Enhancements to the Burnup Credit Criticality Safety Analysis Sequence In SCALE

International Workshop on Advances in Applications of Burnup Credit

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Outline

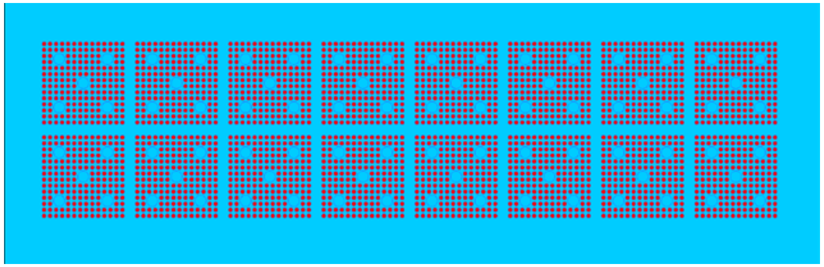
- Overview of STARBUCS features
- New STARBUCS capabilities available in SCALE 6
- Examples of STARBUCS applications

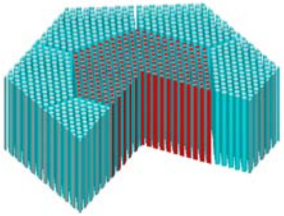
STARBUCS (Standardized Analysis of Reactivity for Burnup Credit Using SCALE)

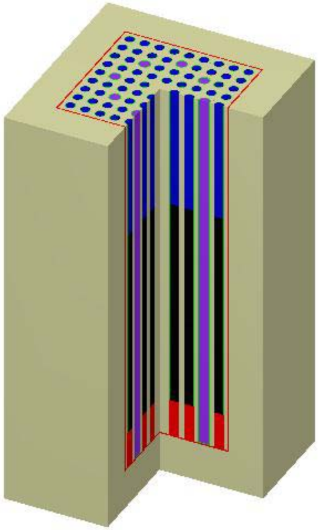
- **Purpose of STARBUCS Sequence**
  - **Initially developed by ORNL to support development of ISG-8 guidance**
  - **Motivated by need to automate SCALE criticality safety analyses employing burnup credit**
  - **Facilitate the application of an acceptable burnup credit approach in burnup credit analysis of spent fuel casks based on U.S. NRC Interim Staff Guidance ISG-8, Rev. 2, recommendations for PWR spent fuel**
  - **Code inputs allow adequate representation of the phenomena identified in ISG-8 to evaluate the impact of various licensing-basis model assumptions on k_{eff}**
- **Application Areas**
  - **Burnup credit criticality analyses for UO_2 spent nuclear fuel systems (e.g., spent fuel casks or pools)**

Overview of STARBUCS Features

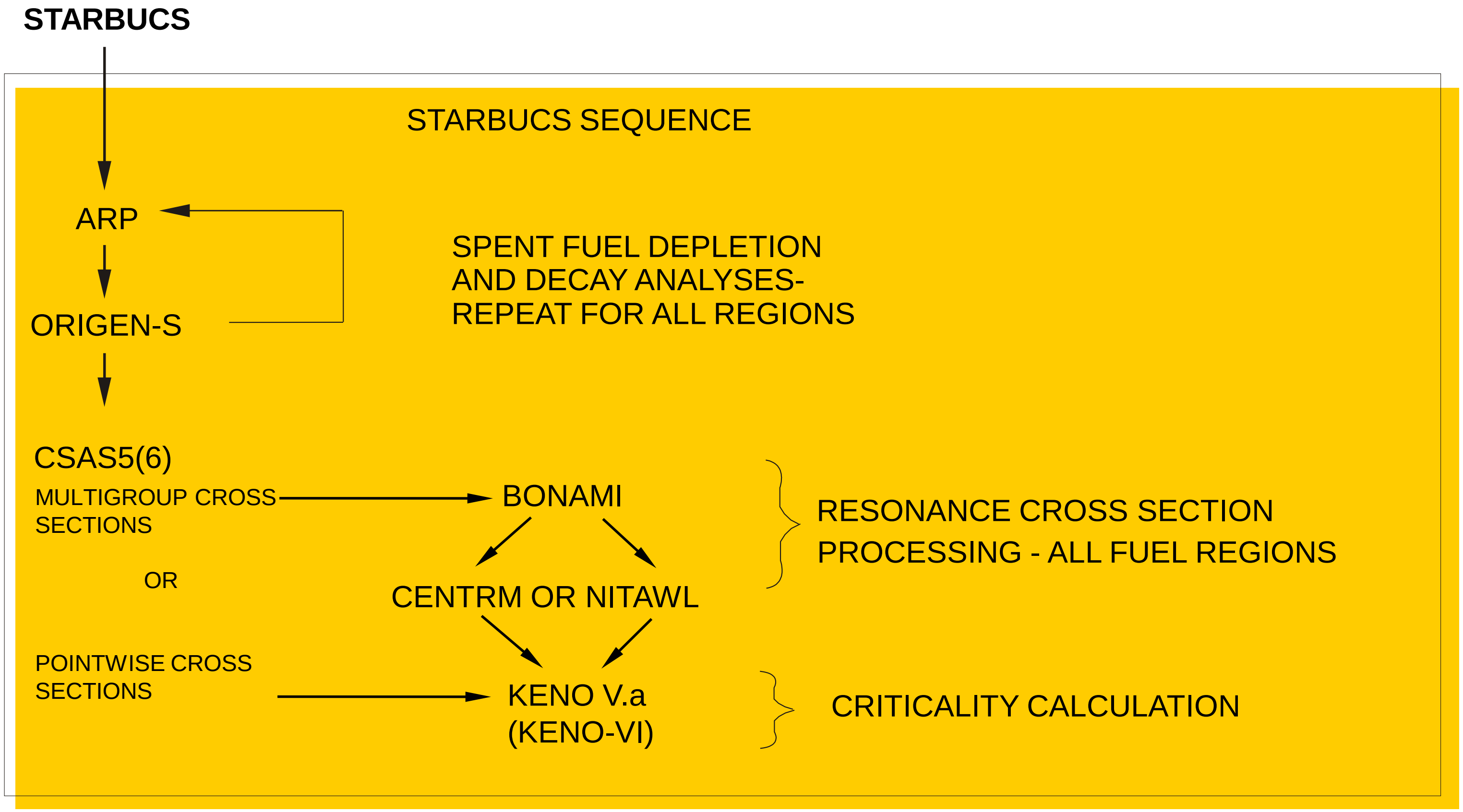
- Perform integrated depletion analysis, cross-section processing, and Monte Carlo criticality calculations for a 3-D system
- Uses existing, well-established modules in the SCALE code system (e.g., ORIGEN-ARP, CSAS, KENO V.a or KENO VI)
  - Use ENDF/B-V, VI, and VII cross-section libraries
  - Use pre-generated parameterized ORIGEN-ARP cross-section libraries for rapid depletion calculations
  - Many 3-D configurations may be analyzed







STARBUCS Analysis Sequence



Input Options

- **Allow user-defined representation of**
  - **Irradiation history detail**
  - **Cooling time**
  - **Nuclides included in burnup credit calculation**
  - **Axial and radial variation of burnup within a fuel assembly**
  - **Isotopic composition bias/uncertainties**

ORIGEN-ARP Depletion Libraries

- **ORIGEN-ARP libraries for a variety of PWR and BWR UO_2 fuel assemblies are distributed with SCALE**
- **Users may create problem-specific ORIGEN-ARP libraries using the TRITON depletion sequence in SCALE for other configurations/conditions**
- **STARBUCS currently limited to one fuel type**

Distributed Reactor and Assembly Libraries

Reactor Type*	Assembly Design Description
PWR LEU* 1.5 – 6.0 wt% 72 GWd/t	Combustion Engineering 14x14
	Combustion Engineering 16x16
	Westinghouse 14x14
	Siemens 14x14
	Westinghouse 15x15
	Westinghouse 17x17
	Westinghouse 17x17 OFA
BWR LEU* 1.5 – 6.0 wt% 72 GWd/t	GE 7x7
	GE 8x8
	ABB 8x8
	GE 9x9
	GE 10x10
	ATRIUM-9 9x9
	ATRIUM-10 10x10
	SVEA-64 8x8
	SVEA-100 10x10

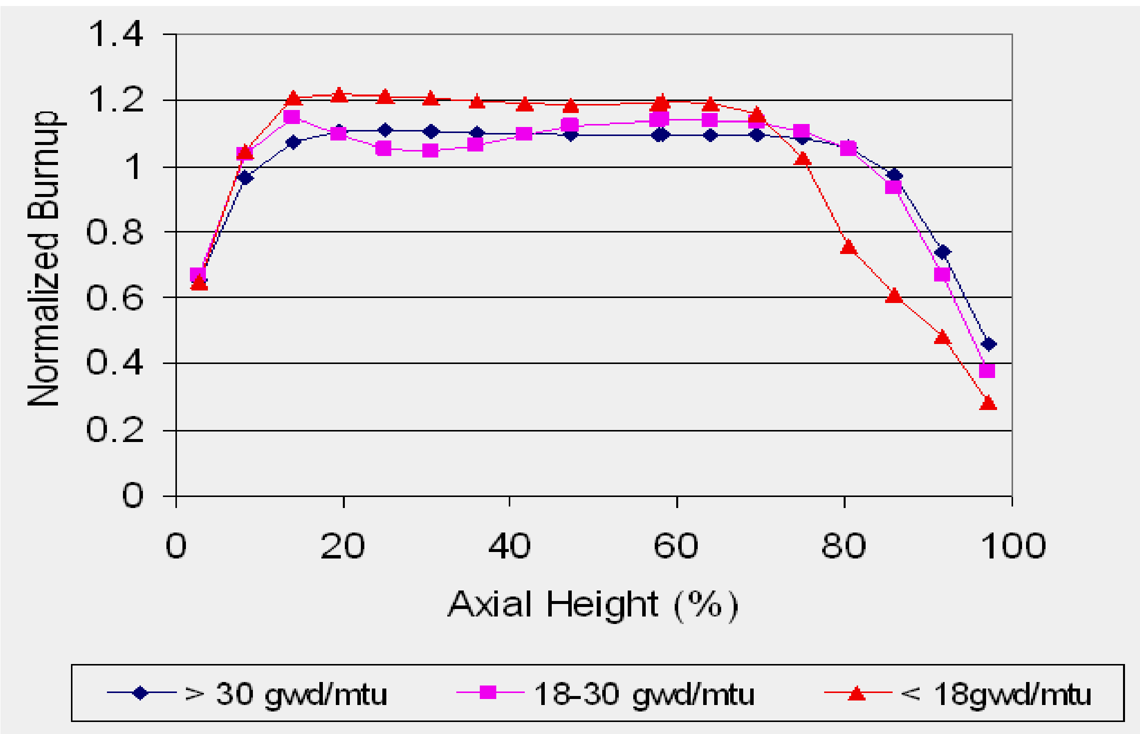
VVER LEU	VVER-440 1.6%, 2.4%, 3.6%
	VVER-440 3.82%
	VVER-440 4.25%
	VVER-440 4.38%
	VVER-1000
CANDU	CANDU 37 element nat uranium
	CANDU 28 element nat uranium
MAGNOX	Natural uranium
AGR	LEU
RBMK	1.8 – 2.2 wt%
PWR MOX	14x14
	15x15
	16x16
	17x17
	18x18
BWR MOX	8x8-2
	9x9-1
	9x9 ATRIUM-9
	10x10 ATRIUM-10

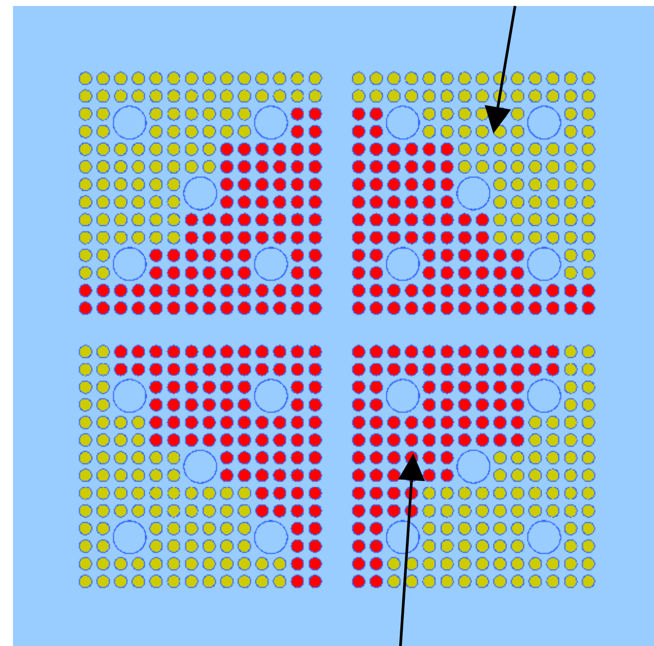
Selection of Burnup Credit Nuclides

- **Actinides and fission product nuclides relevant to burnup credit**
- **All actinide and fission product nuclides available from ORIGEN with cross sections available to KENO**
  - **May be used to evaluate the influence of non-credited nuclides**

Representation of Axial and Radial Burnup Variations within a Fuel Assembly

- **Uniform burnup**
- **Axial (≤ 100 zones) and radial (≤ 7 zones) burnup variations**
  - **Built-in 18-zone axial burnup profiles that adequately bound an axial-burnup profile database (demonstrated in NUREG/CR-6801)**





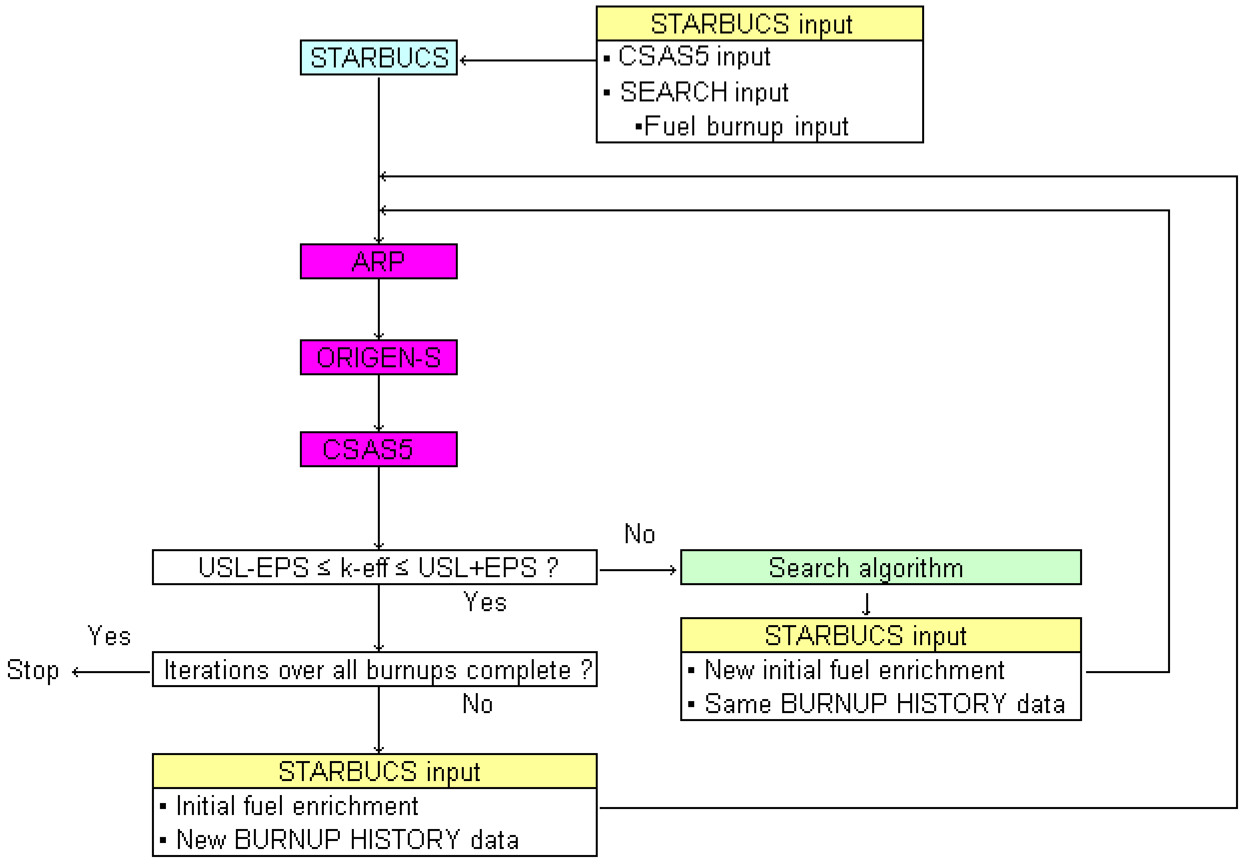
Isotopic Composition Bias and Bias Uncertainty

- **STARBUCS will apply user-supplied isotopic correction factors to conservatively account for isotopic composition bias and/or uncertainty associated with the bias**
- **Alternatively, the uncertainty may be included in the upper subcritical limit defined by user**

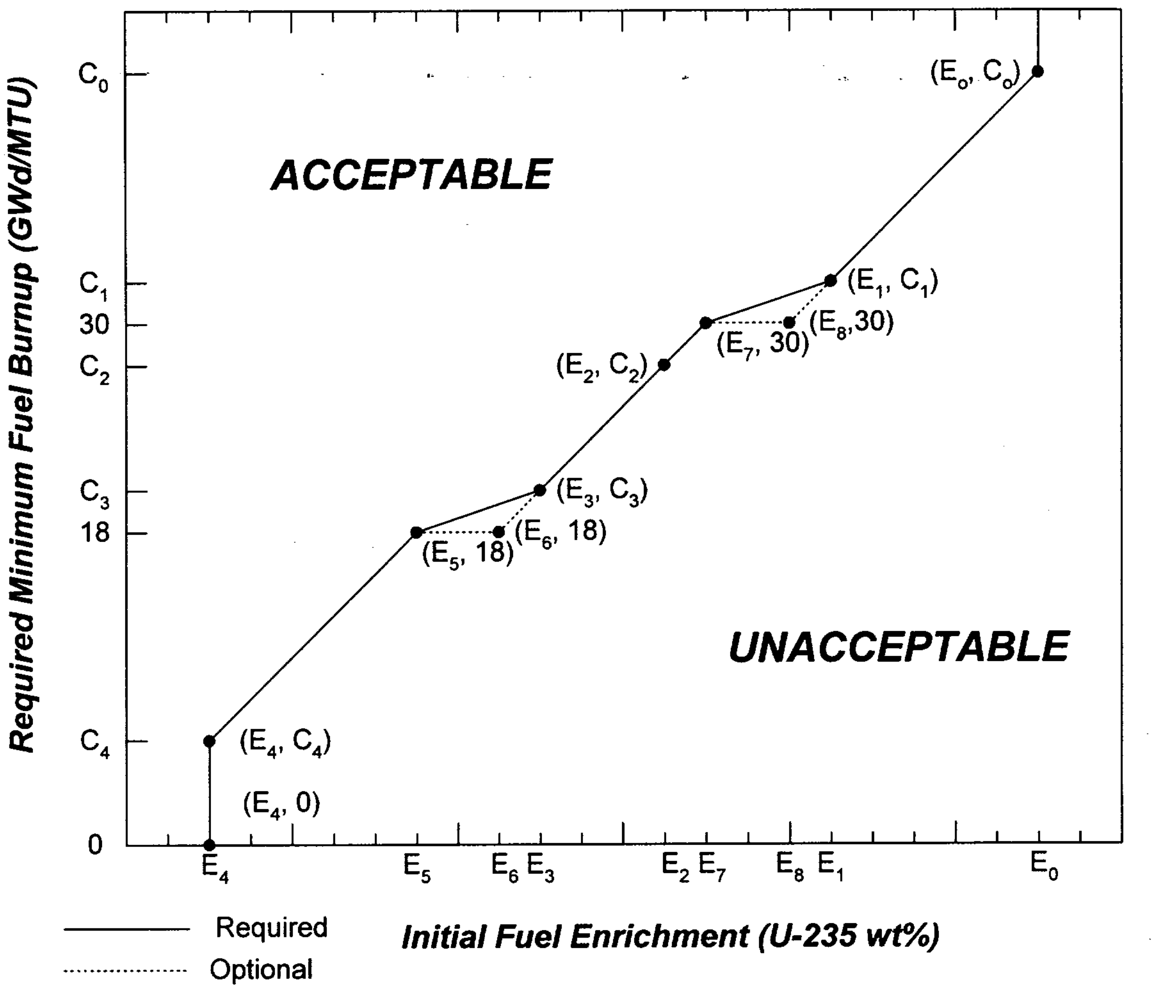
New STARBUCS Capability in SCALE 6: Generation of Burnup Loading Curves

- **STARBUCS performs iterative calculations to determine fuel enrichment and burnup combinations that result in a user-supplied upper subcritical limit (USL) (within a user-defined tolerance margin)**
- **For each user-supplied burnup value, STARBUCS performs a least-squares analysis of the results to determine an initial fuel enrichment value that will yield the USL value**
- **Between 2 and 6 iterations are necessary to achieve convergence for each user-supplied burnup value**
- **Input options**
  - **Maximum 100 input burnup values**
  - **Maximum 10 iterations for each burnup value**
  - **Reduced output**

STARBUCS Burnup Loading Curve Sequence



Loading Curve Generation

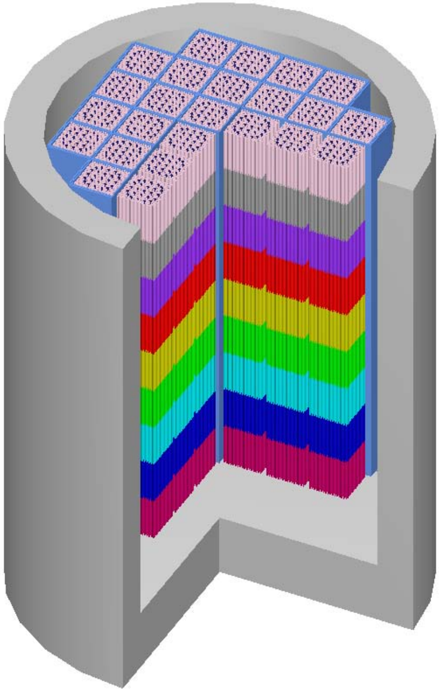


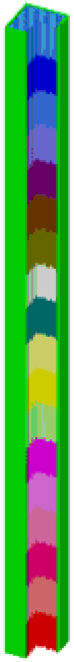
Output Summary Table

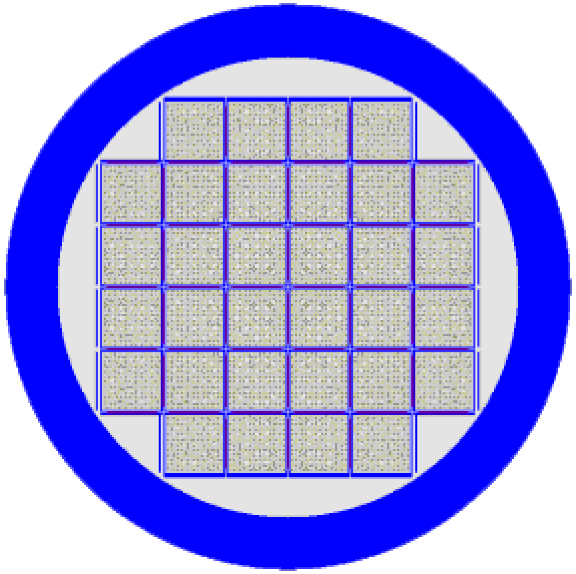
```
pass  1, param  10.00 converged in  5 iterations,   enrichment  2.5648,      k-effective=  0.95321E+00 + or -  0.63149E-03
pass  2, param  15.00 converged in  5 iterations,   enrichment  2.7806,      k-effective=  0.95061E+00 + or -  0.61577E-03
pass  3, param  17.90 converged in  5 iterations,   enrichment  2.9066,      k-effective=  0.94924E+00 + or -  0.64648E-03
pass  4, param  18.10 converged in  5 iterations,   enrichment  3.2851,      k-effective=  0.95115E+00 + or -  0.62479E-03
pass  5, param  20.00 converged in  5 iterations,   enrichment  3.3900,      k-effective=  0.95019E+00 + or -  0.63385E-03
pass  6, param  25.00 converged in  4 iterations,   enrichment  3.7857,      k-effective=  0.95450E+00 + or -  0.65149E-03
pass  7, param  29.90 converged in  1 iterations,   enrichment  4.0001,      k-effective=  0.94603E+00 + or -  0.64125E-03
pass  8, param  30.10 converged in  3 iterations,   enrichment  4.2943,      k-effective=  0.95340E+00 + or -  0.62224E-03
pass  9, param  35.00 converged in  3 iterations,   enrichment  4.6674,      k-effective=  0.95187E+00 + or -  0.63865E-03
pass 10, param  40.00 converged in  3 iterations,   enrichment  5.0358,      k-effective=  0.95291E+00 + or -  0.62495E-03
pass 11, param  45.00 converged in  2 iterations,   enrichment  5.3000,      k-effective=  0.94542E+00 + or -  0.60287E-03

convergence was achieved on pass  5  the parameter was   2.56392E+00
                  the equation used in the search was:
                  k-eff = +4.07096E-01 +3.68068E-01*p -7.88751E-02*p**2 +7.06853E-03*p**3
                  k-effective=  9.51429E-01 + or -  4.44742E-04
```

STARBUCS Application Examples

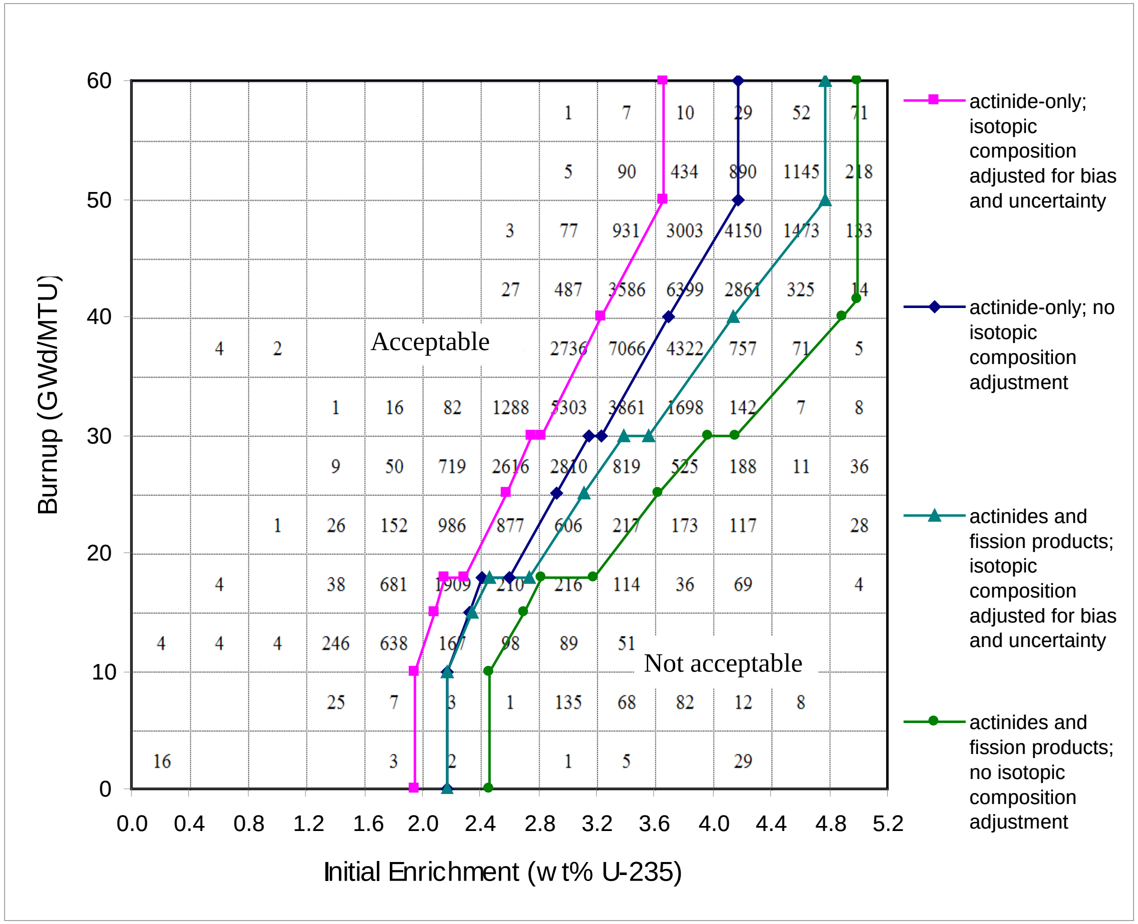
- Evaluation of the effects of various model assumptions on burnup loading curves for a generic cask





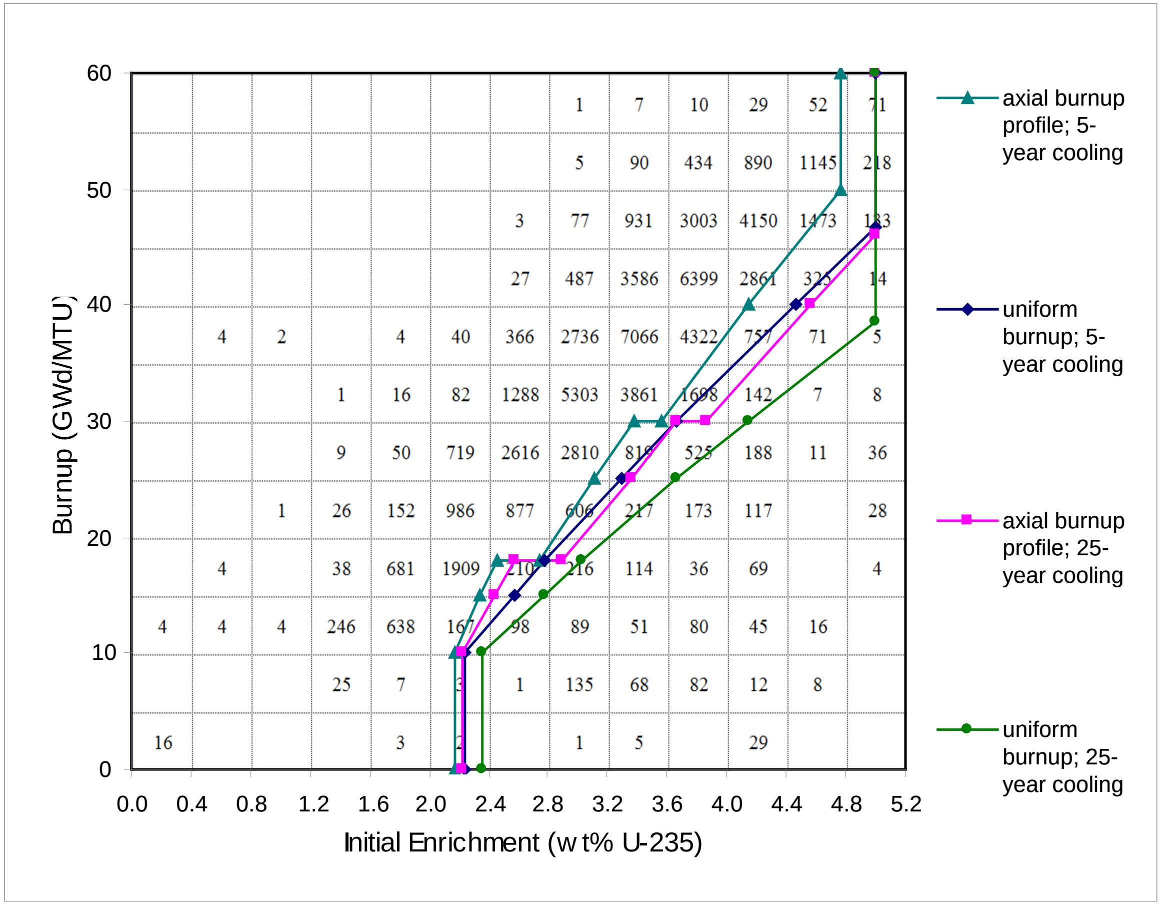


Impact of Credited Nuclides and Isotopic Composition Uncertainty on Burnup Loading Curves

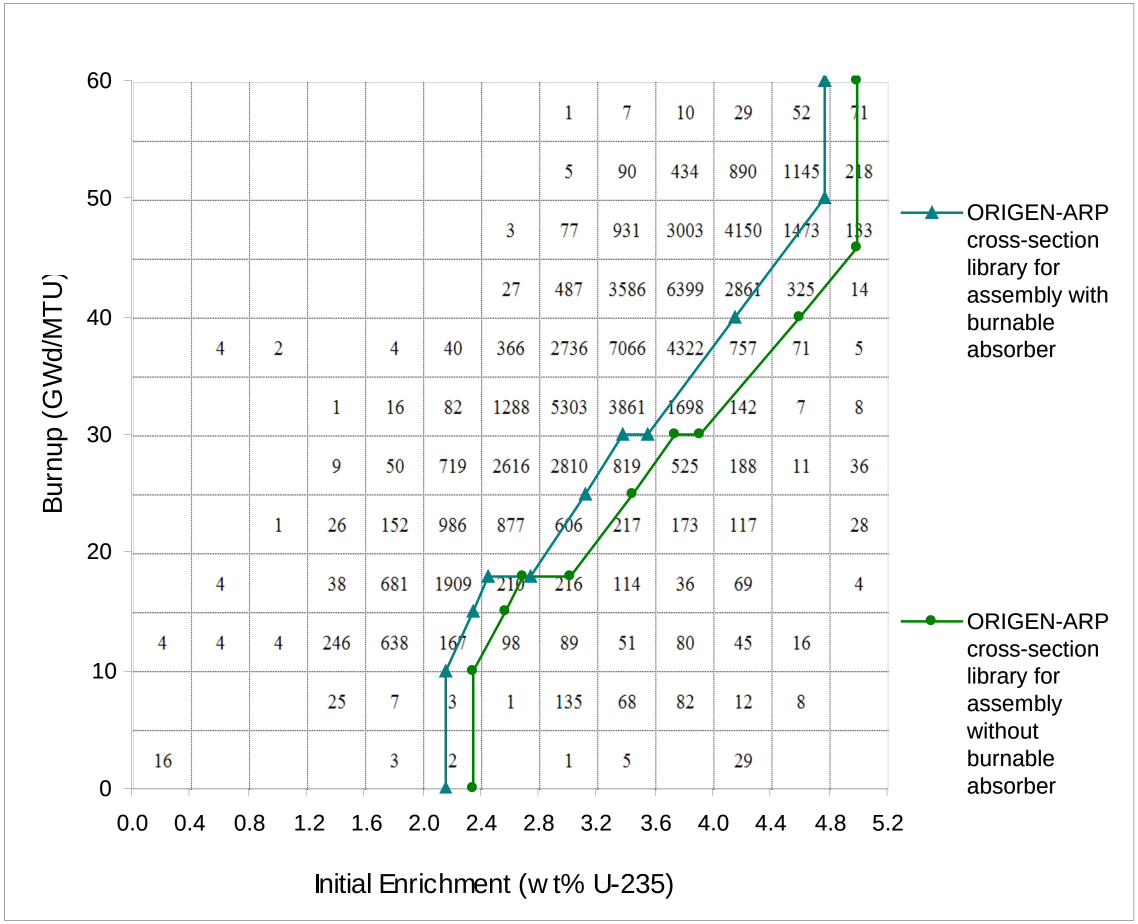


Note: Loading curves were superimposed on a chart showing spent fuel inventory permanently discharged from U.S. commercial power reactors as of 2002.

Impact of Burnup Axial Variation and Decay Time on Burnup Loading Curves



Impact of Irradiation Conditions on Burnup Loading Curves



New STARBUCS Capability in SCALE 6: Continuous Energy Cross-section Libraries

- **Continuous-Energy KENO (CE KENO)**
- **Simplifies input data and eliminates the need for resonance cross-section processing**
- **Reduces the total computer time for some problems**

Comparison of STARBUCS Computer Time Using SCALE Multi-group and Continuous Energy Cross-section Libraries

		Computer time [a] (minutes)		k_{eff} [b]	
		SCALE ENDF/B-VI library			
Case No.	**Model description**	**238 g [c]**	**CE [d]**	**238 g [c]**	**CE [d]**
1	**Infinite pin-cell model with uniform axial burnup; actinide only**	**1.5**	**4**	**1.1795**	**1.1863**
2	**Infinite pin-cell model with 18 burnup-dependent axial zones; actinide only**	**23.1**	**6**	**1.1033**	**1.1043**
3	**2 8 array of CE 14 14 assemblies; 18 burnup-dependent axial zones; 29 actinide + fission product nuclides**	**31.6**	**17.3**	**0.8724**	**0.8723**
4	**2 2 array of CE 14 14 assemblies; 18 burnup-dependent axial zones; 2 burnup-dependent radial zones; 29 actinide + fission product nuclides**	**64.5**	**14.7**	**0.7529**	**0.7545**

[a] CSAS5 computer time.
[b] k_{eff} relative standard deviation is approximately 0.1%.
[c] SCALE 238-group library based on ENDF/B–VI, resonance cross-section processing using BONAMI and CENTRM.
[d] SCALE continuous cross-section library based on ENDF/B–VI.

Conclusions

- **STARBUCS features and input options**
  - **Support SCALE criticality safety analyses employing burnup credit**
  - **Enable simulation of many important burnup credit phenomena**
  - **Enable evaluation of the impact of various licensing-basis model assumptions on criticality safety of spent fuel casks**
  - **Depletion libraries may be generated by the user for plant specific operating assumptions and conditions**
  - **Facilitate determination of loading curves**