

# ***GDP-Based Economic Model for MACCS Nuclear Accident Offsite Consequence Estimation***

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# Overview

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- Alternative MACCS economic model
- RDEIM (Regional Disruption Economic Impact Model)
  - Input-Output Modeling, Data
- GDP loss estimation in MACCS-RDEIM model
  - Parameters and assumptions
  - GDP loss estimation
    - Estimation by grid element and industry
    - Aggregation over time and space
    - Treatment of partially affected counties
    - Multipliers
- Conclusions

# *Alternative Economic Model Goals*

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- Improve business disruption components of MACCS economic model
- Enable impact estimation by industry on the county level for arbitrary geographic areas
- Enable consistent application of Input-Output methodology
- Update the MACCS economics model to use most recent data
- Enable continuous updates

# *RDEIM Overview*

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- Employs Input-Output methodology, based on inter-industry commodity flows
- Uses geographic extent of disruption to estimate GDP losses
  - By industry
  - By county
- Uses Net Total Requirements Multipliers
- Uses Bureau of Economic Analysis (BEA) and U.S. Census Bureau data
- Based on Sandia's REAcct IO model

# *Input-Output Methodology*

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- Represents flow of products between sectors of economy based on actual transactional data
- Linear, allows fast computation, analytically tractable
- Generally uses linear, fixed-proportion production functions
- Effects of local changes to the regional or national levels estimated using multipliers derived from the Regional Input-Output Modeling System (RIMS II)

# *Input-Output History*

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- Developed starting in 1930s by V. Leontief (Harvard, NBER)
- Represents aggregated transactions in economy
- Used extensively for estimating consequences of accidents and disasters, such as earthquakes and hurricanes
- Used for economic planning, on local, regional, and national levels

# *Input-Output Prevalence and Uses*

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- Incorporated into national accounting of many developed countries (USA, UK, EU, Japan...)
- Data are readily available
- Employed by:

DHS, FEMA, Census Bureau, DOE, DoD, Federal Reserve, Bureau of Economic Analysis, Department of Labor, EPA, US Corps of Engineers, HPA (UK, COCO-2 – economic consequences model)

# *REAcct Uses*

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- DHS (NISAC):
  - Since 2004, used for all category 3 or above hurricanes
  - Hurricane swath analysis to enable future planning and response
  - Wildfires
  - Floods
  - BP Oil Spill
- SUMMIT (DHS S&T): used by FEMA for NLE12 and 2013 Moore Tornado



# *RDEIM Fundamentals*

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- Estimates direct GDP reductions for each industry in the affected area
- Calculates indirect impacts on the national scale impacts using the Net Total Requirements Multipliers
- County-level data and results
- Partially automated for ad-hoc disruption areas
- Takes GIS disruption shapes as inputs. Computes rapidly

# *RDEIM Analysis*

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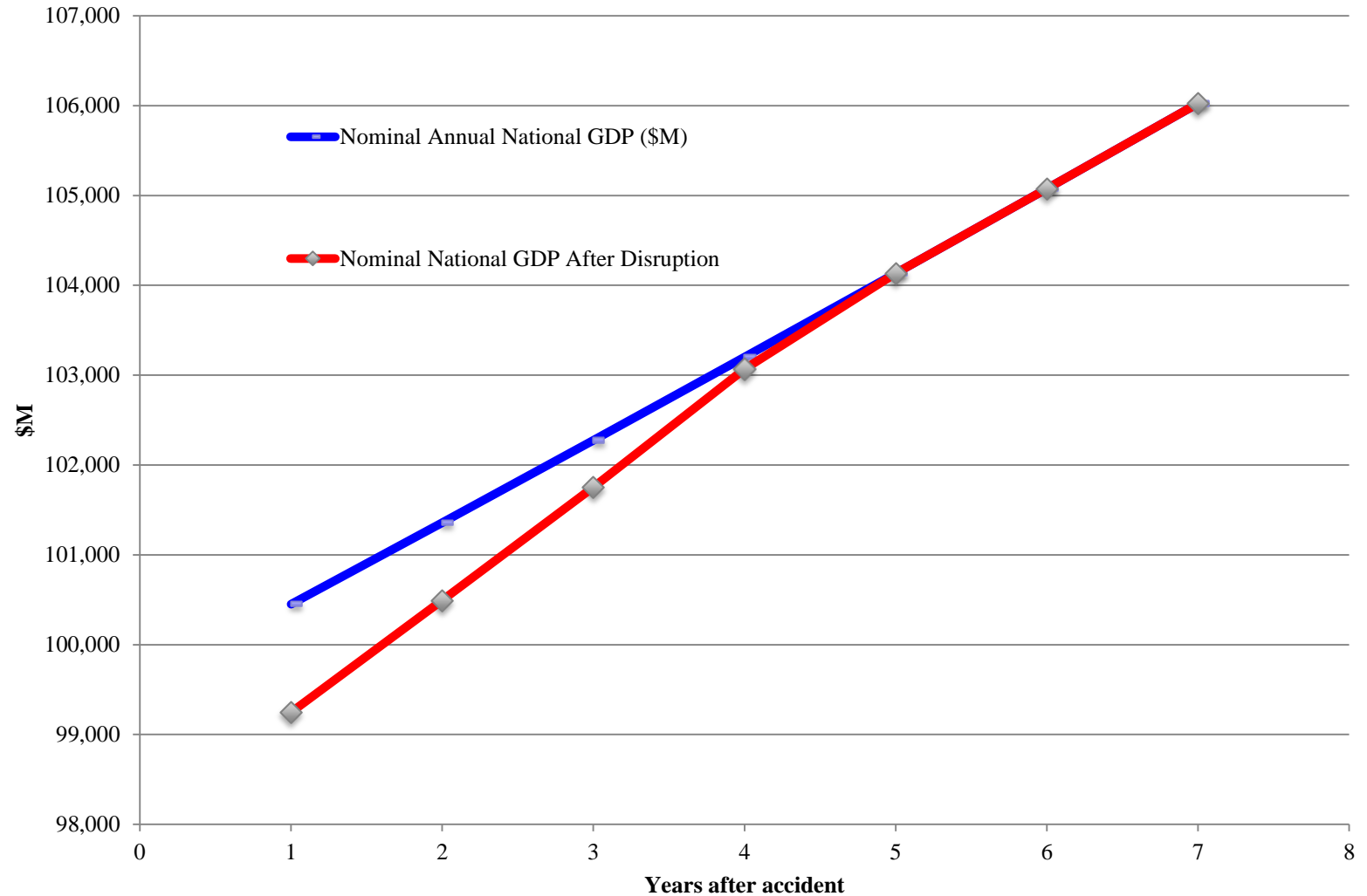
- Analysis includes:
  - Definition of the affected area
  - Calculation of GDP losses by industry for each county
  - Summation across all industries and counties and application of the Net Total Requirements Multipliers to calculate national impacts

# *RDEIM Data*

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- Sources: BEA, U.S. Census Bureau
  - US annual output
  - US annual value added
  - US employment
  - RIMS II Multipliers
  - County private industry employment
  - County government employment

# *Impact Estimation*



# *Inputs to Long-Term Impacts*

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- How long the local impacts last when an area is disrupted
- How long national impacts will last
- How to estimate future years' GDP
- What discount rates to use

# *Model Parameters*

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- GDP growth rate
  - How to estimate GDP in future years?
- Maximum duration of local impact
- Maximum duration of national impact
- Social discount rate
  - How much do we value future as compared to now?
- All parameters can be changed by users within certain bounds

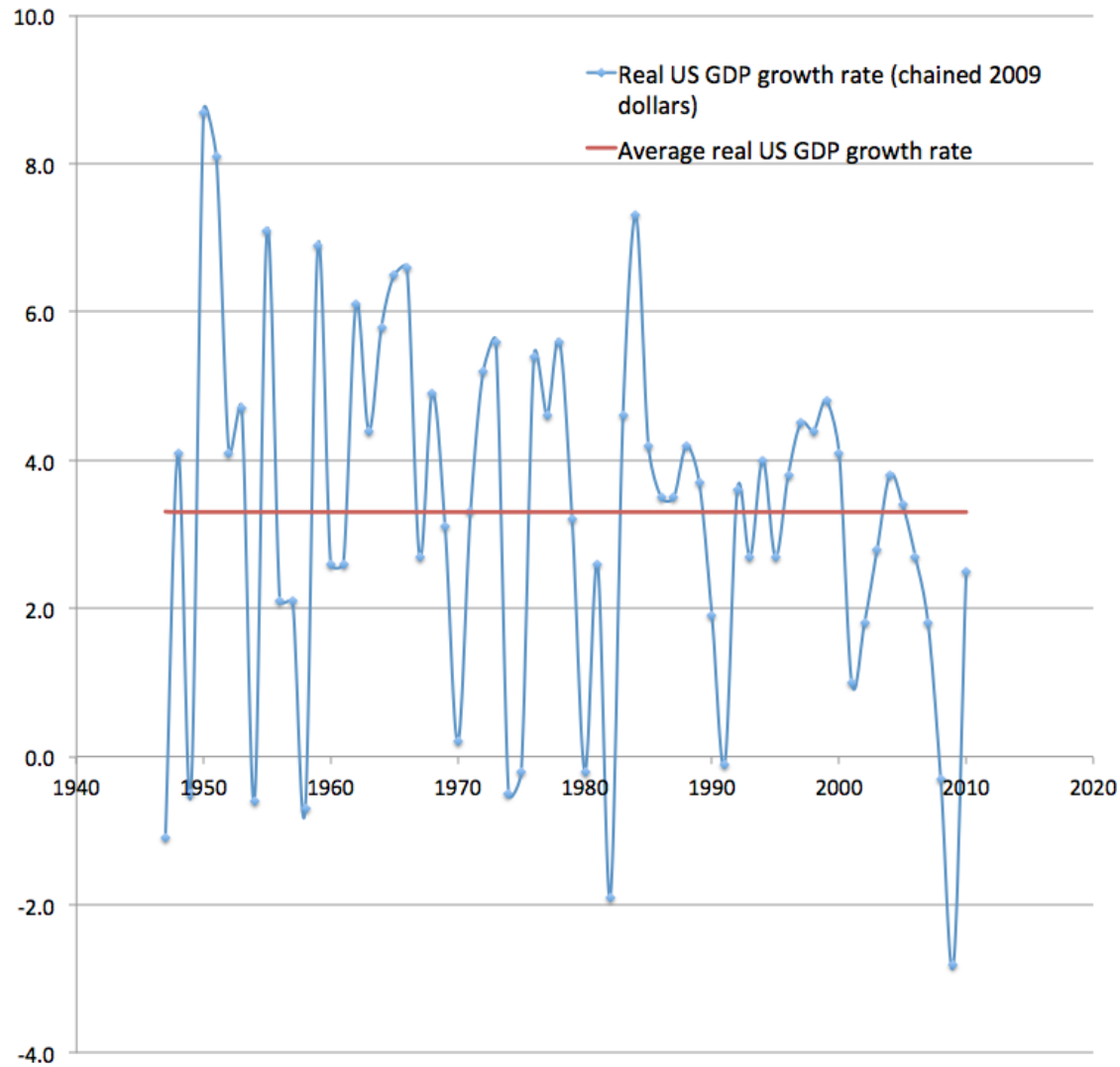
# *Parameter Values and Bounds*

	Default value	Lower bound	Upper bound
Real GDP Growth Rates (%)	2.3	0	10
Social Discount Rate (%)	3	10	10
Max Duration Local Impact (yr)	10	1	30
Max. Duration of Nat. Impact (yr)	3	1	10

## Sources:

- Historic data (US GDP growth rates (BEA), duration of recessions)
- Existing literature (social discount rate, loss calculation duration (COCO-2))
- Government policies and circulars (OMB Circular A-94)

# *Real GDP % Change over Time*





# *Long-term Impacts Assumptions*

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- Do not model adaptation
- Do not model long-term structural change
- Do not model downstream impacts

# *Impact Estimation Workflow*

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- WinMACCS
  - Specify scenario parameters: affected area loss duration
  - Retrieve the annual GDP data from RDEIM
  - Aggregate the RDEIM data over time for the entire affected area taking into account the scenario parameters
- RDEIM
  - Provide the annual GDP and employment data at the county and national levels for MACCS calculation

# Notation

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- $V_i$  – annual value added for industry  $i$
- $\Delta V_i$  – the direct value added change in industry  $i$
- $\Delta V_{i,r}$  – the direct value added change in industry  $i$  in the grid element  $r$ .
- $\Delta V^D, \Delta V^T, \Delta V^{D+I}, \Delta V^P$  – GDP (value added) losses, with indices  $D, T, DI, \text{ and } P$  denoting the total, direct, direct plus indirect, and induced losses respectively.
- $v_i$  – average value added per worker for industry  $i$ .
- $Y_i$  – annual national gross output for industry  $i$ .
- $E_i$  – national employment for industry  $i$
- $g$  – expected real *GDP* growth rate.
- $\rho$  – social discount rate.
- $t$  – Gregorian calendar time, expressed as a real number, in units of year
- $t_0$  – database year (starting time of base year).
- $t_I$  – accident year (starting time of accident year).

# *Notation (cont.)*

$m_i^{I,II}$  – the net total requirements multipliers of Type I or Type II.

$m_i^{I,II}$  – the final demand value added multipliers of Type I or Type II provided by the BEA.

$s_r(t)$  – disruption function representing the state of grid element  $r$ .

$l_{i,r}$  – number of industry  $i$  affected employees in grid element  $r$ .

$T_R$  – maximum duration of economic loss calculation for directly affected area.

$T_N$  – maximum duration of economic loss calculation for indirectly affected area.

# *Direct GDP Losses by Industry and Grid Element*

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- Direct annualized GDP

$$v_{i,r}^D = e^{g(t_I - t_0)} v_i l_{i,r}$$

- Cumulative scenario losses

$$\Delta V_{i,r}^D(T) = e^{g(t_I - t_0)} v_i l_{i,r} \int_0^T s_r(t) e^{(g-\rho)t} dt, \text{ where}$$

$$s_r = \begin{cases} 1, & t \leq T_r \\ 0, & t > T_r \end{cases}$$

# *Direct GDP Loss for Affected Area*

Direct loss until time T: entire area, all industries:

$$\Delta V^D(T) = e^{g(t_I - t_0)} \sum_I v_i \sum_R l_{i,r} S_r(T), \text{ where}$$

$$S_r(t) = \int_0^T s_r(t) e^{(g-\rho)t} dt$$

Analytic Expression:

1)  $g \neq \rho$

$$\Delta V^D(T) = e^{g(t_I - t_0)} \sum_I v_i \sum_R l_{i,r} \frac{e^{(g-\rho)T_r} - 1}{g - \rho}$$

2)  $g = \rho$

$$\Delta V^D(T) = e^{g(t_I - t_0)} \sum_I v_i \sum_R l_{i,r} T_r$$

Note: T – arbitrary => impacts over time

# *Total Impacts*

Similar to Direct. Includes multipliers and national recovery estimates

$$\Delta V^T(T) = e^{g(t_I - t_0)} \sum_I v_i m^I_i \sum_R l_{i,r} \int_0^T s_r(t) s_N(t) e^{(g-\rho)t} dt, \text{ where}$$

$$s_N = \begin{cases} 1 - \frac{t}{T_N}, & t \leq T_N \\ 0, & t > T_N \end{cases}$$

Analytical expressions analogous to direct

# *Indirect and Induced*

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- Indirect

$$\Delta V^I(T) = e^{g(t_I - t_0)} \sum_I v_i \sum_R l_{i,r} \int_0^T s_r(t) (s_N(t) m_i^I - 1) e^{(g - \rho)t} dt$$

- Induced

$$\Delta V^P(T) = \Delta V^T(T) - \Delta V^D(T) - \Delta V^I(T)$$

- Analytical expressions analogous to direct



# *Net Total Requirements Multipliers*

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New multipliers needed:

1. Initial disruption presented as value added losses in impacted area => “national” multipliers should operate on local changes in value added
2. All industries in the affected area are shut down at the same time => multipliers have to be adjusted for intra-affected region trade to avoid double counting

# *Multipliers Calculation*

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Gross total requirements type I national multiplier:

$$m_i^{I,N} = \frac{Y_i}{V_i} \sum_j b_{i,j} \frac{V_j}{Y_j}, \text{ where } b_{i,j}$$

is from National Industry –by Industry TRII

Alternatively:

$$m_i^{I,N} = \frac{Y_i}{V_i} \tilde{m}_i^I$$

Same for intra-regional:

$$m_i^{I,R} = \frac{Y_i}{V_i} \tilde{m}_i^R$$

Net multipliers:  $m_i = m_i^{I,N} - m_i^{I,R} + 1$

Type II multipliers calculation is identical

# *Partially Affected Counties*

		By Area	By Population
Industry # 3	Agriculture, forestry, fishing, and hunting	X	
Industry # 6	Mining	X	
Industry #10	Utilities	X	
Industry #11	Construction	X	
Industry #12	Manufacturing	X	
Industry #34	Wholesale trade		X
Industry #35	Retail trade		X
Industry #36	Transportation and warehousing	X	
Industry #45	Information		X
Industry #51	Finance and insurance		X
Industry #56	Real estate and rental leasing	X	
Industry #60	Professional, scientific, and technical services		X

# *Partially Affected Counties (cont.)*

		By Area	By Population
Industry #64	Management of companies and enterprises		X
Industry #65	Administrative and waste management services	X	
Industry #69	Educational services		X
Industry #70	Health care and social assistance		X
Industry #75	Arts, entertainment, and recreation	X	
Industry #78	Accommodation and food services	X	
Industry #81	Other services, except government		X
Industry #83	Federal Civilian		X
Industry #85	State and Local Government		X

# *Additional Model Features*

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- How to ensure that on-site losses are not included in the total by removing the on-site employees from the estimate of utilities industry employment. No other changes required

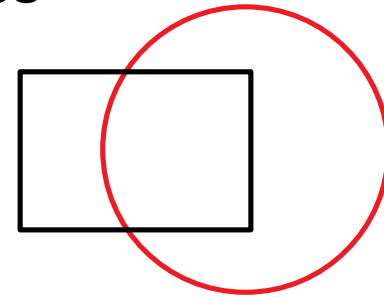
$$l_{utilities,r} - > \max(l_{utilities,r} - l_{NP,r}, 0)$$

- Wealth losses, already estimated by MACCS are added to GDP losses
- Temporal nature of the model allows investigation of impacts of different restoration and decontamination schedules

# Simple Numerical Example

## Employment by industry in affected counties

	County Employment		
Industry	A	B	C
Utilities	100	45	55
Machinery	995	4000	30
Adm. Serv.	10	15	20
Food Serv.	50	300	5



## Fraction of each county affected

	County Fraction in Grid Element		
	A	B	C
By population	0.5	1	1
By area	0.7	1	1

## Grid element recovery schedule

	Grid Element		
	A	B	C
Recovery Time (yr)	3.5	6	11

## Lost employment by grid element and industry

	Lost Employment in Grid Element		
Industry	A	B	C
Utilities	70	45	55
Machinery	498	4000	30
AdmServ	5	15	20
FoodService	25	300	5

# *Other Disruption Parameters*

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Maximum duration of regional disruption,  $T_R = 10$  yr.

The time needed for national recovery,  $T_N = 4$  yr.

GDP growth rate  $g = 2.4\%$

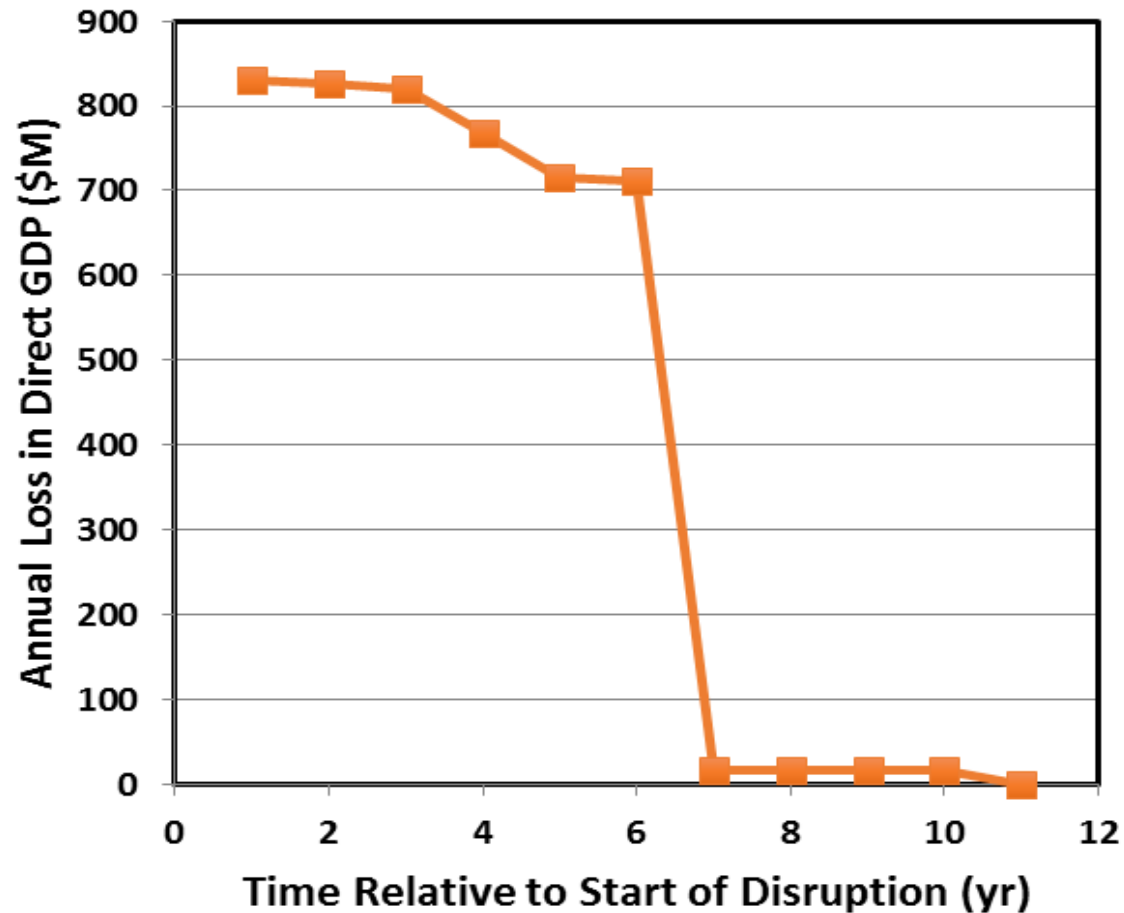
Social discount rate  $\rho = 3.0\%$

Base year = database year = 2011

Annual GDP of affected region = \$3 billion

National GDP = \$100 billion

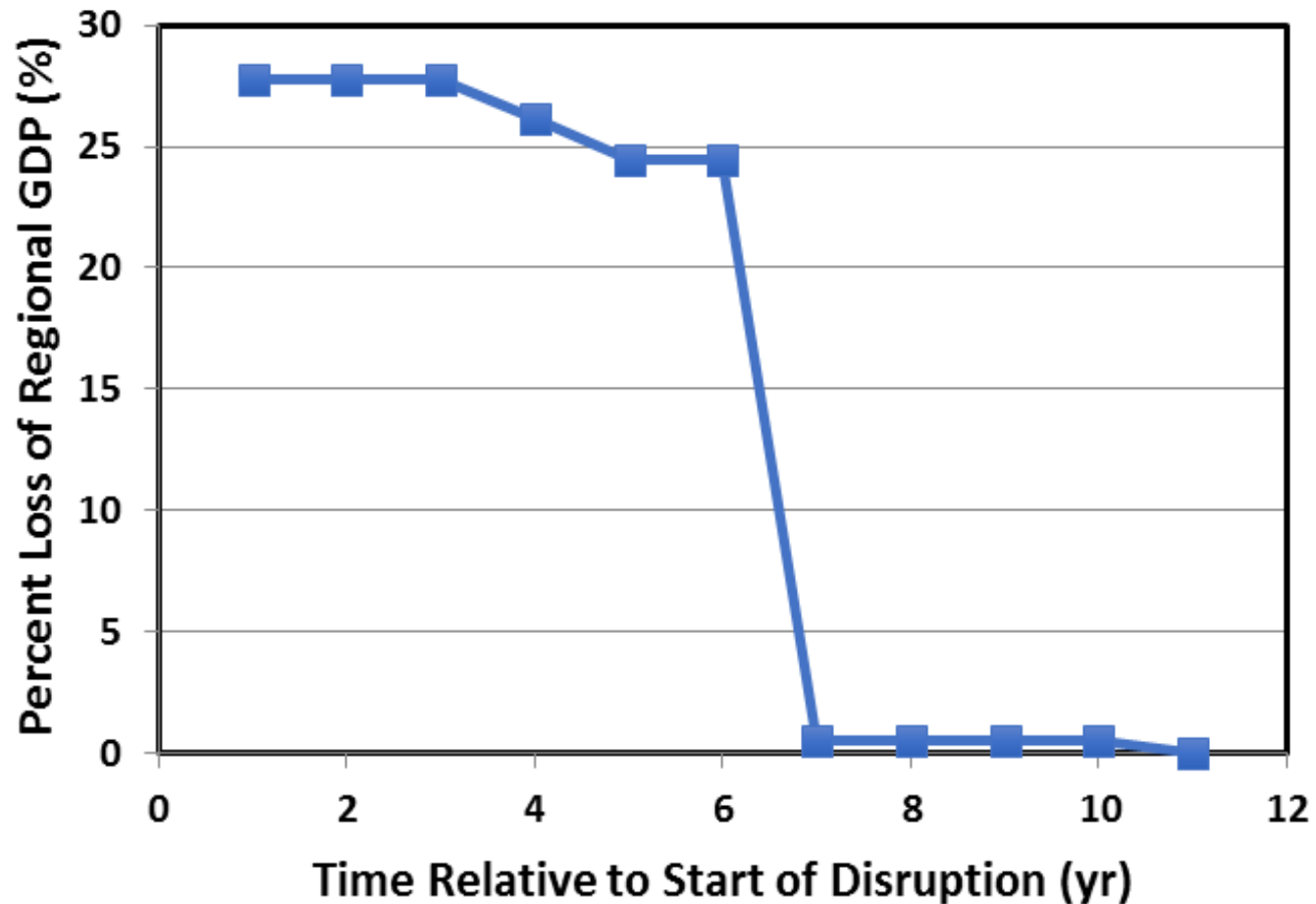
# *Annual Direct Loss*



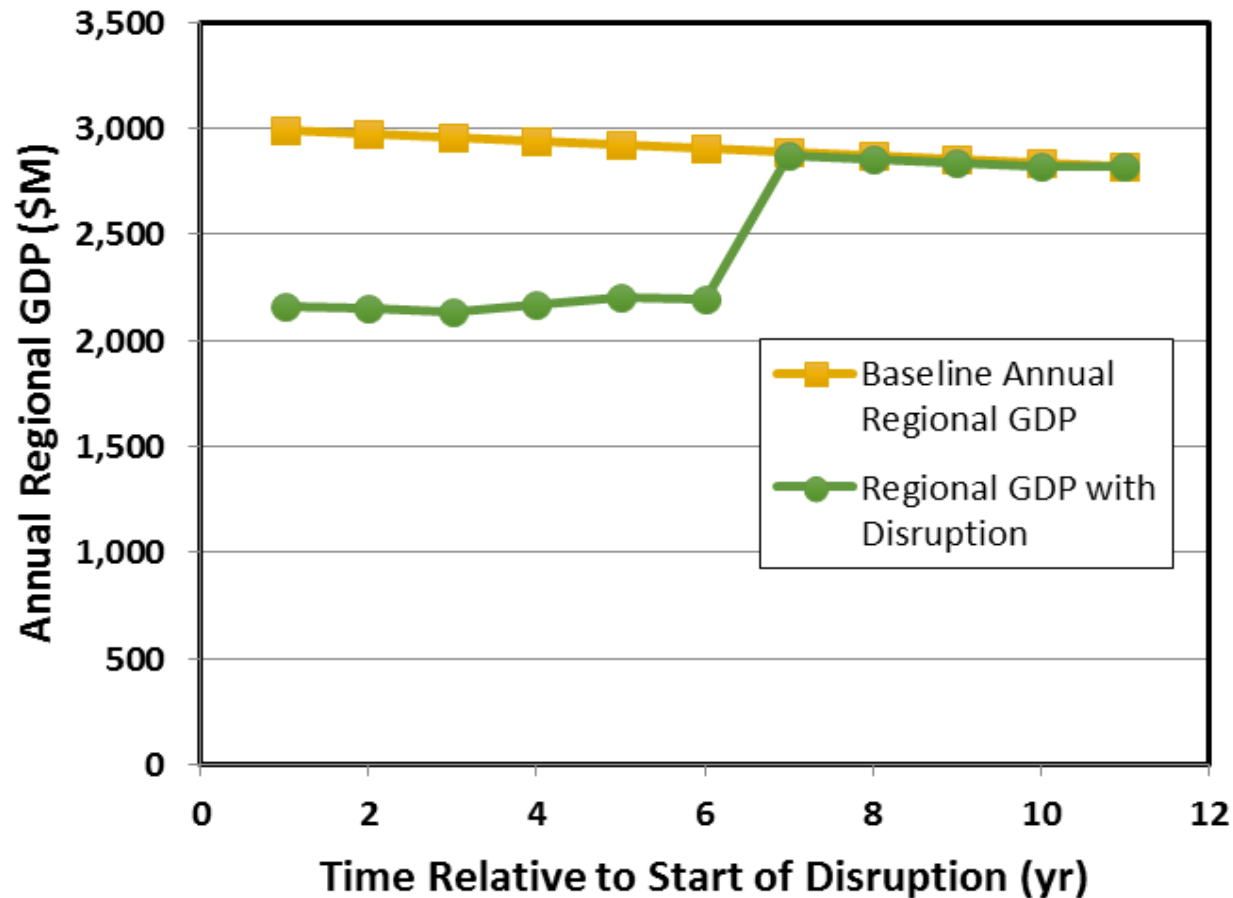


# *Percent Regional GDP Loss*

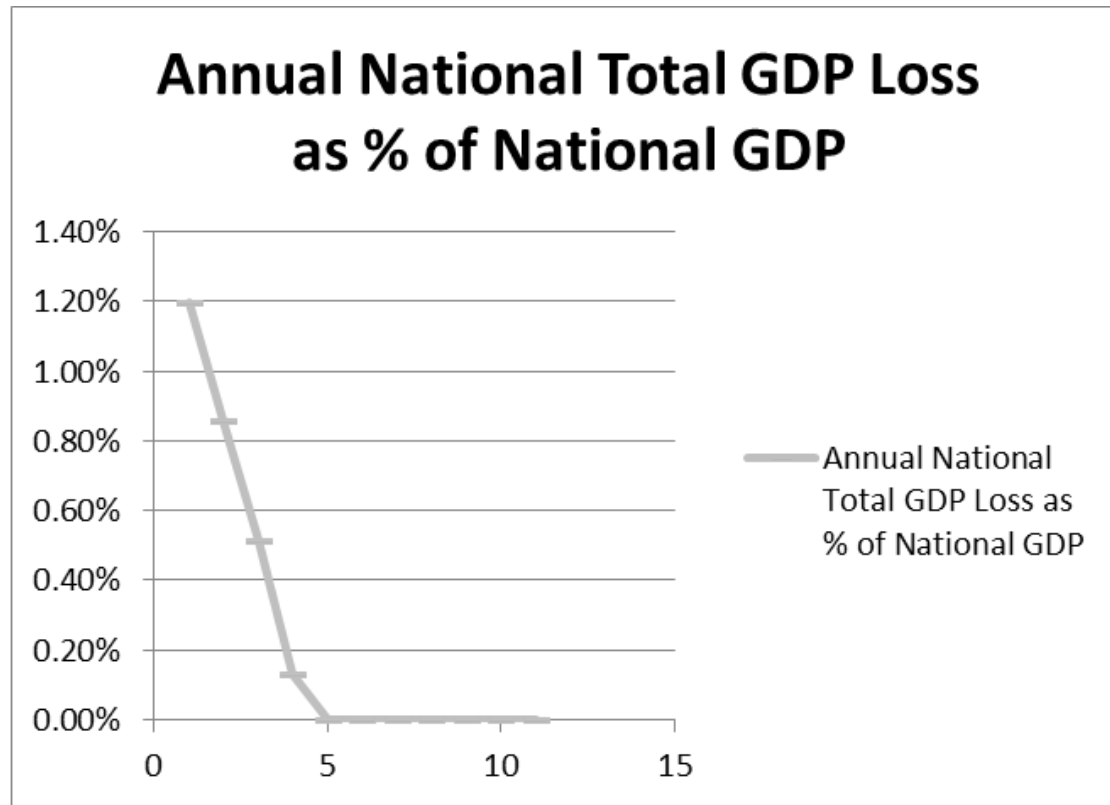
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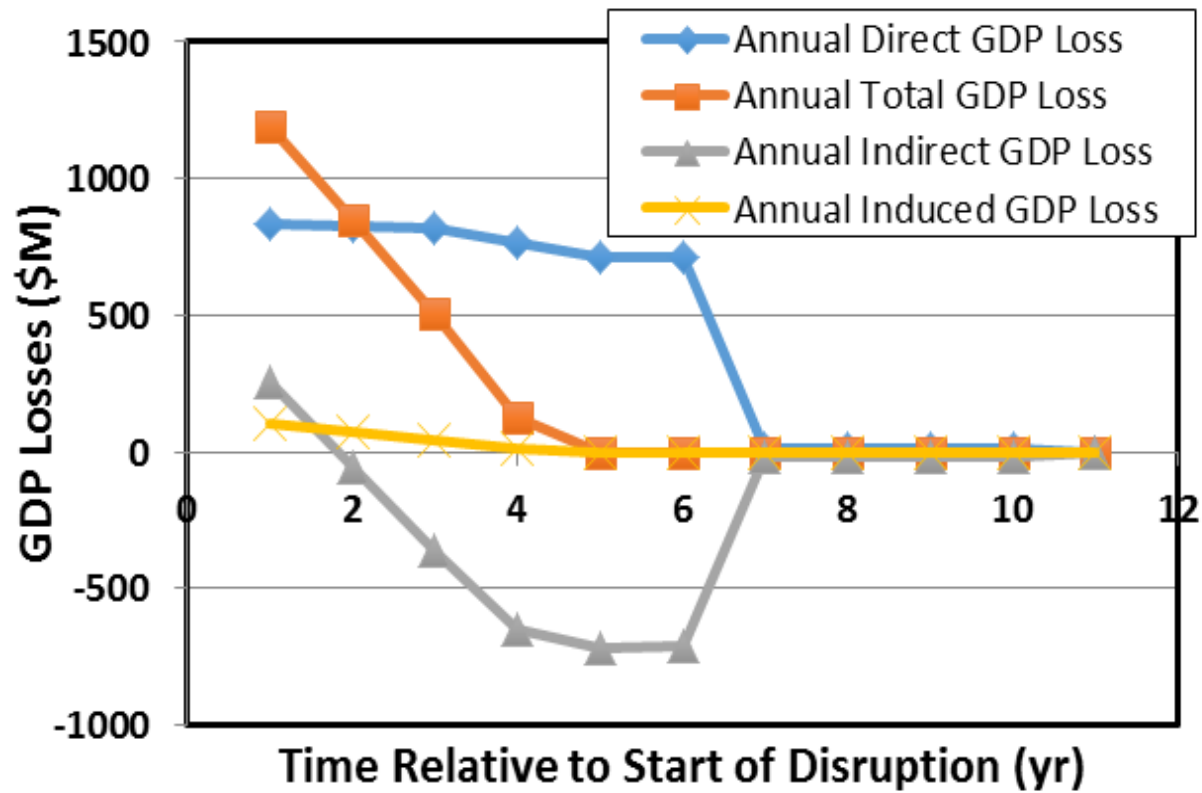
# *Annual Regional GDP*



# *Fraction of National GDP Lost*



# *GDP Loss Summary*



# *Conclusions*

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- Created temporal Input-Output framework for estimating the GDP impacts of nuclear power plant accidents:
  - Calculates impacts over time
  - Distinguishes between national and local scales
  - Represents effects of recovery and restoration
  - Calculates impacts on county level for a set of 21 industries for arbitrary geographic area
  - Quickly estimates direct, indirect, and total GDP impacts for ad-hoc scenarios
  - Has been integrated with WinMACCS
  - Has been compared with MACCS legacy economic model
  - Can be easily updated with new data

*Thank you!*

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