Radioxenon Emission Estimates for Molten Salt Reactors

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Workshop on Sources of Man-made Isotope Production
June 2020
WOSMIP Remote

Nuclear Energy System Development Timeline

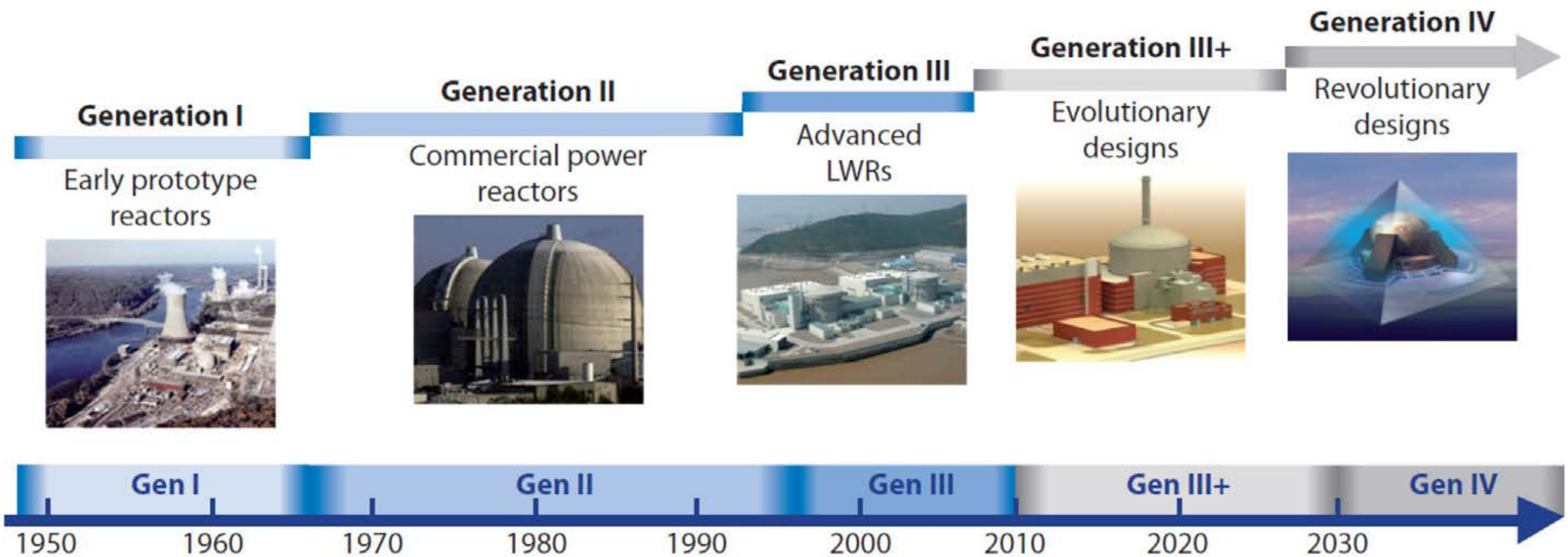
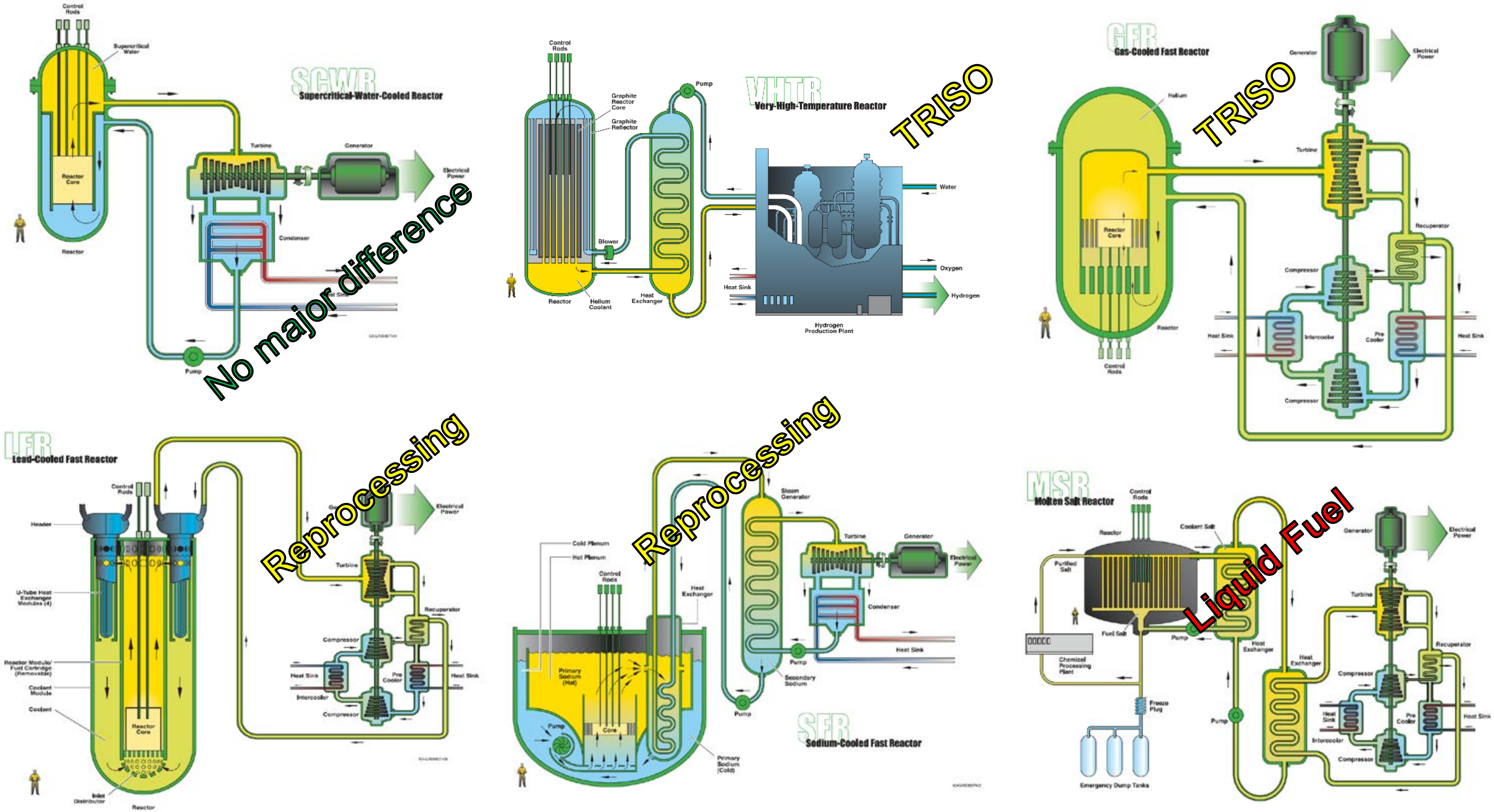


Image Credit:
Technology Roadmap Update for Generation IV Nuclear Energy Systems. Issued by the OECD Nuclear Energy Agency for the Generation IV International Forum. (Jan 2014)

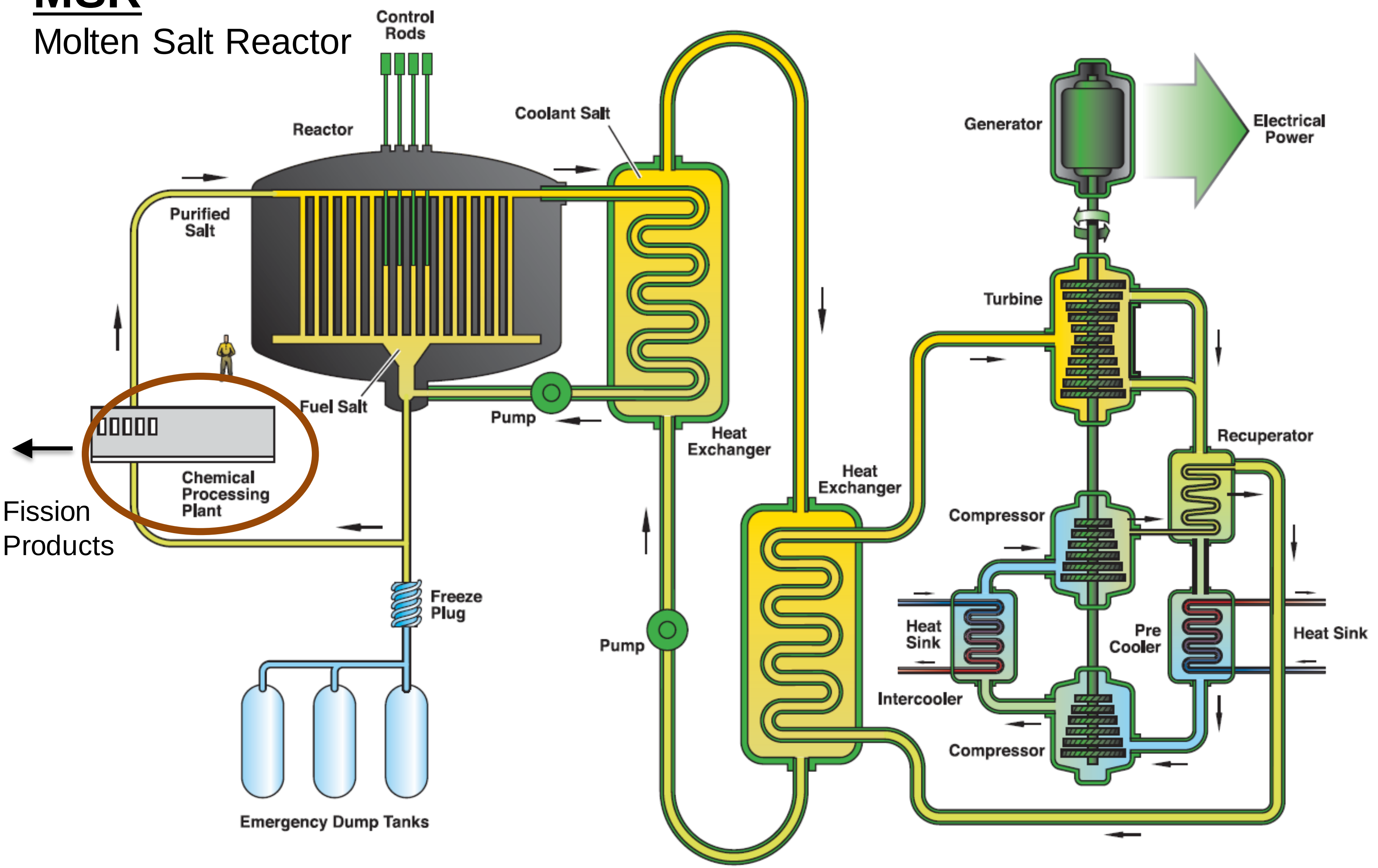
Generation IV Reactor Design Groups



<u>Image Credit:</u>
A Technology Roadmap for Generation IV Nuclear Energy Systems. Issued by the US DOE Nuclear Energy Advisory Committee and the Generation IV International Forum. (Dec 2002)

MSR

Molten Salt Reactor



$$P = \frac{E}{t} \qquad 100\text{ MW} = 6.2 \times 10^{20}\,\frac{MeV}{s} = 2.7 \times 10^{23}\,\frac{fissions}{d}$$

Assume Cumulative Fission Yield for Xe-133 = 5%

$$2.7 \times 10^{23}\,\frac{fissions}{d} = 1.3 \times 10^{22}\,\frac{atoms}{d} = \boxed{2.2 \times 10^{16}\,\frac{Bq}{d}}$$

per 100 MW

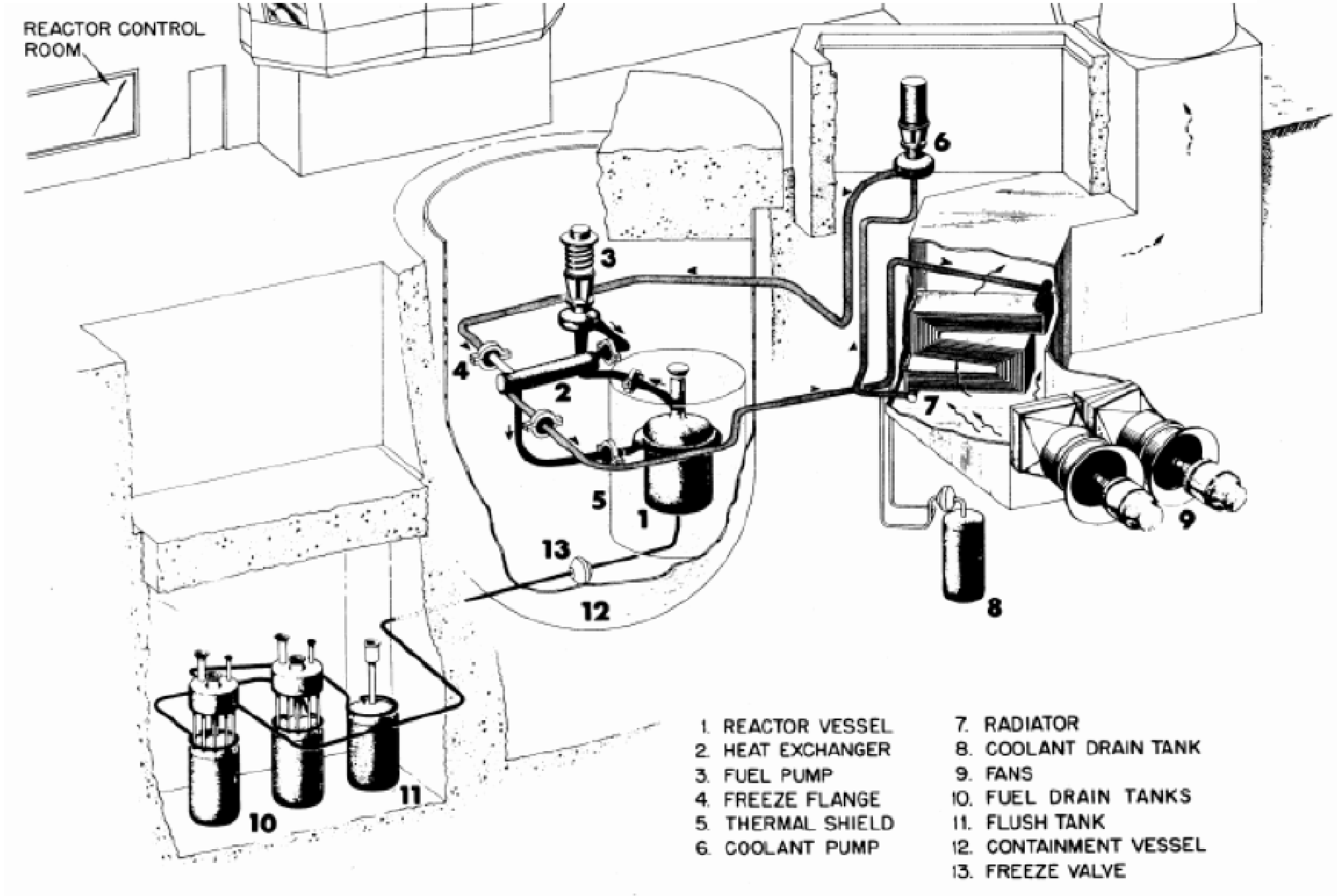
Emissions could be 10^{-6}-100% of inventory depending on retention tech

Molten Salt Research Experiment

1960's US Department of Energy project

Max 10 MWth reactor

Radioxenon release limits of <2.5x10^{14} Bq/day



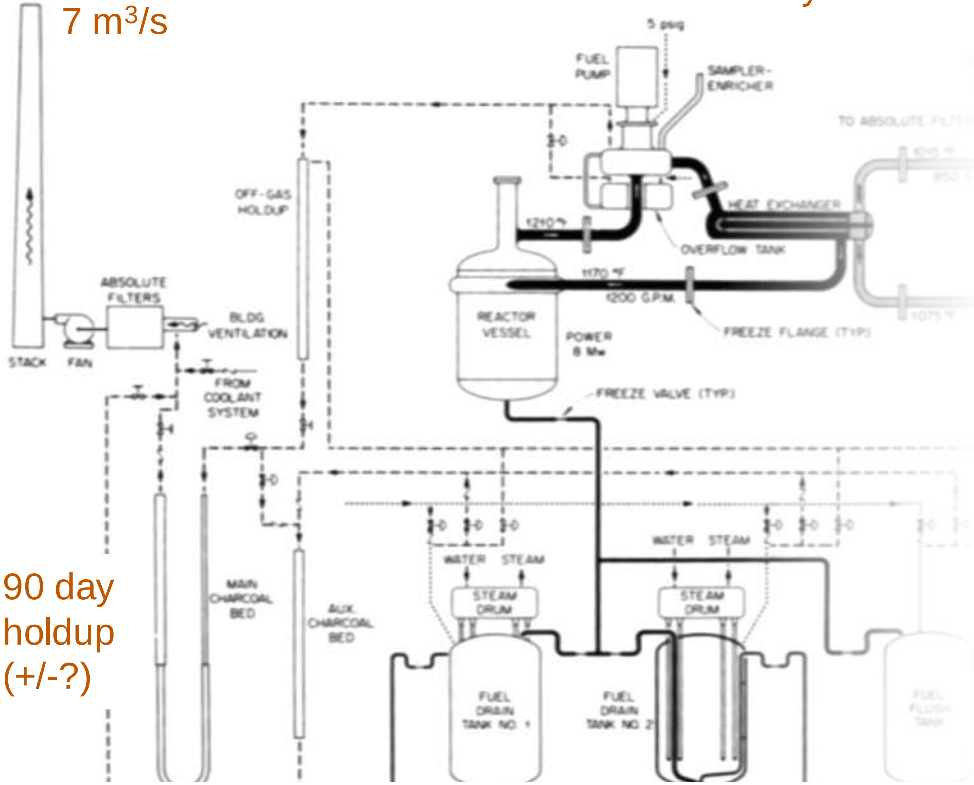
Haubenreich, P. N., & Engel, J. R. (1970). Experience with the Molten-Salt Reactor Experiment. Nuclear Applications & Technology, 8.

ORIGEN 2 Model of MSRE

38% NG removal/cycle

7 m³/s

90 day holdup (+/-?)

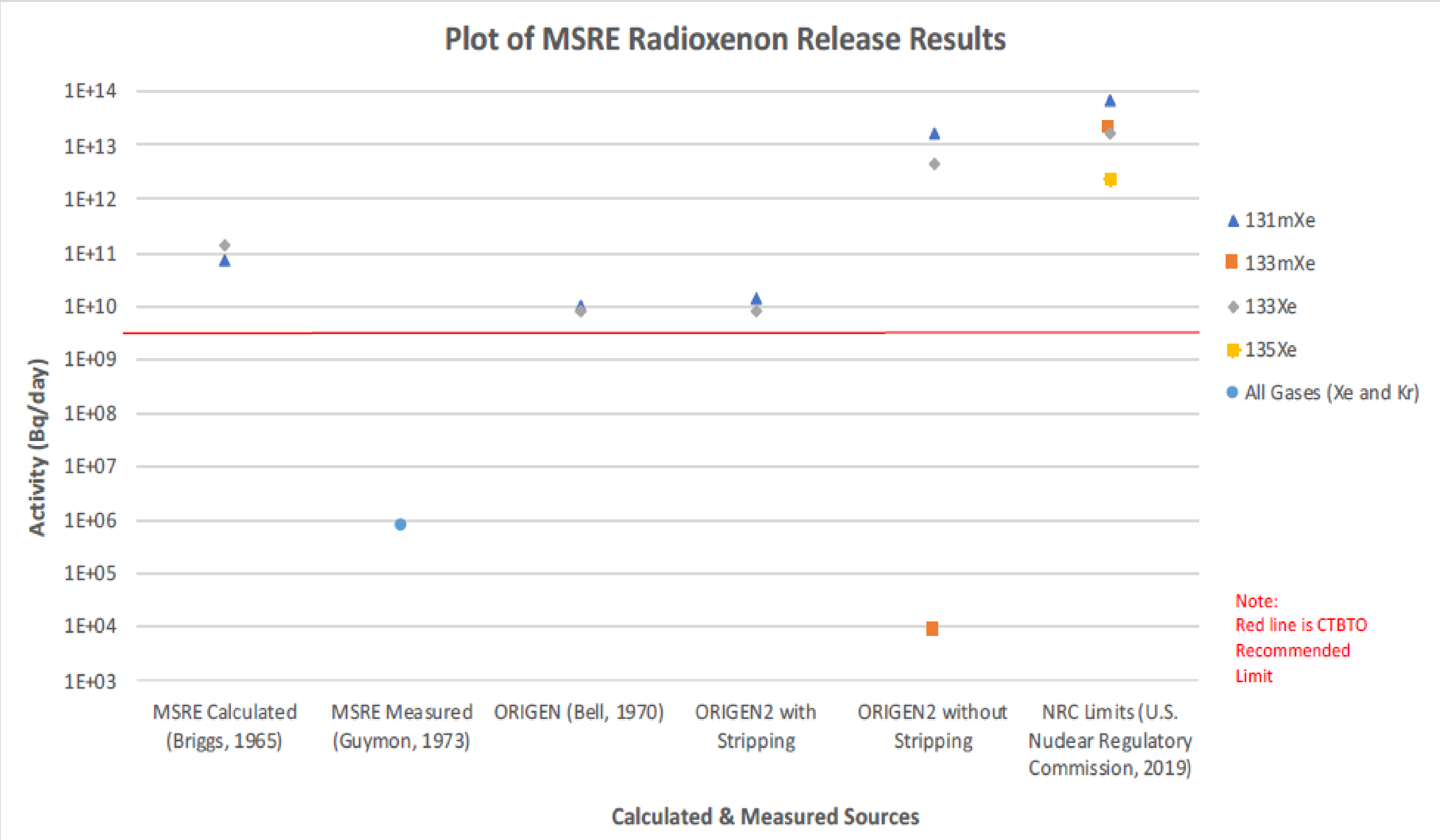


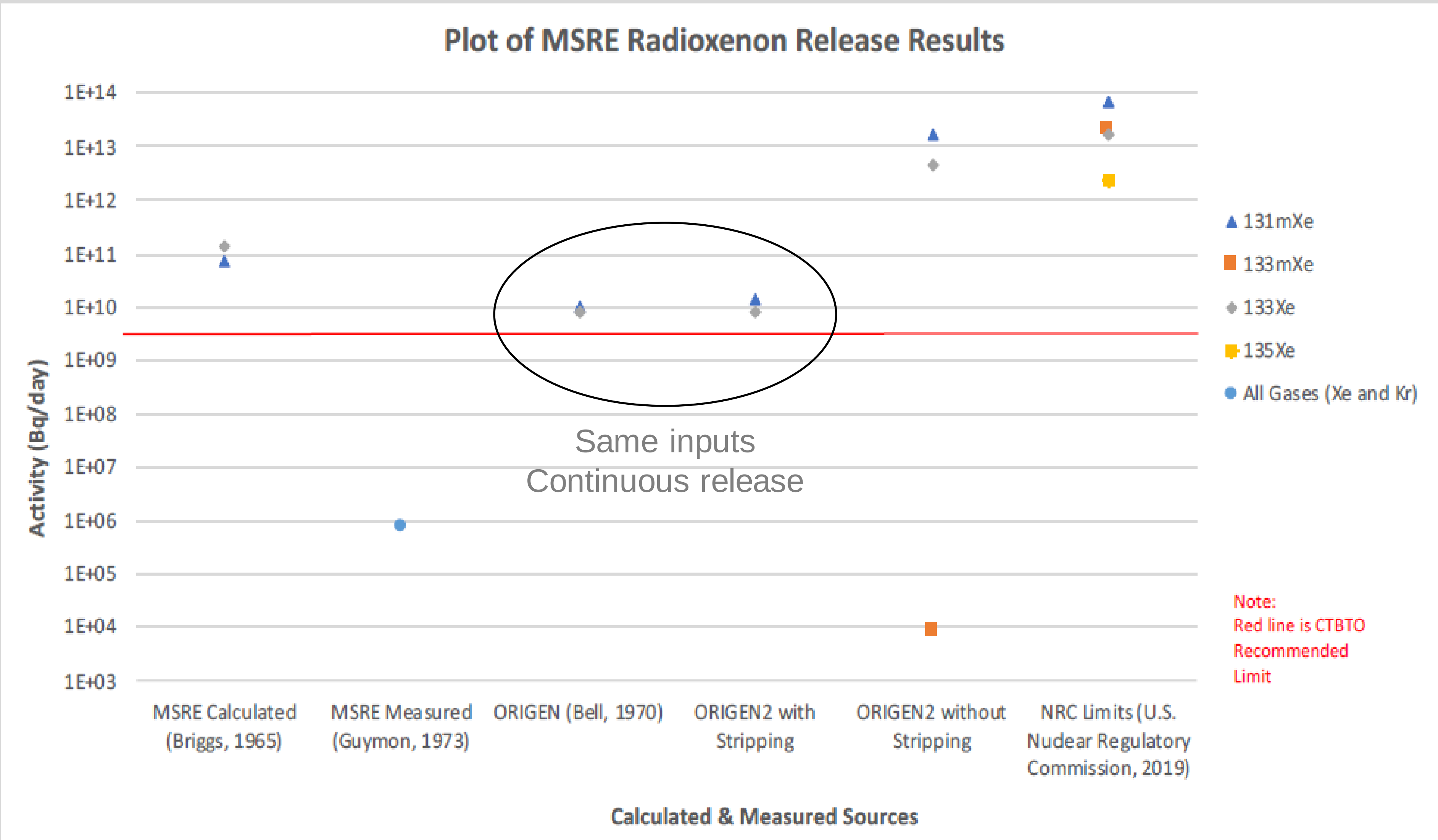
Haubenreich, P. N., & Engel, J. R. (1970). Experience with the Molten-Salt Reactor Experiment. Nuclear Applications & Technology, 8.

Goal 1: Confirm Bell's calculations from 1970⁺

Goal 2: Develop a starting point to evaluate other abatement systems

+ Bell, M. J. (1970). CALCULATED RADIOACTIVITY OF MSRE FUEL SALT (ORNLTM-2970 United States 10.2172/4138373 Dep. CFSTI. ORNL English).


Plot of MSRE Radioxenon Release Results
Activity (Bq/day)
1E+14
1E+13
1E+12
1E+11
1E+10
1E+09
1E+08
1E+07
1E+06
1E+05
1E+04
1E+03
MSRE Calculated (Briggs, 1965)
MSRE Measured (Guymon, 1973)
ORIGEN (Bell, 1970)
ORIGEN2 with Stripping
ORIGEN2 without Stripping
NRC Limits (U.S. Nuclear Regulatory Commission, 2019)
Calculated & Measured Sources
131mXe
133mXe
133Xe
135Xe
All Gases (Xe and Kr)
Note:
Red line is CTBTO Recommended Limit


Plot of MSRE Radioxenon Release Results
1E+14
1E+13
1E+12
1E+11
1E+10
1E+09
1E+08
1E+07
1E+06
1E+05
1E+04
1E+03
Activity (Bq/day)
Same inputs
Continuous release
MSRE Calculated (Briggs, 1965)
MSRE Measured (Guymon, 1973)
ORIGEN (Bell, 1970)
ORIGEN2 with Stripping
ORIGEN2 without Stripping
NRC Limits (U.S. Nuclear Regulatory Commission, 2019)
Calculated & Measured Sources
131mXe
133mXe
133Xe
135Xe
All Gases (Xe and Kr)
Note:
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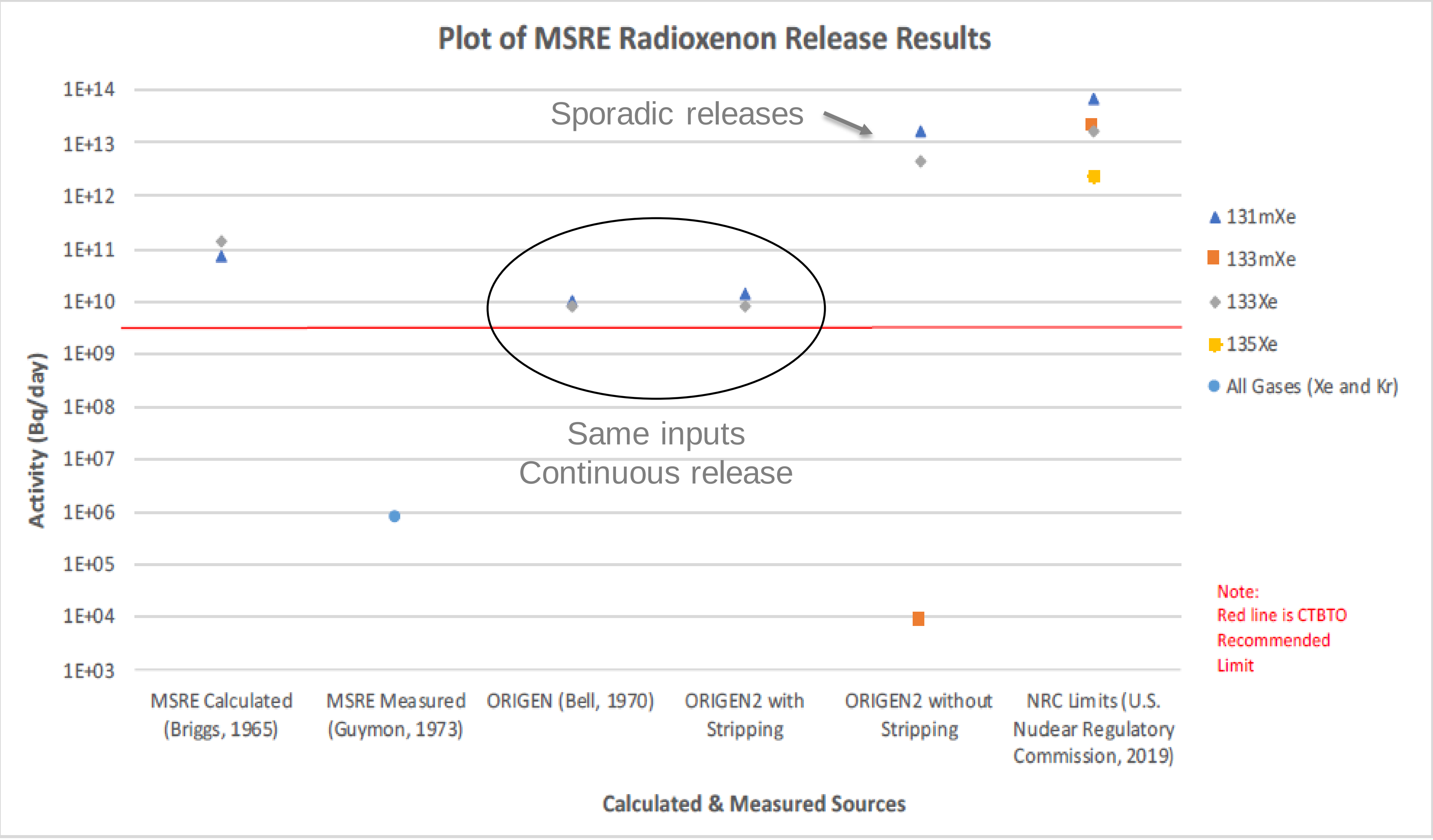
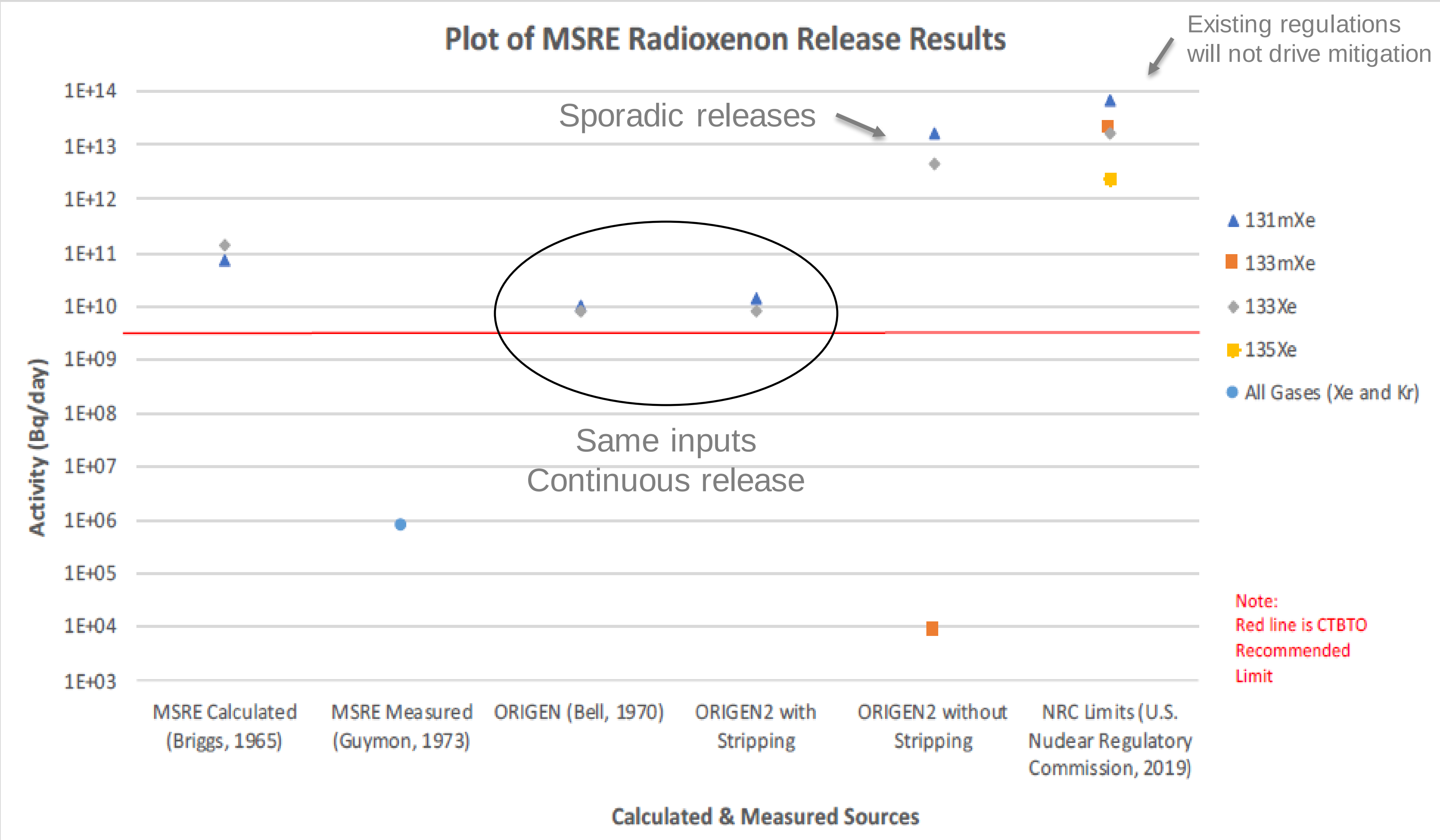
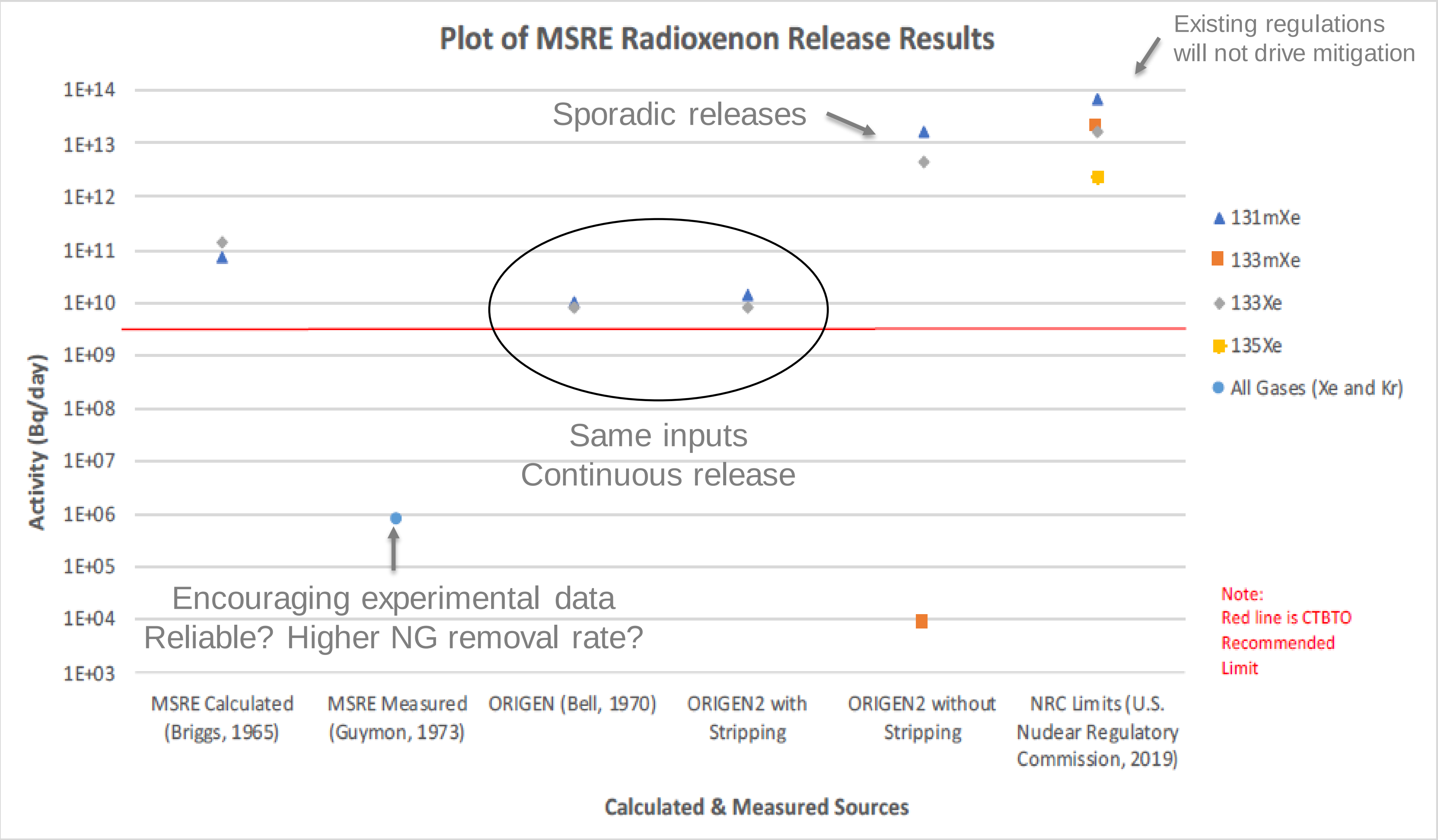

Plot of MSRE Radioxenon Release Results
Sporadic releases
Same inputs
Continuous release
1E+14
1E+13
1E+12
1E+11
1E+10
1E+09
1E+08
1E+07
1E+06
1E+05
1E+04
1E+03
Activity (Bq/day)
MSRE Calculated (Briggs, 1965)
MSRE Measured (Guymon, 1973)
ORIGEN (Bell, 1970)
ORIGEN2 with Stripping
ORIGEN2 without Stripping
NRC Limits (U.S. Nuclear Regulatory Commission, 2019)
Calculated & Measured Sources
131mXe
133mXe
133Xe
135Xe
All Gases (Xe and Kr)
Note:
Red line is CTBTO Recommended Limit


Plot of MSRE Radioxenon Release Results
Existing regulations will not drive mitigation
Sporadic releases
Same inputs
Continuous release
Activity (Bq/day)
1E+14
1E+13
1E+12
1E+11
1E+10
1E+09
1E+08
1E+07
1E+06
1E+05
1E+04
1E+03
MSRE Calculated (Briggs, 1965)
MSRE Measured (Guymon, 1973)
ORIGEN (Bell, 1970)
ORIGEN2 with Stripping
ORIGEN2 without Stripping
NRC Limits (U.S. Nuclear Regulatory Commission, 2019)
Calculated & Measured Sources
131mXe
133mXe
133Xe
135Xe
All Gases (Xe and Kr)
Note:
Red line is CTBTO Recommended Limit


Plot of MSRE Radioxenon Release Results
Existing regulations will not drive mitigation
Sporadic releases
Same inputs
Continuous release
Encouraging experimental data
Reliable? Higher NG removal rate?
Activity (Bq/day)
1E+14
1E+13
1E+12
1E+11
1E+10
1E+09
1E+08
1E+07
1E+06
1E+05
1E+04
1E+03
MSRE Calculated (Briggs, 1965)
MSRE Measured (Guymon, 1973)
ORIGEN (Bell, 1970)
ORIGEN2 with Stripping
ORIGEN2 without Stripping
NRC Limits (U.S. Nuclear Regulatory Commission, 2019)
Calculated & Measured Sources
131mXe
133mXe
133Xe
135Xe
All Gases (Xe and Kr)
Note:
Red line is CTBTO Recommended Limit

Conclusions

1. Continuous, efficient noble gas removal from fuel can significantly reduce daily emission values.

2. Sealed molten salt systems will be a source of large, sporadic releases of radioxenon when reactor fuel lines are disconnected.

3. More modeling and new experiments are needed to guide reactor subsystem designs to minimize emissions.

Promising Developments

Identification of Potential Waste Processing and Waste Form Options for Molten Salt Reactors

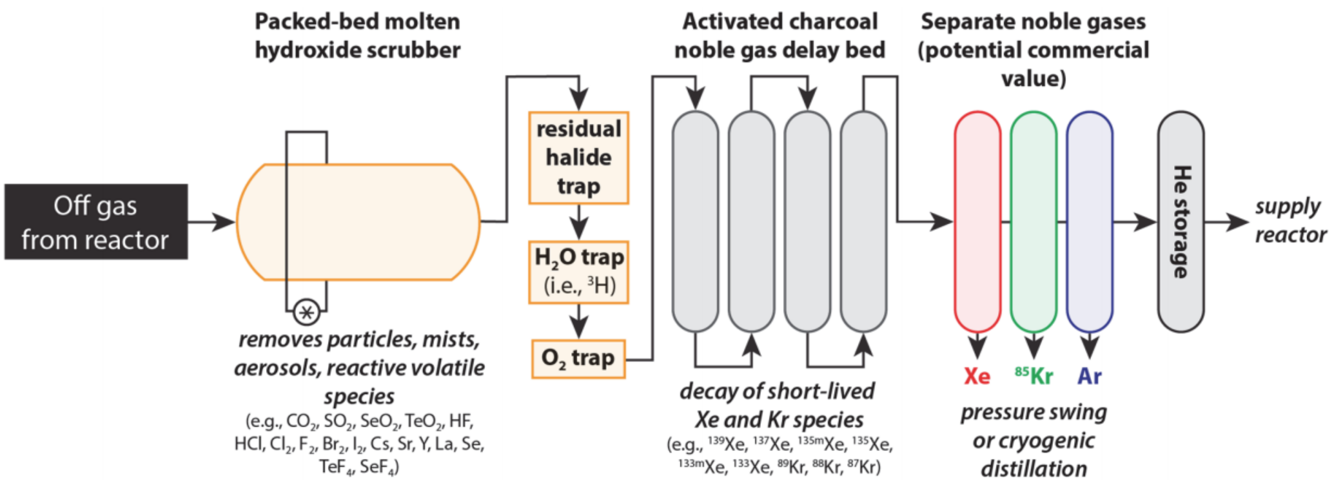


Figure 3-5. Schematic of the overall off-gas system for a commercial MSR based on the MSRE experience. All of the components shown, except the molten hydroxide packed-bed scrubber, are commercially available.

Prepared for
U.S. Department of Energy
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