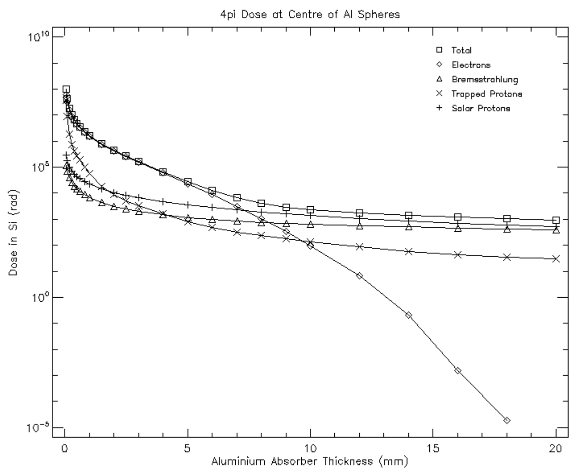

Figure 9: Dose received vs. Shielding in mm

3.4 Single Event Upsets

3.4.1 Linear Energy Transfer (LET) Spectrum

The LET spectra was calculated using SPENVIS, including solar particles, trapped protons and galactic cosmic rays, with a shielding of 1 g/cm^2 (c.f. fig. 10).

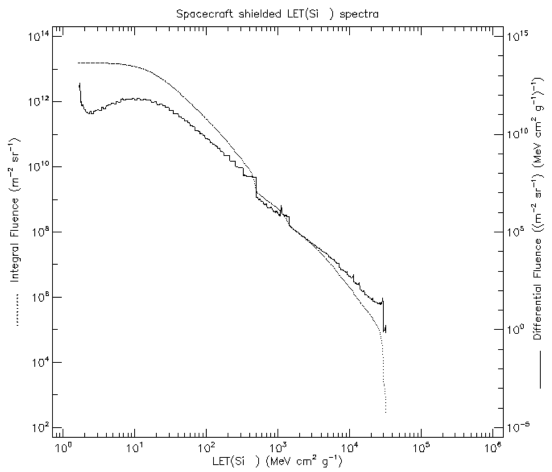

Figure 10: LET spectra for the full mission

3.4.2 Cross Section and Components Characteristics

For the SEU estimation several parameters are needed for the SMJ329C50GFAM66 to determine its cross-section which is determined by a Weibull function.

$$\sigma(L) = \begin{cases} 0 & L \geq L_0 \\ C_s \left(1 - e^{\left(\frac{L-L_0}{W}\right)^s}\right) & L < L_0 \end{cases}$$

Using the mono-beam experimental results ([?]) the final parameters calculated with a Weibull-fit in Matlab are:

L_0	$1.01 MeV \cdot cm^2/mg$	LET Threshold
C_s	$4.98510^{-6} cm^2$	saturated crosssection
W	$4.985 MeV \cdot cm^2/mg$	Weight of the distribution
s	0.7	shape parameter

Table 1: Results of the Weibull-Fit

The code responsible for the fit is generated using the Matlab Curve-Fit Toolbox (c.f. Listing 1) using data from [?] (c.f. Listing 2), the graphical result of the fit is shown in figure 11.

Listing 1: Autogenerated Matlabcode for fitting

```

function [fitresult, gof] = createFit(stopping, crossSec)
%CREATEFIT(STOPPING,CROSSSEC)
%  Create a fit.
%
%  Data for 'Weibull' fit:
%      X Input : stopping
%      Y Output: crossSec
%  Output:
%      fitresult : a fit object representing the fit.
%      gof : structure with goodness-of fit info.
%
%  See also FIT, CFIT, SFIT.

%  Auto-generated by MATLAB on 27-Mar-2016 22:16:28

[xData, yData] = prepareCurveData( stopping, crossSec );

% Set up fittype and options.
ft = fittype( 'C*(1-exp(-((x-L)/w)^s))', 'independent', 'x', '
    dependent', 'y' );
opts = fitoptions( 'Method', 'NonlinearLeastSquares' );
opts.Display = 'Off';
opts.StartPoint = [0.0003 1 1 2];

% Fit model to data.
[fitresult, gof] = fit( xData, yData, ft, opts );
```

Listing 2: Inputvalues for the fit

```
flips =[8 7497 22514 23986 33810 29991 21022 18043]; %from instructions
exTime = [5 5 5 5 5 10 10 15]; %from instructions
flux = [25e6 25e6 25e6 17e6 23e6 10e6 7e6 4e6]; %from instructions
energyBeam = [0.6 0.72 9.6 4.8 20 56 84 786]; %from instructions
u = [12 12 12 16 40 56 84 131]; %from instructions
energy = energyBeam./(u); %Where it has to be read from the table
crossSec=flips./(exTime.*60.*flux); %crosssection
LET = [2.73E+03 3.13E+03 4.65E+03 7.23E+03 1.77E+04 2.77E+04 3.74E+04 5.72E+04]./1000; %MEV cm^2/mg, read from table
```

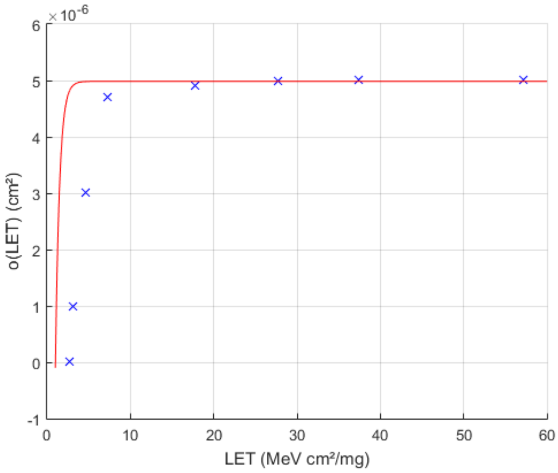

Figure 11: Weibull fit result

3.4.3 SEU Estimation

To determine which device is best for the mission it is neccessary which possible device is most immune to radiation to minimize malicious operation or data corruption.

This is done by estimating the SEU (single-event upset).

The SEU is calculated with the following formula (assuming omnidirectional flux), which was done using the results from the SPENVIS simulation in Matlab.

$$\frac{dU}{dt} = 4\pi \int_0^{\infty} \sigma\left(LET\right) \sum_{z=92}^{z=0} h\left(LET\right) dLET$$

The resulting SEU in $frac1sec$ are

As one can see easily in table 3.4.3 the CMOS R160 has the lowest SEU rates of all devices, thus it is the best choice.

NMOS2164	$9.6 \cdot 10^{-3}$
CMOS R160-25	$2.5 \cdot 10^{-6}$
Bipolar 93L422	$13.8 \cdot 10^{-3}$
SMJ329C50GFAM66	$3.0 \cdot 10^{-3}$

Table 2: SEU rates

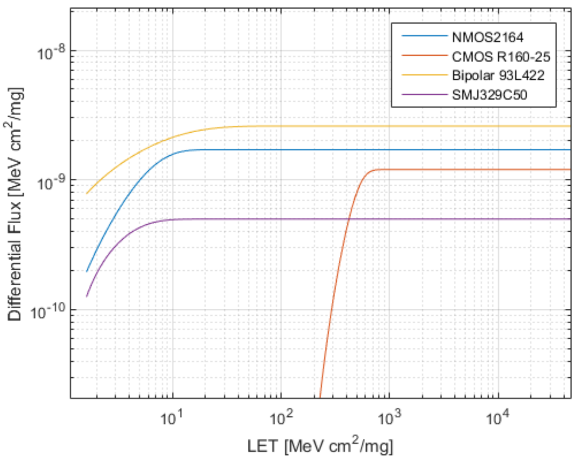

Figure 12: Plot of different LETs

4 Discussion

Appendix

A.1 Orbital Parameters of Cluster-II FM8 Tango

```
CLUSTER II-FM8 (TANGO)
1 26464U 00045B 16087.81656212 .00000382 00000-0 00000+0 0 9996
2 26464 131.5572 328.3783 5181518 141.3516 0.4910 0.44219885 51441
```

Table 3: Cluster-II Tango Parameters extracted of TLE set

Parameter	Value
Satellite Common Name	CLUSTER II-FM8 TANGO
Satellite Number	26464
Elset Classification	U
International Designator	00
Launch Number of the Year	045
Epoch Year	16
Epoch	87.81656212
BSTAR Drag Term	0.00000382
Inclination (deg)	131.5572
RAAN (deg)	328.3782
Eccentricity	0.5181518
Argument of Perigee (deg)	141.3516
Mean Anomaly (deg)	0.4910
Mean Motion (rev/day)	0.44219885
Rev number at epoch	5144