Total kinetic energy distribution for spontaneous fission of Rf isotopes

54th ASCR International Workshop

JAEA Tokai, 2019

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on behalf of SHIP collaboration
Outline

- Spontaneous fission properties
- Synthesis and identification
- Total kinetic energies of $^{255}\text{Rf}$, $^{256}\text{Rf}$ and $^{258}\text{Rf}$
Trans-fermium region

$^{255}\text{Rf}$: $T_{1/2} = 1.68(9)$ s
SF: 58.00%

$^{256}\text{Rf}$: $T_{1/2} = 6.67(10)$ ms
SF: 99.68%

$^{258}\text{Rf}$: $T_{1/2} = 10.1(1.1)$ ms
SF: 95.00%

[NNDC]

Fission characteristics

Mass distribution of fragments

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<th>A of Fragments</th>
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Total kinetic energy

Fission characteristics

Mass distribution of fragments

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Bi-modal fission “classical cases”

$^{258}$Fm, $^{259,260}$Md or $^{258,262}$No


We have improved experimental data on SF of $^{255,256,258}$Rf

- Do we see any sign of change in fission mode?
  - Study of TKE can give us a hint
Reactions:

\[\text{\(50\)Ti + \(207\)Pb} \rightarrow \text{\(257\)Rf*} \rightarrow \text{\(255\)Rf} + (2n)\]

\[\text{\(50\)Ti + \(207\)Pb} \rightarrow \text{\(257\)Rf*} \rightarrow \text{\(256\)Rf} + (1n)\]

\[\text{\(50\)Ti + \(209\)Bi} \rightarrow \text{\(259\)Db*} \rightarrow \text{\(258\)Db} + (1n) \rightarrow \text{\(258\)Rf}\]

Production and detection

\[M_{\text{MCN}} \approx 10^{-22}\text{s}\]

\[\text{Evaporated particles}\]

\[\approx 10^{-15}\text{s}\]

\[\text{Separator for Heavy Ion reaction Products}\]

\[\text{Detectors}\]

\[\gamma\]

\[\gamma\]

\[\text{Evaporation residue}\]

\[\text{Fusion products}\]
Production and detection

Reactions:

50Ti + 207Pb → 257Rf* → 255Rf + (2n)

50Ti + 208Pb → 258Rf* → 256Rf + (2n)

50Ti + 209Bi → 259Db* → 258Db + (1n) → 258Rf

EC

256Rf

255Rf

258Rf

(2n)
Range of fragments

Implantation of ER to STOP detector

"beam" view

Implantation depth
(6–7μm)

ER Implantation direction

Dead layer
(11.6 μg/cm²)

Range of fragments
(~20μm)

Side view

STOP detector
Range of fragments

Implantation of ER to STOP detector

“beam” view

Side view

How to reconstruct the energy of escaped fragments?

Dead layer (11.6 μg/cm²)

Range of fragments (~20μm)
3 possible cases

- Escape to BOX detector
- Both fragments in STOP
- One fragment complete escape

Impossible to separate!!

- 30% of all events
- Two dead layers
- Energy reconstruction possible
  ➔ STOP + BOX

- 70% of all events (50+20)
- 20% events with incomplete energy
3 possible cases

- Escape to BOX detector
- Both fragments in STOP
- One fragment complete escape

Impossible to separate !!

- 30% of all events
- Two dead layers
- Energy reconstruction possible ➔ STOP + BOX amplitude

- 70% of all events (50+20)
- 20% events with incomplete energy
3 possible cases

- Escape to BOX detector
- Both fragments in STOP
- One fragment complete escape

What about the detector response?

- 30% of all events
- Two dead layers
- Energy reconstruction possible ➔ STOP + BOX amplitude

- 70% of all events (50+20)
- 20% events with incomplete energy
Detected TKE

Calibration by alpha lines =

= Energy deficit in detected fragments' TKE

Pulse height defect

Difference in detected energy between light (e.g. alphas) and heavy ions (e.g. fragments) with the same kinetic energy

- Dead layer losses
- Not-ionizing interactions with atoms in detector
- Recombination of e-h

strongly depends on implantation depths

Corrections needed!!!
Detected TKE

Calibration by alpha lines =

= Energy deficit in detected fragments' TKE

Pulse height defect

Difference in detected energy between light (e.g. alphas) and heavy ions (e.g. fragments) with the same kinetic energy

- Dead layer losses
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- Recombination of e-h
  - strongly depends on implantation depths

Corrections needed!!!
Detected TKE

 Calibration by alpha lines =

= Energy deficit in detected fragments' TKE

Let's prepare the correction to this energy deficit!

Not ionizing interactions with atoms in detector:
- Recombination of e-h
  - strongly depends on implantation depths

Corrections needed!!!
Energy deficit in detected TKE ($^{252}\text{No}$)

Effect already studied on $^{252}\text{No}$ in 2006 at SHIP*

- **Why $^{252}\text{No}$?**
  - Relatively high production cross-section
  - Known $<\text{TKE}> = 194.3$ MeV
  - Close to Rf isotopes in Z and N
  - Implanted in 6 different depths to STOP detector
  - TKE vs. impl. depth

We evaluated previously measured data on $^{252}\text{No}$ from 2006 and used LISE++ for impl. depths.


Energy deficit in detected TKE ($^{252}$No)

Effect already studied on $^{252}$No in 2006 at SHIP*
- Why $^{252}$No?
  - Relatively high production cross-section
  - Known TKE = 194.3 MeV
  - Close to Rf isotopes
  - Implanted in 6 different depths to STOP detector

Now we can reconstruct the TKE!

*implantation depths calculated by LISE++ (O. B. Tarasov and D. Bazin., Nucl. Instr. Meth. B 266, 4657 (2008)).


Total kinetic energy of $^{255,256,258}\text{Rf}$
Total kinetic energy of $^{255,256,258}$Rf

$^{255}$Rf

$\langle TKE \rangle = 201.2 \pm 0.9$ MeV

FWHM = $31.3 \pm 1.7$ MeV

$^{256}$Rf

$\langle TKE \rangle = 197.5 \pm 1.0$ MeV

FWHM = $31.2 \pm 2.0$ MeV

$^{258}$Rf

$\langle TKE \rangle = 198.5 \pm 1.1$ MeV

FWHM = $28.4 \pm 2.2$ MeV
Total kinetic energy of $^{255,256,258}$Rf

$^{255}$Rf

$\langle \text{TKE} \rangle_L = 188 \pm 10 \text{ MeV}$

FWHM$_L = 20 \text{ MeV (fixed)}$

$\langle \text{TKE} \rangle_H = 210 \pm 4 \text{ MeV}$

FWHM$_H = 20 \text{ MeV (fixed)}$

$^{256}$Rf

$\langle \text{TKE} \rangle_L = 194 \pm 3 \text{ MeV}$

FWHM$_L = 20 \text{ MeV (fixed)}$

$\langle \text{TKE} \rangle_H = 217 \pm 4 \text{ MeV}$

FWHM$_H = 20 \text{ MeV (fixed)}$

$^{258}$Rf

$\langle \text{TKE} \rangle_L = 188 \pm 10 \text{ MeV}$

FWHM$_L = 20 \text{ MeV (fixed)}$

$\langle \text{TKE} \rangle_H = 210 \pm 4 \text{ MeV}$

FWHM$_H = 20 \text{ MeV (fixed)}$
Total kinetic energy of $^{255,256,258}$Rf

Summary

- $^{255, 256, 258}$Rf produced in fusion-evaporation reactions with $^{50}$Ti beam and $^{207, 208}$Pb and $^{209}$Bi targets

- Correction to pulse-height-defect determined using exp. data for TKE of $^{252}$No and ER implantation calculation by LISE++

- Evaluation of $<\text{TKE}>$ and study of TKE distributions for $^{255, 256, 258}$Rf

Thank you
Bi-modal fission

“classical cases”

\( ^{258}\text{Fm}, \, ^{259,260}\text{Md} \text{ or } ^{258,262}\text{No} \)


TKE distributions for Rf isotopes:

- \( ^{260}\text{Rf}, \, ^{258}\text{Rf} \) – reasonable statistics
  (no bi-modal fission clearly observed)

- \( ^{255}\text{Rf}, \, ^{256}\text{Rf} \) – very limited statistics
  (<30 counts)
Energy deficit in detected TKE ($^{252}$No)

\[ f(x) = \frac{ax}{b+x} + c \]