A Comparison of the TRITON and ORIGEN2 Source Generation Programs

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PATRAM 2010

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Introduction

- **The Battelle Energy Alliance Research Reactor (BRR) Package is designed to transport irradiated fuel from the following three reactors:**
  - **University of Missouri Research Reactor (MURR)**
  - **Massachusetts Institute of Technology Research Reactor (MITR-II)**
  - **Advanced Test Reactor (ATR)**
- **To support licensing of the BRR package, source terms from each reactor were needed**
- **All three reactor sites chose to use the ORIGEN2 computer program for the source term generation**

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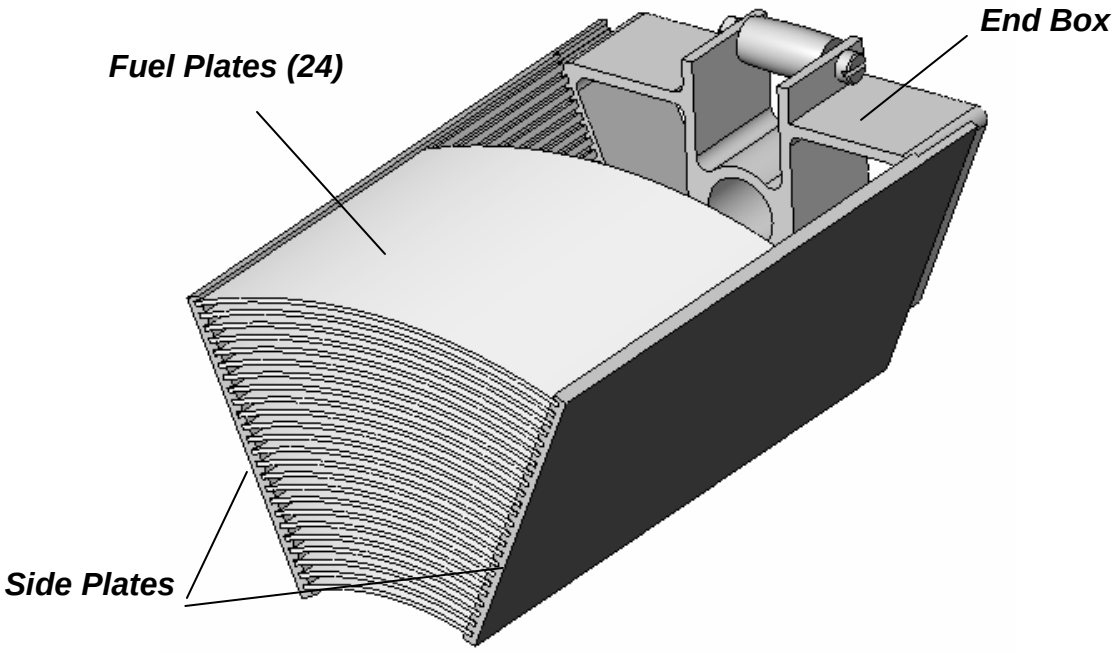
Introduction

- **All three reactors use high-enriched (93% U-235) aluminide plate fuels**



ORIGEN2

- ORIGEN2 has been in use since 1980, and is in widespread use in the nuclear industry in the U.S.
- It is no longer supported by the computer program developer
- ORIGEN2 is a simple “zero dimensional” program - no fuel element geometry is required as input
- Libraries do not specifically include aluminide plate fuel types
- Data libraries are included with the program for a variety of reactors
  - MURR used the THERMAL library
  - MITR-II used the PWRUS library
  - ATR used an ATR-specific library

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TRITON

- To check ORIGEN2 output, it was decided to generate the source terms using TRITON
- TRITON is part of the SCALE6 computer program package
- TRITON has the capability of 2 Dimensional modeling of a fuel element - therefore, MURR, MITR-II, and ATR fuel elements could be modeled explicitly
- No pre-determined reactor libraries are needed by TRITON
- The necessary fluxes used to collapse the cross section set for depletion calculations are determined based on the geometry of the modeled fuel element

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Basic Reactor Data

- **MURR**
  - **Burnup = 180 MWD**
  - **Decay Time = 180 days**
  - **Uranium mass per element = 825 g**
- **MITR-II**
  - **Burnup = 225 MWD**
  - **Decay Time = 930 days**
  - **Uranium mass per element = 538 g**
- **ATR**
  - **Burnup = 350 MWD**
  - **Decay Time = 1280 days**
  - **Uranium mass = 1145 g**

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ORIGEN2 vs. TRITON, Gammas

- **ORIGEN2 and TRITON compared remarkably well for the gamma sources**
- **Total gamma source (γ/s) increases using TRITON:**
  - **MURR: 3.2%**
  - **MITR-II: 11.0%**
  - **ATR: 1.8%**
- **There are huge increases for some high energy groups, but they contribute little to the total dose rate**

MURR Gamma Source Comparison

Mean Photon Energy (MeV)	ORIGEN2	TRITON	% Change
1.00E-02	3.322E+14	3.334E+14	0.4%
2.50E-02	7.122E+13	6.966E+13	-2.2%
3.75E-02	8.163E+13	8.513E+13	4.3%
5.75E-02	6.650E+13	5.847E+13	-12.1%
8.50E-02	4.752E+13	4.401E+13	-7.4%
1.25E-01	7.077E+13	8.001E+13	13.1%
2.25E-01	3.866E+13	4.044E+13	4.6%
3.75E-01	1.873E+13	1.960E+13	4.6%
5.75E-01	6.015E+13	7.095E+13	17.9%
8.50E-01	3.184E+14	3.389E+14	6.4%
1.25E+00	3.547E+12	4.045E+12	14.0%
1.75E+00	4.426E+11	8.629E+11	95.0%
2.25E+00	2.282E+12	2.173E+12	-4.8%
2.75E+00	8.308E+09	8.769E+09	5.6%
3.50E+00	5.794E+08	4.661E+08	-19.6%
5.00E+00	5.166E-01	1.193E+02	22990.8%
7.00E+00	5.697E-02	1.355E+01	23676.8%
9.50E+00	6.390E-03	1.544E+00	24067.4%
Total (γ/s)	1.112E+15	1.148E+15	3.2%

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MITR-II Gamma Source Comparison

Mean Photon Energy (MeV)	ORIGEN2	TRITON	% Change
1.00E-02	5.357E+13	5.586E+13	4.3%
2.50E-02	1.167E+13	1.187E+13	1.7%
3.75E-02	1.335E+13	1.465E+13	9.7%
5.75E-02	1.076E+13	9.871E+12	-8.3%
8.50E-02	7.521E+12	7.366E+12	-2.1%
1.25E-01	9.086E+12	1.089E+13	19.8%
2.25E-01	6.179E+12	6.672E+12	8.0%
3.75E-01	3.156E+12	3.354E+12	6.3%
5.75E-01	4.251E+13	5.041E+13	18.6%
8.50E-01	1.125E+13	1.648E+13	46.5%
1.25E+00	1.624E+12	1.995E+12	22.8%
1.75E+00	7.615E+10	1.511E+11	98.4%
2.25E+00	2.911E+11	2.880E+11	-1.1%
2.75E+00	1.225E+09	1.392E+09	13.7%
3.50E+00	1.266E+08	1.061E+08	-16.2%
5.00E+00	9.235E+01	1.720E+03	1762.4%
7.00E+00	9.919E+00	1.968E+02	1884.4%
9.50E+00	1.093E+00	2.256E+01	1964.0%
Total (γ/s)	1.710E+14	1.898E+14	11.0%

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ATR Gamma Source Comparison

Mean Photon Energy (MeV)	ORIGEN2	TRITON	% Change
1.00E-02	8.557E+13	8.623E+13	0.8%
2.50E-02	1.868E+13	1.839E+13	-1.5%
3.75E-02	2.117E+13	2.240E+13	5.8%
5.75E-02	1.717E+13	1.524E+13	-11.2%
8.50E-02	1.200E+13	1.134E+13	-5.5%
1.25E-01	1.438E+13	1.662E+13	15.6%
2.25E-01	9.878E+12	1.033E+13	4.6%
3.75E-01	5.090E+12	5.251E+12	3.2%
5.75E-01	5.375E+13	5.533E+13	2.9%
8.50E-01	8.026E+12	8.995E+12	12.1%
1.25E+00	1.711E+12	1.561E+12	-8.8%
1.75E+00	1.162E+11	2.075E+11	78.6%
2.25E+00	4.708E+11	4.547E+11	-3.4%
2.75E+00	2.057E+09	2.104E+09	2.3%
3.50E+00	2.151E+08	1.586E+08	-26.3%
5.00E+00	1.335E+02	1.757E+02	31.6%
7.00E+00	1.506E+01	1.990E+01	32.2%
9.50E+00	1.708E+00	2.267E+00	32.8%
Total (γ/s)	2.480E+14	2.524E+14	1.8%

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ORIGEN2 vs. TRITON, Gammas

- **Package surface gamma dose rate (mrem/hr) increases modestly when using the TRITON generated source:**
  - **MURR: 0.3%**
  - **MITR-II: 11.4%**
  - **ATR: 3.3%**
- **These differences are insignificant given the uncertainties and conservatism of a dose rate calculation**

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ORIGEN2 vs. TRITON, Neutrons

- **The neutron source magnitude was dramatically different between ORIGEN2 and TRITON. Ratio of TRITON to ORIGEN2 neutron source magnitude:**
  - **MURR: 1600**
  - **MITR-II: 35**
  - **ATR: 12**
- **Ratio of new maximum cask neutron surface dose rate (mrem/hr) using TRITON source to old dose rate:**
  - **MURR: 1500**
  - **MITR-II: 33**
  - **ATR: 11**
- **Why so different?**

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ORIGEN2 vs. TRITON, Neutrons

- Neutrons are generated both by spontaneous fission and by alpha bombardment of certain target nuclei.
- ORIGEN2 assumes commercial reactor fuel where the alpha target is oxygen-17 and oxygen-18, present in very low abundances (most oxygen is oxygen-16, which does not generate neutrons)
- ORIGEN2 does not consider any aluminum, which is an abundant alpha target element in the subject fuels
- TRITON correctly uses the aluminum matrix to generate the neutron source
- The correct treatment of the alpha target leads to an order of magnitude increase in the neutron magnitude when using TRITON

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ORIGEN2 vs. TRITON, Neutrons

- The abundance of alpha particles is dependent upon the transmutation of U-238 in the fuel to plutonium
- This transmutation requires higher-energy neutrons
- MURR had the worst agreement between ORIGEN2 and TRITON because the THERMAL library was used, which resulted in essentially no plutonium production, and no alphas to bombard aluminum
- MITR-II had much better agreement than MURR, although the PWR library may not be entirely representative of the MITR-II fuel
- The agreement between ORIGEN2 and TRITON was the best for ATR, because ATR staff developed an ATR-specific ORIGEN2 library

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ORIGEN2 vs. TRITON, Neutrons

- **Most of the neutron source difference for the MITR-II and ATR fuels was related to the improper treatment of the aluminum alpha target**
- **Most of the difference for the MURR fuel was due to a lack of alphas, as well as improper treatment of the aluminum target**
- **TRITON computes the neutron source much more accurately than ORIGEN2 for these fuel types**

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Overall Dose Rate Change

- **The overall package dose rate increase was small**
  - **The gamma dose rate increase was small**
  - **The neutron dose rate *increase* was large using TRITON, but the original ORIGEN2 neutron dose rate was very small to begin with**
  - **Net effect: dose rate still negligible compared to limit of 200 mrem/hr**
- **The original and new maximum surface (total) dose rates are as follows:**
  - **MURR: 9.9 mrem/hr to 11.1 mrem/hr**
  - **MITR-II: 3.2 mrem/hr to 13.4 mrem/hr**
  - **ATR: 1.8 mrem/hr to 3.1 mrem/hr**

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Conclusions

- ORIGEN2 does not properly account for neutrons under certain circumstances such as aluminide research reactor fuels, especially if the THERMAL library is used
- The TRITON program is an acceptable alternative
- For the subject fuels, ORIGEN2 and TRITON agree reasonably well for the gamma source
- The agreement is generally poor for the neutron source
- The neutron source is sensitive to the use of the proper alpha target nucleus, as well as the energy spectrum of the neutron flux (i.e., the abundance of alpha-producing nuclides)
- TRITON will handle these parameters much more rigorously than ORIGEN2

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