III. INJURY CRITERIA

This section contains a description of the Injury Criteria and Injury Criteria Performance Limits (ICPL) proposed for the SNPRM on advanced frontal air bags. NHTSA is proposing separate ICPLs for each dummy size. This section describes how the dummy head, neck, chest and femur responses measured by the dummies relate to human tolerance/injury risk potential and the associated probability of injury. NHTSA is proposing ICPLs for head injury criterion (HIC), neck injury criterion (Nij), chest acceleration (chest g s), chest deflection and femur axial loads for each dummy size.

Based on an analysis of the docket comments, NHTSA is proposing to compute HIC (maximum) using a 15 ms time interval (compared to 36 ms in today s FMVSS 208) and new HIC threshold ICPLs are proposed for each dummy size. The SNPRM proposes a new neck injury criteria (Nij) formulation employing revised critical intercept values based on comments to Docket No. 98-4405. The alternative ICPL of 1.0 proposed in the NPRM for Nij is being adopted in the SNPRM for the new formulation. The NPRM proposals: (1) Nij <= 1.4 and (2) the alternative Box Method for neck injury assessment are not being proposed in the SNPRM.

The chest acceleration (chest g s) ICPL values proposed in the SNPRM are the same as those in the NPRM, except for the 3-year-old child and 12-month-old infant (CRABI) dummies. However, peak chest deflection threshold ICPL values for each dummy size have changed to reflect a proposed change in the 50th percentile male deflection ICPL from 76 mm to 63 mm (maximum). The deflection ICPLs for the other dummy sizes were subsequently scaled from this value for equivalent injury risk levels. The femur axial load ICPLs for the 50th percentile male and 5th percentile female dummies in the SNPRM are identical to the NPRM proposal. The Combined Thoracic Index (CTI) is not being proposed as an injury criteria in the SNPRM However, the CTI concept of chest injury risk as proposed in the NPRM is used for analysis purposes in Chapter V, Benefits, to calculate chest injury risk reductions and subsequent benefits. For example, the Injury Assessment Reference Value (IARV) of 1.0 as applied to CTI in the benefits analysis section represents a 25 percent probability of an AIS 3+ human chest injury.[1]

In addition, this section includes a discussion of 95th percentile male dummy injury criteria and concomitant IARVs, as these are used for analysis purposes to assess the MY97 (baseline) vs MY99 (redesigned) Buick Century and Chevy Venture sled buck air bag test series. The 95th percentile dummy sled test responses are compared to the applicable injury criteria and appropriate IARVs.

Furthermore, a lower extremity injury criterion called the Tibia Index with an IARV of 1.3 is discussed. The Tibia Index has been used by the European community to assess the potential of lower leg injuries using the 50th percentile male and 5th percentile female dummies. The

[1] ICPLs are proposed in the SNPRM to support the proposed injury criteria, whereas IARVs are used in conjunction with the injury criteria for analysis purposes only.

agency s analysis examines lower leg injury risk for the proposed 56 kmph (35 mph) offset deformable barrier (ODB), 40 percent overlap, test procedure.

NHTSA s National Transportation Biomechanics Research Center (NTBRC) has prepared a separate amended biomechanics document that discusses each selected ICPL, the associated injury risk functions and the risk tolerance curves.[2]

A. Summary of NHTSA s ICPL Proposal

Head - After analysis of the comments to the NPRM Docket 98-4405, the agency is proposing to change the HIC (maximum) calculation time interval from 36 ms to 15 ms. This results in a HIC_{15} ICPL value of 700 for the 50^{th} percentile male dummy. In addition, NHTSA is proposing HIC_{15} 700 for the 5th percentile female and 6-year-old dummies for the advanced frontal air bag final rule. Also, the agency is proposing HIC_{15}=570 and HIC_{15} =390 for the 3-year-old and 12-month-old infant (CRABI) dummies, respectively, which have been scaled from the 50th percentile dummy. Table III-1 shows the proposed ICPLs for each body region by dummy size.

[2] Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems -II, October, 1999, The original document was Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems, June, 1998. See Docket No. NHTSA-1998-4405-9.

Table III-1
Proposed Injury Criteria and Injury Criteria Performance Levels (ICPLs) for FMVSS No. 208 SNPRM by Anthropomorphic Dummy Size

Proposed Injury Criteria	Hybrid III Mid-Sized Male	Hybrid III Small Female	Hybrid III 6-Year-Old Child	Hybrid III 3-Year-Old Child	12-Month-Old Infant (CRABI)
Head Criteria HIC_{15}	700	700	700	570	390
Neck Criteria					
Nij	1.0	1.0	1.0	1.0	1.0
Nij Critical Intercept Values					
$F_{Z\ CRIT}$: Tension (N)	4500	3370	2800	2120	1465
$F_{Z\ CRIT}$: Compression (N)	4500	3370	2800	2120	1465
$M_{Y\ CRIT}$: Flexion (N-m)	310	155	93	68	43
$M_{Y\ CRIT}$: Extension (N-m)	125	62	39	27	17
Thoracic Criteria					
A_C Critical Chest Acceler. (g s)	60	60	60	55	50
D_C Critical Chest Deflect (mm)	63 (2.5")	52 (2.0")	40 (1.6")	34 (1.4")	30 * (1.2")
Lower Extremity Criterion					
Femur Axial Loads (kN)	10.0 **	6.8	NA	NA	NA

* The 12-month-old infant (CRABI) dummy is not currently capable of measuring chest deflection. ** The actual femur axial load ICPL is 10,008 Newtons, but this has been rounded to the nearest whole number in Table III-1. NA - not applicable.

Neck - NHTSA is proposing the same neck injury criterion (Nij) as proposed in the NPRM, but with revised critical intercept values for the SNPRM. Nij = 1.0 applies regardless of dummy size. Nij = 1.0 was proposed as an alternative ICPL in the NPRM. Nij is a linear combination of the normalized neck axial load (tension or compression) and normalized neck moment about the occipital condyle. The critical neck intercept values being proposed to compute the normalized neck axial load (tension or compression) and normalized neck moment are different for each dummy size. (See Table III-1)

Chest - The chest acceleration ICPL values proposed in the SNPRM are the same as the NPRM for the 50^{th} percentile male, 5^{th} percentile female and 6-year-old child dummies, but have been revised for the 3-year-old child and 12-month-old infant dummies. In addition, the chest deflection threshold values for all the dummies have been re-scaled to reflect that the 50^{th} percentile male s maximum allowable chest deflection which has been revised from 76 mm to 63 mm (3" to 2.5"). This essentially reduces the risk of an AIS-3+ chest injury from 47 to 33 percent (NHTSA estimate) or 96 to 60 percent (Mertz estimate). The maximum deflection thresholds for the other dummy sizes have been scaled from the 50 percentile male dummy. Test data shows this 17 percent reduction in the central chest deflection ICPL is practicable for many of the full-scale crash test proposed conditions, but may be more problematic for the static OOP test conditions. [Note: 12-Month-Old Infant (CRABI) dummy does not currently have chest deflection measurement capability.] (See Table III-1)

Femurs - FMVSS 208 specifies a femur axial compressive load ICPL of 10,000 N (2,250 lbs.) for the 50th percentile male dummy. In the NPRM, NHTSA proposed a femur axial compression ICPL of 10,000 N (2,250 lbs.) for the 50^{th} percentile male dummy and 6,800 N (1,530 lbs.) for the 5th percentile female femur, based on scaling of the cross-sectional area of the femur bone. These same values are proposed in the SNPRM. Femur loads are not included for the child dummies because the testing configurations specified in the SNPRM for the 6-year-old child dummy, namely OOP testing, do not impose substantial loading on the lower extremities. (See Table III-1)

The scaling methods used to derive the head, neck critical intercept values, chest deflection, chest acceleration, and femur ICPLs by dummy size are described in the previously referred to amended biomechanics report placed in the docket.

B. Injury Risk Curves

Head Injury Criterion (HIC_{15})

The HIC_{15} of 700 for the 50th percentile male dummy can be directly correlated to HIC_{36} of 1000 [$HIC_{15} = 0.7\ HIC_{36}$] and is designed to provide protection from head injury (e.g., skull fracture) for long duration events where there is no head contact with hard vehicle interior points. HIC was developed from short duration, hard rigid surface, cadaveric head drop data and was designed to minimize skull fracture/brain injury due to head contacts with interior compartment components. A short duration impact could include a direct driver head impact with the steering wheel rim/hub or a child s head contacting the unpadded face of the instrument panel. As shown in Table III-1, a maximum HIC_{15} of 700 is proposed for the 50^{th} percentile male dummy as well as the new 5th percentile female and the new 6-year-old child dummies. In addition, HIC_{15} = 570 is proposed for the new 3-year-old and HIC_{15} = 390 is proposed for the new 12-month-old infant (CRABI) dummy. The 3-year-old and 12-month-old infant HIC values were scaled.

Prasad and Mertz estimated head injury risk as a function of HIC and employed a 15 ms maximum time interval to calculate HIC.[3] The 15 ms time interval represented a hard rigid impact surface. NHTSA has used the 36 ms maximum time interval to compute HIC because it is believed to closely represent the softer vehicle interior head impact environment and indirectly provides neck tension protection by limiting Z-axis g s.[4] With the new neck criterion (Nij) HIC_{15} can be seriously considered. The Prasad/ Mertz HIC values are shown in Table III-2.[5] NHTSA has expanded the Prasad/ Mertz curve to include other AIS levels (see Figure III-1). The lognormal curve values for HIC developed by Hertz of NHTSA are shown in Table III-3 and Figure III-2. The Hertz curves are representative of HIC_{15} as they were derived from short duration head drop data. See the amended biomechanics report for a further discussion

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[3] Assessing the Safety Performance of Occupant Restraint Systems, Viano, D.C. and Arepally, S., Biomedical Science Department, GM Research Laboratories, General Motors Corporation, Warren, MI, SAE #902328. The Position of the U.S. Delegation to the ISO Working Group 6 on the Use of HIC in the Automotive Environment, P. Prasad of Ford Motor Company and H. J. Mertz of General Motors Corporation, SAE #851246 and Injury Risk Curves for Children and Adults in Front and Rear Collisions, H.J. Mertz, General Motors, P. Prasad, Ford Motor Co. and A.L. Irwin, General Motors, #973318.

[4] Final Regulatory Evaluation, FMVSS 208 - Front Seat Occupant Protection, Amendment to Provide a New Method for Calculating Head Injury Criterion (HIC), August 1986, Office of Regulatory Analysis, Plans and Policy, NHTSA/DOT.

[5] Final Regulatory Evaluation, Actions to Reduce Adverse Effects of Air Bags, FMVSS 208, DEPOWERING, February 1997, Office of Regulatory Analysis, Plans and Policy, NHTSA/DOT.

of HIC_{15} vs HIC_{36} and the scaling factors used to derive ICPL values by dummy size.

Table III-2
Expanded Prasad/Mertz Curves
Chance of Specific Injury Level for a Given HIC_{15} Level

HIC	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	FATAL	NO INJURY
50	0.3%	0.1%	0.1%	0.0%	0.0%	0.0%	99.5%
150	8.7%	2.8%	1.2%	0.3%	0.0%	0.0%	87.0%
250	21.8%	7.4%	2.9%	0.7%	0.1%	0.0%	67.2%
350	33.8%	13.7%	5.1%	1.3%	0.1%	0.0%	45.9%
450	40.1%	21.5%	8.1%	2.1%	0.2%	0.0%	28.1%
550	39.1%	29.7%	11.9%	3.2%	0.3%	0.0%	15.8%
650	33.0%	36.7%	16.7%	4.6%	0.5%	0.0%	8.5%
750	25.2%	40.8%	22.2%	6.6%	0.7%	0.0%	4.4%
850	17.8%	41.3%	28.2%	9.2%	1.2%	0.0%	2.3%
950	12.0%	38.5%	33.9%	12.6%	1.8%	0.1%	1.2%
1050	7.8%	33.5%	38.4%	16.8%	2.8%	0.2%	0.6%
1150	4.9%	27.6%	41.0%	21.7%	4.2%	0.3%	0.3%
1250	3.1%	21.7%	41.2%	27.0%	6.3%	0.5%	0.2%
1350	1.9%	16.5%	39.2%	32.1%	9.3%	0.8%	0.1%
1450	1.2%	12.2%	35.3%	36.3%	13.5%	1.5%	0.0%
1550	0.7%	8.8%	30.3%	38.7%	18.8%	2.6%	0.0%
1650	0.5%	6.3%	24.9%	38.7%	25.1%	4.6%	0.0%
1750	0.3%	4.4%	19.7%	36.1%	31.7%	7.8%	0.0%
1850	0.2%	3.1%	15.2%	31.3%	37.1%	13.1%	0.0%
1950	0.1%	2.2%	11.4%	25.4%	39.9%	21.0%	0.0%
2050	0.1%	1.5%	8.4%	19.4%	38.6%	32.0%	0.0%
2150	0.0%	1.0%	6.1%	14.0%	33.4%	45.4%	0.0%
2250	0.0%	0.7%	4.4%	9.7%	25.6%	59.5%	0.0%
2350	0.0%	0.5%	3.2%	6.5%	17.7%	72.2%	0.0%
2450	0.0%	0.3%	2.3%	4.2%	11.1%	82.1%	0.0%
2550	0.0%	0.2%	1.6%	2.7%	6.5%	89.0%	0.0%
2650	0.0%	0.2%	1.1%	1.7%	3.5%	93.4%	0.0%
2750	0.0%	0.1%	0.8%	1.1%	1.8%	96.2%	0.0%
2850	0.0%	0.1%	0.6%	0.6%	0.9%	97.8%	0.0%
2950	0.0%	0.1%	0.4%	0.4%	0.4%	98.7%	0.0%
3050	0.0%	0.0%	0.3%	0.2%	0.2%	99.3%	0.0%
3150	0.0%	0.0%	0.2%	0.1%	1.0%	99.6%	0.0%

Table III-3
Lognormal Curves Chance of Specific Injury Level for a Given HIC15 Level

HIC	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	FATAL	NO INJURY
50	7.6%	0.02%	0.00%	0.00%	0.00%	0.00%	92.38%
150	35.53%	1.01%	0.05%	0.00%	0.00%	0.00%	63.41%
250	52.06%	3.97%	0.44%	0.01%	0.01%	0.00%	43.52%
350	59.44%	8.01%	1.42%	0.06%	0.06%	0.04%	30.98%
450	61.55%	12.15%	2.96%	0.18%	0.19%	0.17%	22.80%
550	60.74%	15.84%	4.84%	0.40%	0.42%	0.51%	17.25%
650	58.37%	18.86%	6.81%	0.70%	0.73%	1.18%	13.36%
750	55.21%	21.16%	8.69%	1.06%	1.10%	2.24%	10.54%
850	51.72%	22.81%	10.34%	1.44%	1.50%	3.74%	8.45%
950	48.16%	23.88%	11.70%	1.81%	1.89%	5.70%	6.37%
1050	44.68%	24.47%	12.76%	2.15%	2.24%	8.08%	5.65%
1150	41.35%	24.67%	13.47%	2.44%	2.55%	10.83%	4.70%
1250	38.22%	24.57%	13.90%	2.68%	2.79%	13.89%	3.94%
1350	35.31%	24.24%	14.09%	2.86%	2.98%	17.19%	3.33%
1450	32.62%	23.73%	14.06%	2.98%	3.10%	20.68%	2.84%
1550	30.13%	23.08%	13.86%	3.04%	3.17%	24.28%	2.44%
1650	27.85%	22.35%	13.51%	3.06%	3.18%	27.95%	2.11%
1750	25.76%	21.55%	13.05%	3.03%	3.16%	31.62%	1.83%
1850	23.86%	20.71%	12.51%	2.97%	3.10%	35.27%	1.59%
1950	22.09%	19.85%	11.92%	2.88%	3.00%	38.86%	1.40%
2050	20.48%	18.99%	11.29%	2.77%	2.89%	42.35%	1.23%
2150	19.01%	18.13%	10.63%	2.65%	2.76%	45.74%	1.09%
2250	17.66%	17.29%	9.97%	2.51%	2.61%	49.01%	0.97%
2350	16.42%	16.46%	9.31%	2.36%	2.46%	52.14%	0.86%
2450	15.23%	15.66%	8.68%	2.21%	2.30%	55.12%	0.77%
2550	14.23%	14.89%	8.03%	2.06%	2.14%	57.96%	0.69%
2650	13.27%	14.14%	7.42%	1.91%	1.99%	60.65%	0.62%
2750	12.39%	13.43%	6.84%	1.76%	1.83%	63.20%	0.56%
2850	11.57%	12.75%	6.28%	1.62%	1.68%	65.60%	0.50%
2950	10.82%	12.10%	5.75%	1.48%	1.54%	67.86%	0.46%
3050	10.13%	11.47%	5.25%	1.35%	1.40%	69.98%	0.41%
3150	9.49%	10.89%	4.78%	1.22%	1.27%	71.98%	0.38%
3250	8.89%	10.33%	4.34%	1.10%	1.15%	73.84%	0.34%

Figure III-1 Mertz HIC Risk Curves

Figure III-2 Lognormal Hertz Curves

Neck Injury Criterion (Nij)

NHTSA is proposing the same neck injury criterion (Nij) as proposed in the NPRM except with revised critical intercept values. The NPRM alternative ICPL of 1.0 is proposed for the SNPRM. This method combines neck axial tension/compression and neck moments (flexion/extension) into one ICPL. This criterion employs the summation of normalized neck axial force and normalized neck moment at the occipital condyle. The formulation is $Nij = F_{NZ} + M_{NY,}$ where: $F_{NZ} = F_Z / F_{Z\ CRIT.}$ and $M_{NY} = M_Y / M_{Y\ CRIT.}$ The measured neck values are; F_Z = neck axial load (tension or compression) and M_Y = neck bending moment (flexion or extension) at the occipital condyle. F_Z and M_Y are measured at the same point in time. The $F_{Z\ CRIT.}$ and $M_{Y\ CRIT.}$ values by dummy size are shown in Table III-1. Nij can not exceed 1.0 at any point in time.

As shown in Table III-1, NHTSA is proposing critical intercept values for axial neck tension/ compression ($F_{Z\ crit.}$) as well as neck flexion/ extension moment ($M_{Y\ crit.}$) to be used in computing Nij for each dummy size. This approach (the so-called Kite Method) is based on a dependent relationship between neck axial loads and neck moments in assessing neck injury risk. Prasad and Daniel (SAE #841656) suggested that a linear combination of axial load and bending moment is a better predictor of injury than the individual limits.[6] The neck shear load is only used for the calculation of the My moment at the occipital condyles. Figure III-3 shows an example of the Nij related critical neck values and the formation of a kite shape, for the 50th percentile male dummy. The kite shape is based on the critical intercept values in Table III-1 and

[6] A Biomechanical Analysis of Head, Neck and Torso Injuries to Child Surrogates Due to Sudden Torso Acceleration, Prasad, P. and Daniel, R.P., 1984 SAE International Congress and Exposition, Paper # 841656.

is equivalent to Nij=1.0.

Figure III-3 Illustration of the Proposed Neck Injury Criterion (Nij <= 1.0) for the 50^{th} percentile Male Dummy (Kite Method)

In order to pass the proposed test, the Nij computation can not exceed 1.0, thus it must stay within or at the boundary of the kite. Figure III-4 presents the same neck injury criteria (Nij <=1.0) for the 5th percentile female dummy. The formulas for Percent Injury Probability at AIS-2+ through AIS-5+ injury, as a function of Nij values are as follows:

AIS-2+ Percent Injury Probability = $[1/ (1 + \exp^{(2.0536\ -1.1955*Nij\ )})] \times 100\%$.

AIS-3+ Percent Injury Probability = $[1/ (1 + \exp^{(3.227\ -\ 1.969*Nij\ )})] \times 100\%$.

AIS-4+ Percent Injury Probability = $[1/ (1 + \exp^{(2.693\ -1.196*Nij\ )})] \times 100\%$.

AIS-5+ Percent Injury Probability = $[1/ (1 + \exp^{(3.817\ -\ 1.196*Nij\ )})] \times 100\%$.

Fatality Percent Injury Probability = $[1/ (1 + \exp^{(3.817\ -\ 1.196*Nij\ )})] \times 100\%$. (Same as AIS-5+)

The probability of injury as a function of Nij for a family of risk curves is shown in Figure III-5. The Nij formula is the same regardless of dummy size because the critical values, $F_{Z\ CRIT.}$ and $M_{Y\ CRIT.}$ are scaled.

Nij Calculation (Kite Method)

Regardless of dummy size, NHTSA is proposing that the biomechanical neck injury criteria, Nij (max.), not exceed a value of 1.0 at any point in time. The following procedure is used to compute Nij. The axial force (Fz) tension/compression and the neck flexion/extension moment about the occipital condyle (My) are used to calculate four combined injury predictors, collectively referred to as Nij. Nij (in Index Notation format) represents four combinations of loads that predict injury outcome. These four combined values represent the probability of

Figure III-4 Illustration of the Proposed Neck Injury Criterion (Nij <=1.0) for the 5th Percentile Female Dummy (Kite method)

Figure III-5 Illustration of Family of Injury Probability Curves (AIS 2-5) for the Proposed Nij.

sustaining each of the four primary types of cervical injuries, namely tension-extension (N_{TE}), tension-flexion (N_{TF}), compression-extension (N_{CE}) and compression-flexion (N_{CF}) injuries. Each measurement recorded by the upper neck load cell is first normalized against the critical intercept values for each specific dummy, where the normalized loads and moments can be expressed as: $F_{NZ} = F_Z / F_{ZCRIT.}$, and $M_{NY} = M_Y / M_{Y\,CRIT.}$ and where $F_{Z\,CRIT.}$ and $M_{Y\,CRIT.}$ are the critical intercept values previously discussed in Table III-1 for each specific dummy.

The critical intercept values for calculating the Nij are uniquely specified for each dummy and are defined in Table III-1 for the 50th percentile male, 5th percentile female, 6-year-old child, 3-year-old child and 12-month-old infant (CRABI) dummies. Source code for a C++ program to calculate the Nij criteria is included in Appendix G of the revised biomechanics report. This source code, as well as executable version of the program, is also available from the NHTSA web site at http://www.nhtsa.dot.gov. The revise biomechanics report describes how the Nij calculation is made.

Chest Injury Risk Functions and ICPLs

Chest g s and chest deflection, currently required by FMVSS 208 for the 50th percentile male dummy, were proposed in the NPRM as alternatives to CTI. The proposed chest acceleration ICPLs in the SNPRM are identical to those proposed in the NPRM for the 50th percentile male, 5th percentile female and 6-year-old child dummies. New revised chest acceleration ICPLs are proposed in the SNPRM for the 3-year-old child and 12-month-old infant (CRABI) dummies. NHTSA is proposing to reduce the chest deflection ICPLs proposed in the NPRM for the 50th percentile dummy by 17 percent, from 76 mm to 63 mm. The 63 mm (2.5") deflection represents a 33 percent chance of an AIS-3+ injury. Figure III-6 illustrates the proposed thoracic injury criteria (D_C & A_C) for the 50th percentile male dummy. The chest deflection threshold values for the other dummy sizes have been scaled from this adjusted value to maintain equivalent injury risk at maximum chest displacement.

Injury probability as a function of chest acceleration based on a 3 ms clip of the spinal acceleration on the 50th percentile male dummy is given below.[7] This acceleration is designated A_C for purposes of the preliminary economic assessment. The chest acceleration threshold values for the other dummy sizes were scaled from the 50th percentile male. The family of chest acceleration risk curves for the 50th percentile male dummy is illustrated in Figure III-7.

AIS-2+ Percent Injury Probability = $[1/ (1 + \exp^{(1.2324 - 0.0576 * Ac)})] \times 100\%$.

AIS-3+ Percent Injury Probability = $[1/ (1 + \exp^{(3.1493 - 0.0630 * Ac)})] \times 100\%$.

AIS-4+ Percent Injury Probability = $[1/ (1 + \exp^{(4.3425 - 0.0630 * Ac)})] \times 100\%$.

AIS-5+ Percent Injury Probability = $[1/ (1 + \exp^{(8.7652 - 0.0659 * Ac)})] \times 100\%$.

[7] The spinal acceleration is measured by accelerometer on the 50th percentile dummy at a point identified as T1. This has been re-designated as chest acceleration A_C for this report.

Figure III-6 Illustration of Proposed Thoracic Injury Criteria (SNPRM) Critical Chest Deflection (D_C) and Critical Chest Acceleration (A_C).

Figure III -7 and III-8 Illustration of the Family of Injury Probability Curves for Critical Chest Acceleration (A_C) and Critical Chest Deflection (D_C) for the 50th percentile male dummy.

Injury probability as a function of maximum chest deflection (D_C) at the center of the chest for the 50th percentile male dummy is described below. The family of risk curves for chest deflection is illustrated in Figure III-8.

AIS-2+ Percent Injury Probability = $[1/(1 + \exp^{(1.8706 - 0.04439 * Dc)})] \times 100\%$.

AIS-3+ Percent Injury Probability = $[1/(1 + \exp^{(3.7124 - 0.0475 * Dc)})] \times 100\%$.

AIS-4+ Percent Injury Probability = $[1/(1 + \exp^{(5.0952 - 0.0475 * Dc)})] \times 100\%$.

AIS-5+ Percent Injury Probability = $[1/(1 + \exp^{(8.8274 - 0.0459 * Dc)})] \times 100\%$.

Combined Thoracic Index (CTI) Adopted for Chapter V. Benefits, for Analysis Purposes

NHTSA proposed a new chest injury criterion called the Combined Thoracic Index (CTI) in the NPRM. Based on the analysis of the docket comments, NHTSA is proposing independent chest g s and chest deflection measures for the SNPRM, specifically, 60 g s and 63 mm (2.5 in.) for the 50th percentile male dummy. The other dummy sizes are scaled from this based on geometry and material properties. This is similar to AAMA s proposal. However, the agency has adopted the CTI injury risk function for purposes of assessing chest injury risk reduction and subsequent benefits. For the purposes of benefits analysis, rather than assess risk for each independent chest injury criterion, it is more convenient, to adopt the CTI risk function proposed in the NPRM as both independent chest injury criterion are combined.

CTI is the summation of the normalized 3 ms clip chest g s and the normalized chest deflection. The normalized 3 ms chest g s is found by dividing the specific dummy chest g s response (A

$_{max}$) , for a given test, by the chest acceleration critical intercept value (A_{int})for the specific size dummy. The normalized chest deflection is found by dividing the specific dummy chest deflection response (D_{max}) , for a given test, by the chest deflection critical intercept value (D_{int})for the specific size dummy. The formulation is: CTI =[(A_{max} / $A_{int.}$) + (D_{max} / $D_{int.}$)], where $A_{max.}$ is the maximum chest acceleration (g s) measured, $A_{int.}$ is the X-axis intercept value (specific to each dummy) for chest acceleration (g s), $D_{max.}$ is the maximum chest deflection (mm) measured and $D_{int.}$ is the Y-axis intercept value (specific to each dummy) for chest deflection (mm). Compared to the NPRM, the constants (D_{int} and A_{int}) in the CTI formula have been adjusted slightly in response to docket comments as shown in Table III-4.

Compared to other chest injury predictors studied by NHTSA, and based on the agency s cadaveric data, CTI is a better predictor of chest injury than chest acceleration or chest deflection alone. However, there are still questions regarding the interpretation of the data used in the development of CTI. More data and analysis is needed to evaluate the efficacy of a CTI based injury criteria.

Analysis of the cadaveric data indicates that if sternal deflection is plotted along the vertical axis and chest acceleration is plotted along the horizontal axis, a line drawn between the coordinates (0,4) and (90,0) would represent a 50 percent probability of an AIS-3+ injury for the population of cadavers studied (mean age 60 years). Because of the increased fragility of the cadavers and the age difference between the cadaver population studied and the human population, the actual risk of injury for an IARV of 1.0, for example, for CTI is estimated to be a 25 percent probability of an AIS 3+ for the driving population. Table III-4 shows the chest deflection Y-axis intercept (D_{int}) and the chest acceleration X-axis intercept (A_{int}) to set-up the 50 percent AIS-3+ threshold for each dummy size. Deflection and acceleration limits for each dummy size were obtained using geometric scaling from Mertz along with bone modulus scaling from Melvin.

Table III-4
Critical Intercept Values ($D_{int.}$ and $A_{int.}$) for the CTI = 1.0 by Dummy Size
Used for Analysis Purposes Only.

	50th Percentile	**5th Percentile**	**6-Year-Old Child**	**3-Year-Old Child**	**12-Month-Old Infant (CRABI)**
D_{int} (Chest Deflection, Y-Axis Intercept)	103 mm (4.0")	84 mm (3.3")	64 mm (2.6")	57 mm (2.2")	50 mm (2.0")
A_{int} (Chest Acceleration, X-Axis Intercept)	90	90	90	74	57

Figure III-9 shows an example of D_{int} and A_{int} used to establish the CTI=1.0 threshold for the 50th percentile male dummy. Figure III-10 illustrates the family of CTI risk functions for AIS-2+, 3+, 4+ , 5+ and fatal injury for the 50th percentile male dummy. The formula for percent injury probability at AIS-2+ through AIS-5+ injury, as a function of CTI values are as follows:

AIS-2+ Percent Injury Probability = $[1/ (1 + \exp^{(4.847 - 6.036*CTI)})]$ X 100%.

AIS-3+ Percent Injury Probability = $[1/ (1 + \exp^{(8.224 - 7.125*CTI)})]$ X 100%.

AIS-4+ Percent Injury Probability = $[1/ (1 + \exp^{(9.872 - 7.125*CTI)})]$ X 100%.

AIS-5+ Percent Injury Probability = $[1/ (1 + \exp^{(14.242 - 6.589*CTI)})]$ X 100%.

Fatality Percent Injury Probability = $[1/ (1 + \exp^{(14.242 - 6.589*CTI)})]$ X 100%. (Same as AIS-5+)

Figure III-9 Illustration of Combined Thoracic Index (CTI<=1.0) for the 50th Percentile Male Dummy, where $CTI = A_{MAX} /90 + D_{MAX.} /103 = 1.0$.

Figure III-10 Family of Risk Curves (AIS 2-5) for the Combined Thoracic Index (CTI)

Femur Risk Function and ICPLs

As shown in Table III-1, femur axial load limits for the 50th percentile male and 5th percentile female dummies are being proposed in the SNPRM at 10,000 N (2,250 lbs.) and 6,800 N (1,530 lbs.), respectively. In frontal crashes, particularly with air bags, the dummy knees often make contact and load the instrument panel or knee bolster. NHTSA has estimated that for the 50th percentile dummy, 10,000 N (2,250 lbs.) femur axial compression represents a 35 percent risk of an AIS 2+ injury. The AIS-2+ risk function for the 50th percentile male dummy is [$1/1+e^{(5.795-0.5196Fx)}$ times 100%], where Fx is the femur axial load measured in kN. Figure III-11 illustrates this risk function. The 5th percentile femur ICPL of 6,800 (1,530 lbs.) was scaled from the 50th percentile dummy values using 5th percentile female femur bone cross-sectional area. NHTSA is not proposing femur ICPLs for the 12-month-old infant (CRABI), the 3-year-old or the 6-year-old child dummies. Lower extremity injuries (femur fractures) are rarely experienced for OOP children.

C. Injury Criteria and IARVs for Analysis Purposes

95th Percentile Male Dummy IARVs

Chapter VI, Fatality Comparison of Pre-MY98 to MY98/99 Air Bags, describes a series of 95th percentile male dummy tests conducted by the agency. In order to interpret the significance of agency sled results it was necessary to derive appropriate IARVs for the 95th percentile dummy based on the same injury criteria proposed for the other dummies. These are shown in Table III-5.

Figure III-11 Femur Axial Load Risk Function (> = AIS 2) for the 50th Percentile Male Dummy

Lower Leg Injury Criteria and IARV

In order to assess lower leg injury risk of the 50th and 5th percentile dummies in 22-35 mph unbelted offset deformable barrier (ODB) based on surrogate 37.5 mph belted ODB tests, NHTSA has employed the Tibia Index of 1.3 for analysis purposes. The Tibia Index represents a summation of the normalized tibia axial load F_{NZ} and normalized tibia moment M_{NY}, where $F_{NZ} = F_Z / F_{Zcrit.}$ and $M_{NY} = M_Y / M_{Ycrit.}$ F_Z and M_Y are measured independent of time. Table III-6 shows the critical tibia axial load $F_{Zcrit.}$ and moment $M_{Ycrit.}$ values by dummy size. The summation should not exceed the IARV of 1.3.

Table III-5
Injury Criteria and Injury Assessment Reference Values (IARVs) derived for the 95th Percentile Male Dummy, Used for Analysis Purposes Only

Proposed Injury Criteria	Hybrid III 95th Percentile Male Dummy IARVs
Head Criteria HIC15	700
Neck Criteria Nij	1.0
Nij Critical Intercept Values	
Fz crit. Tension (N)	5440
Fz crit. Compression (N)	5440
My crit. Flexion (N-m)	415
My crit. Extension (N-m)	166
Thoracic Criteria	
1. **T1**: Critical Spine Acceleration (g)	55
2. **D**: Critical Chest Deflection (mm)	70
3. Combined Thoracic Index (CTI)	
CTI Intercept values	
Aint. Accel. (G)	83
Dint. Deflection (mm)	114
Lower Extremity Criteria	
Femur Loads (kN)	10

Table III-6
Tibia Index Critical Values by Dummy Size

	50th Percentile Male Dummy	5th Percentile Female Dummy
Critical Tibia Axial Load $F_{Zcrit.}$	35.9 kN	22.9 kN
Critical Tibia Moment $M_{Ycrit.}$	225 N-m	115 N-m