Modeling the Physical Processes that Impact the Fate and Fallout of Radioactive Materials

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Overview

Topics for Discussion

- Emergency response guidance
- Estimation of source terms starting with the reactor core
- Atmospheric processes related to transport, dispersion, and deposition of reactor effluents
- Uncertainty in measurements and modeling

Emergency Response Guidance (US Model)

- Fukushima Type Event
- Earthquake → Reactor Shutdown
  - Declare an Unusual Event or Alert within 15 minutes
- Earthquake → Reactor Shutdown + Loss of Offsite Power
  - Declare a Site Area Emergency within 15 minutes, consider possible end states and do initial consequence assessment in next 15 minutes including protective action recommendations.
  - LOCA is possible end state
- Tsunami → Loss of Emergency Generators
  - Declare a General Emergency and update consequence assessment and protective action recommendations within 15 minutes
  - LOCA end state is likely
- Release starts when core becomes uncovered and increases as core damage occurs and barriers to release are breached.

When Do We Need a Source Term Estimate?

- ***A source term is needed before the first consequence assessment is required!***
- ***And, the source term needs to be reasonable***

Source Term Definition

- Core inventory
- Nuclides of interest
  - Inhalation, external radiation, ingestion
  - Time of interest (e.g. 1 week, 1 year, 50 years)
- Release rates
- Release configuration
  - Release height (ground level or elevated)
  - Point or area source
- Release duration

Reactor Information

	Fukushima	US Surrogate		Fukushima	US Surrogate
	Unit 1	Duane Arnold		Unit 2, 3	Cooper
Design	GE 3/ Mark I	GE 4/Mark I		GE 4/ Mark I	GE 4//Mark I
Construction/Operation	9/1967 3/1971	6/1970 3/1974		5/1969 7/1974	6/1968 7/1974
Power (MWt)	1380	1658		2381	2381
Fuel Assem.	400	368		548	548
Uranium (MT)	69	67.4		94	101.2

Reactor Core Inventory At Shutdown (Bq)

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				Total
	Unit 1	Unit 2	Unit 3	Units 1-3
Cs-134	5.6E+17	7.6E+17	7.5E+17	2.1E+18
Cs-137*	3.6E+17	4.9E+17	4.7E+17	1.3E+18
I-131	1.5E+18	2.0E+18	2.0E+18	5.6E+18
Cs-136	1.4E+17	1.9E+17	1.8E+17	5.2E+17
Ba-140	2.7E+18	3.7E+18	3.7E+18	1.0E+19
Sr-89	1.4E+18	1.9E+18	2.0E+18	5.3E+18
Zr-95	2.6E+18	3.6E+18	3.6E+18	9.7E+18
Nb-95	2.6E+18	3.6E+18	3.6E+18	9.8E+18
Ru-103	2.4E+18	3.3E+18	3.2E+18	8.9E+18
Ru-106*	1.0E+18	1.4E+18	1.4E+18	3.8E+18
Last Startup	9/27/2010	9/23/2010	11/18/2010	

Release Fractions

- Chornobyl
  - 20% to 50% of Iodines
  - 12% to 30% of Cesiums
  - 3% to 4% of less volatile radionuclides (Sr, Zr, Ce, Ru)
- Fukushima
  - Significantly less than Chornobyl
- I-131
  - < 3% of I-131 (Inoue 2012)
  - 1.3×10^{17} Bq (NSC); 1.6×10^{17} Bq (NISA)
  - ~3% to ~10% of core inventory (SOARCA for Peach Bottom 2012)
  - 2% of I-131 inventory from previous slide = 1.1×10^{17} Bq
- Cs-137
  - < 2% of Cs-134 and Cs-137 (Inoue 2012)
  - 1.1×10^{16} Bq (NSC); 1.5×10^{16} Bq (NISA)
  - ~2% to ~3% of core inventory (SOARCA for Peach Bottom 2012)
  - 2% of Cs-137 inventory from previous slide = 1.3×10^{16} Bq

Relative Importance to Ground Shine Dose 30 Days After Shutdown

	SBGT Release		Bypass Release	
1	Cs-134	61.423%	Cs-134	62.239%
2	Cs-137*	16.030%	Cs-137*	16.285%
3	I-131	5.695%	I-131	6.312%
4	Cs-136	4.960%	Cs-136	5.277%
5	Ba-140	3.623%	Ba-140	3.011%
6	Sr-89	2.278%	Sr-89	1.847%
7	Zr-95	2.146%	Zr-95	1.631%
8	Nb-95	1.765%	Nb-95	1.413%
9	Ru-103	0.851%	Ru-103	0.905%
10	Ru-106*	0.367%	Ru-106*	0.380%
	Total	99.136%		99.300%

Atmospheric Transport

- Simple
  - Straight-line model
  - Limited topography (terrain elevation) and meteorology
  - Sequence of steady state events
- Moderate complexity
  - Lagrangian puff model
  - Time varying source term
  - Time and spatially varying meteorological conditions (2d)
- Most complex
  - Particle model
  - Time varying source term
  - Time and spatial varying meteorological conditions (3d)

Dispersion

- Near field
  - Series of steady-state conditions
  - Local turbulence (wind speed, stability, surface roughness)
  - Downwind variable (distance or time)
- Far field
  - Wind shear
  - Changing meteorological conditions
  - Downwind variable (time)

Deposition

- Dry deposition
  - Large particles (>10 micron)
  - Small particles and gases
    - Deposition velocity
  - Iodine is mixture of particles and gases
- Wet deposition
  - Washout of particles
  - Scavenging of gases

Deposition Velocities

Deposition Velocities (m/s) for Reactive Gases and Small Particles.

	Stability Class	Wind Speed (m/s)				
		1	2	3	5	10
Reactive Gas	B	0.0037	0.0062	0.0082	0.011	0.016
	D	0.0027	0.0047	0.0064	0.0091	0.014
	F	0.0021	0.0037	0.0051	0.0073	0.011
Particles	B	0.0047	0.0064	0.0073	0.0082	0.0090
	D	0.0039	0.0056	0.0065	0.0076	0.0086
	F	0.0031	0.0048	0.0058	0.0070	0.0082

Dry Deposition Velocities (m/s) for Iodines

	Stability Class	Wind Speed (m/s)				
		1	2	3	5	10
Iodine	B	0.0023	0.0035	0.0043	0.0055	0.0072
	D	0.0018	0.0028	0.0035	0.0046	0.0063
	F	0.0014	0.0023	0.0030	0.0039	0.0055

Depletion

- Source-term depletion
  - Simple models
  - Deposited activity removed from whole plume
- Surface-depletion
  - Complex models
  - Activity deposited by dry deposition and wet deposition of gases removed from surface layer
  - Activity deposited by washout of particles removed from whole plume

Surface Processes Affecting Doses from Deposited Activity

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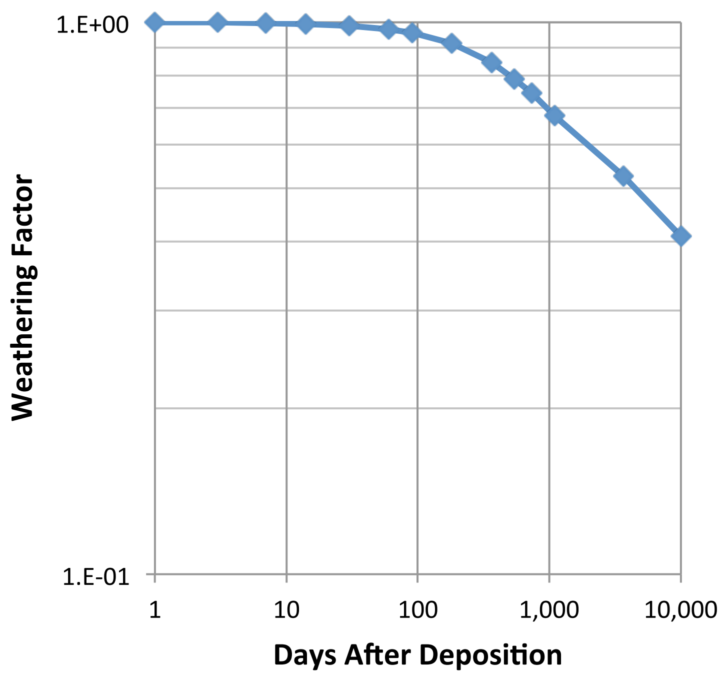
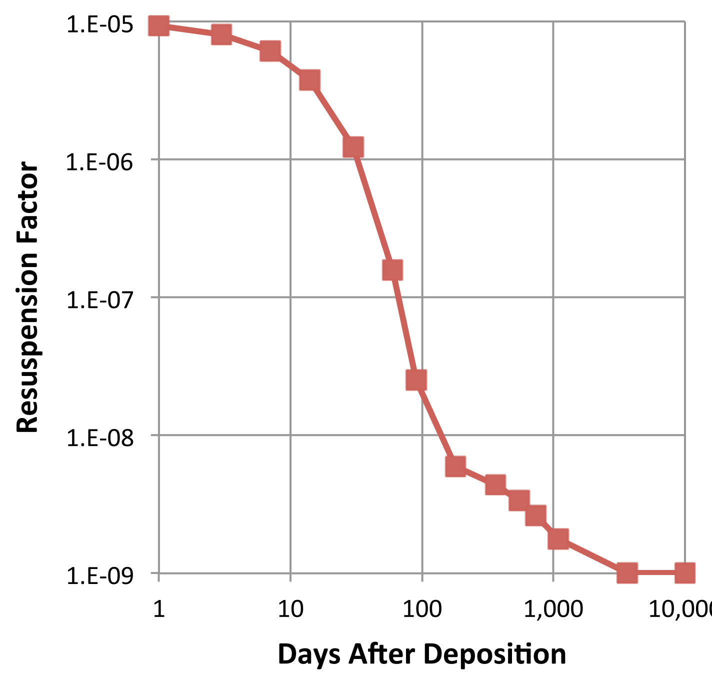
- Weathering (groundshine doses)
  - Anspaugh et al. 2002
- Resuspension (inhalation and submersion doses)
  - Maxwell and Anspaugh 2011
- Occupancy
- Sheltering (See Till and Meyer 1983)

Weathering and Resuspension

Weathering
(Anspaugh et al. 2002)



Resuspension (1/m)
(Maxwell and Anspaugh 2011)



Decay and Daughter Ingrowth

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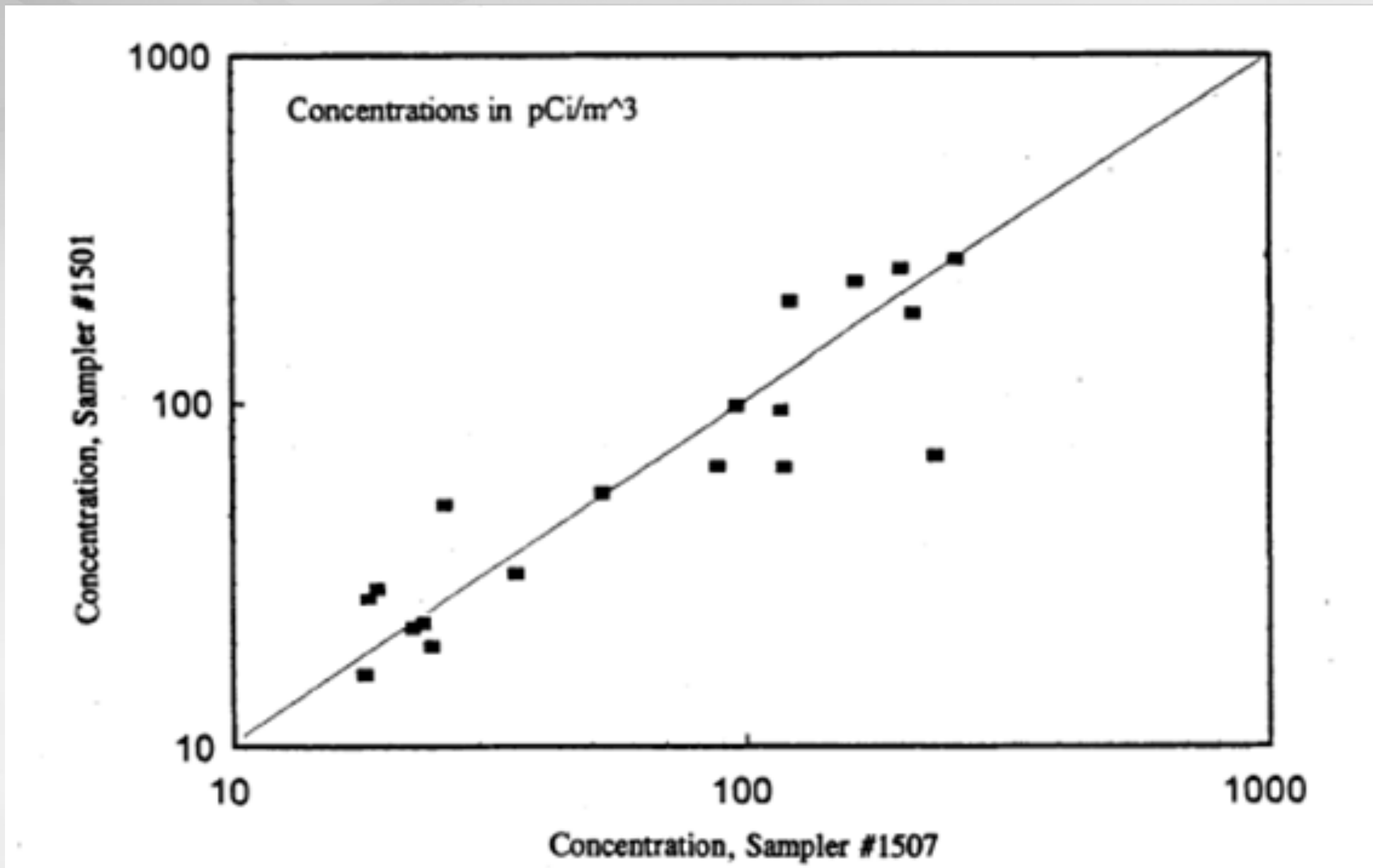
- Bateman equations

- Important nuclides (after 30 days)
  - Simple decay (most nuclides)
  - Equilibrium (Cs-137, Ru-106, Ce-144)

Uncertainty

- Measurements
  - Point measurements
  - Integrated measurements
- Example – Hanford Kr-85 monitoring data
- Model parameters
  - Basic data
  - Correlations
- Example – September 1963 Iodine-131 Release

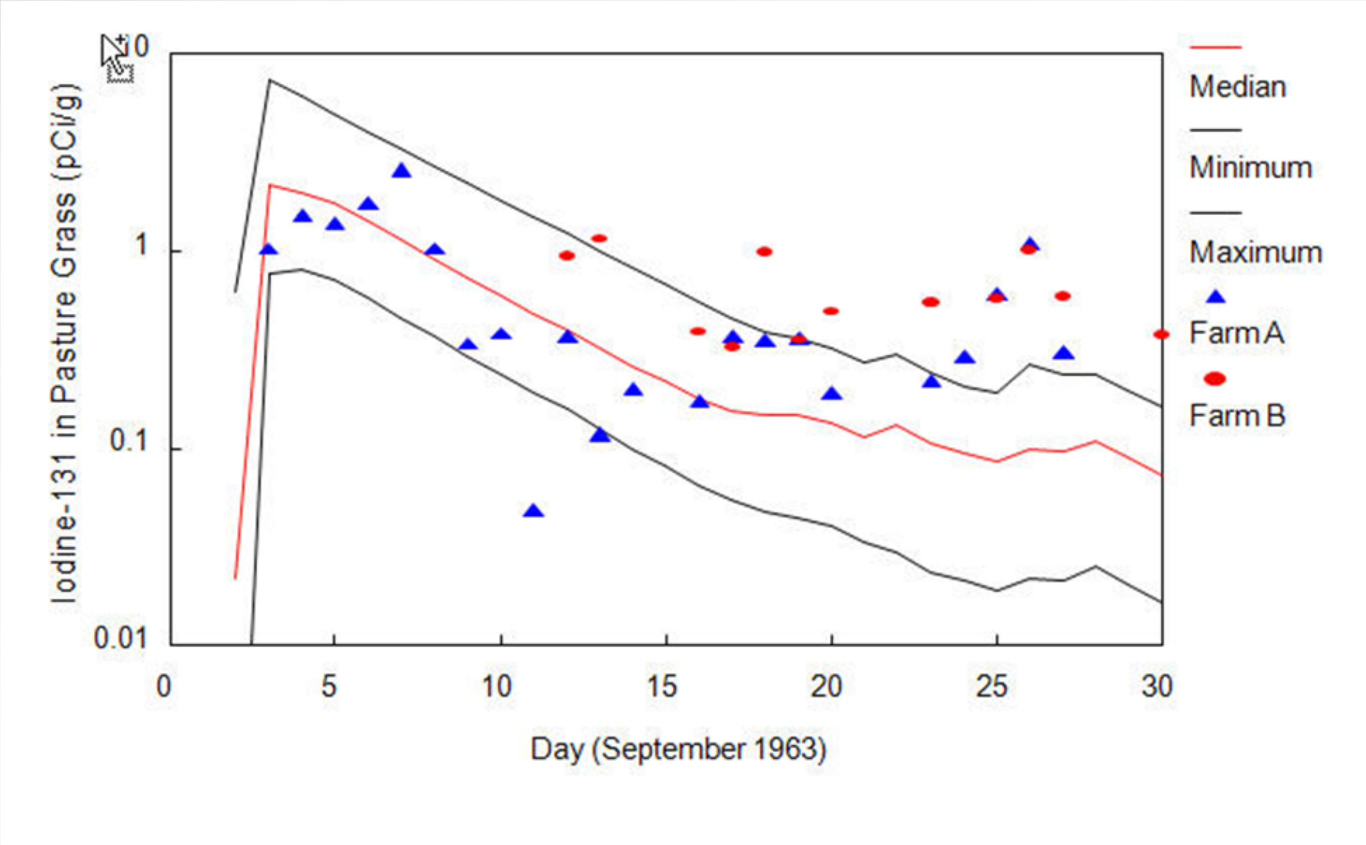
Measurement Uncertainty



Hanford Iodine-131 Release, September 1963

- Unplanned, but monitored, release of about 72 Ci of I-131 through 60 m stack
- Release over several days (high for 2 days followed by low levels for several weeks)
- Hourly meteorological data, no significant rain
- Environmental measurements of I-131 in grass for about a month about 20 miles from the release point.

Iodine-131 in Pasture Grass September 1963



Iodine-131 in Milk
September 1963

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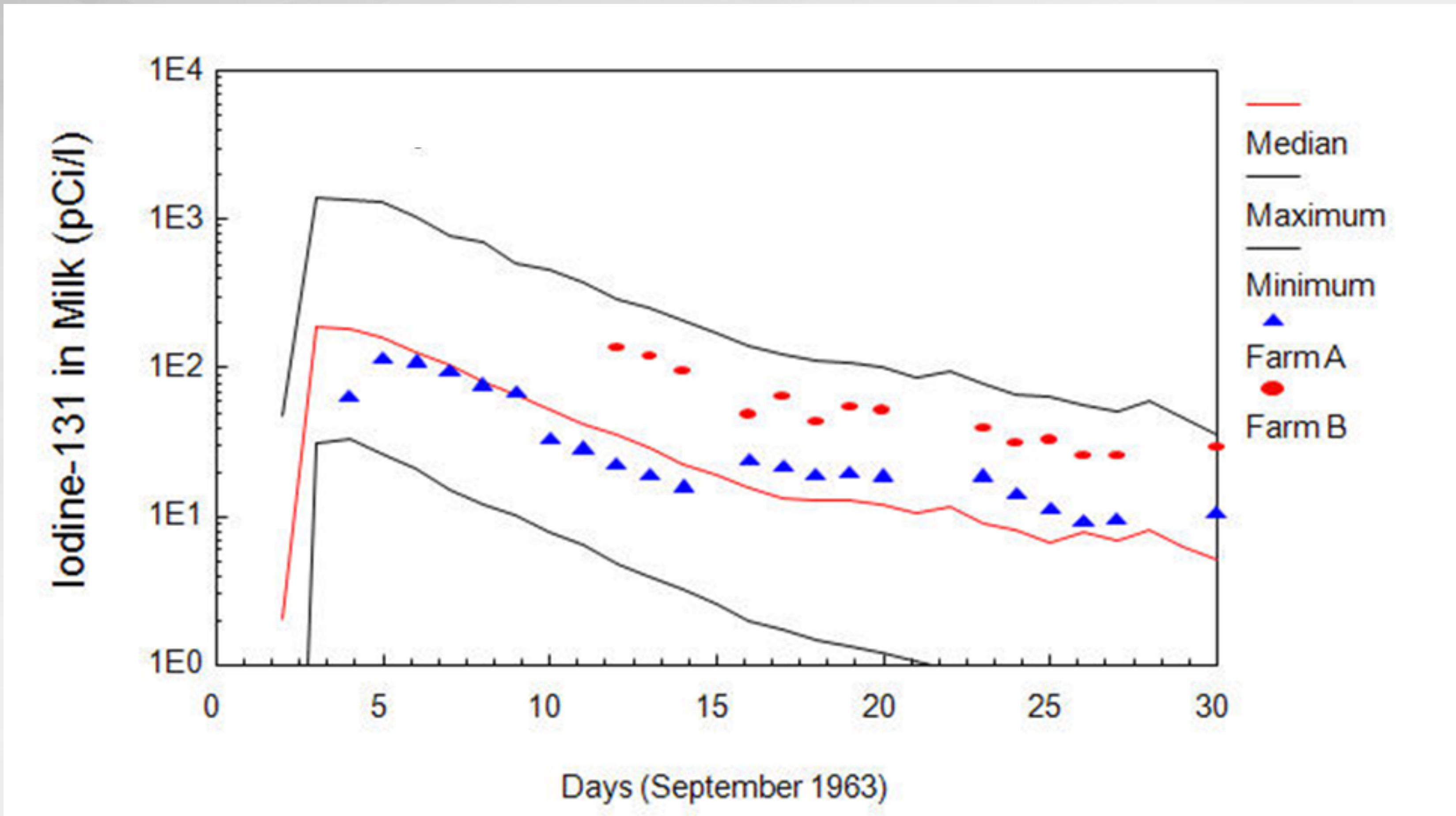

Conclusions

- Modeling should be based on best available estimate of release configuration and release rates.
- Modeling should include appropriate representations of atmospheric processes.
- Modeling should include appropriate consideration of model form and parameter uncertainty.
- Intermediate and final model results should be compared with known information when possible.
- Comparisons between model predictions and measured values should include consideration of model uncertainty and variability of measured values.

Information Sources

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