



Full wwPDB X-ray Structure Validation Report ⓘ

Mar 14, 2026 – 02:41 PM UTC

PDB ID : 4APB / pdb_00004apb
Title : Crystal structure of Mycobacterium tuberculosis fumarase (Rv1098c) S318C
in complex with fumarate
Authors : Bellinzoni, M.; Haouz, A.; Mechaly, A.E.; Alzari, P.M.
Deposited on : 2012-03-31
Resolution : 1.94 Å(reported)

This is a Full wwPDB X-ray Structure Validation Report for a publicly released PDB entry.

We welcome your comments at validation@mail.wwpdb.org

A user guide is available at

<https://www.wwpdb.org/validation/2017/XrayValidationReportHelp>

with specific help available everywhere you see the ⓘ symbol.

The types of validation reports are described at

<http://www.wwpdb.org/validation/2017/FAQs#types>.

The following versions of software and data (see [references ⓘ](#)) were used in the production of this report:

MolProbity	:	4-5-2 with Phenix2.0
Mogul	:	2022.3.0, CSD as543be (2022)
Xtriage (Phenix)	:	2.0
EDS	:	3.0
Percentile statistics	:	20250101.v01 (using entries in the PDB archive January 1st 2025)
CCP4	:	9.0.010 (Gargrove)
Density-Fitness	:	1.0.12
Ideal geometry (proteins)	:	Engh & Huber (2001)
Ideal geometry (DNA, RNA)	:	Parkinson et al. (1996)
Validation Pipeline (wwPDB-VP)	:	2.49

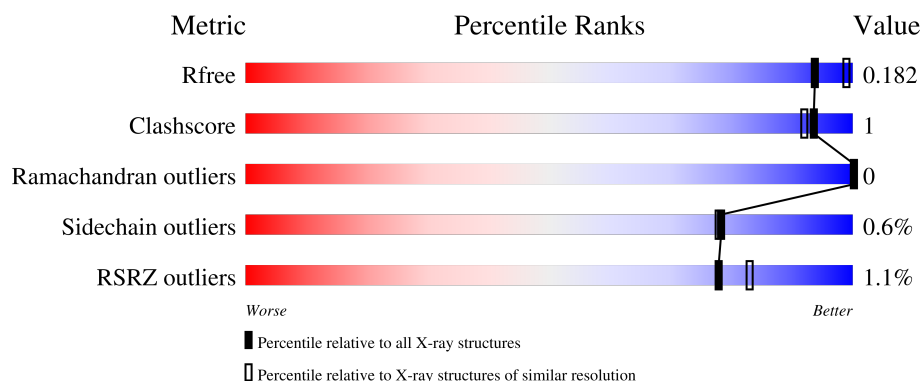
1 Overall quality at a glance

The following experimental techniques were used to determine the structure:

X-RAY DIFFRACTION

The reported resolution of this entry is 1.94 Å.

Percentile scores (ranging between 0-100) for global validation metrics of the entry are shown in the following graphic. The table shows the number of entries on which the scores are based.



Metric	Whole archive (#Entries)	Similar resolution (#Entries, resolution range(Å))
R_{free}	180053	1452 (1.94-1.94)
Clashscore	190562	1494 (1.94-1.94)
Ramachandran outliers	187476	1479 (1.94-1.94)
Sidechain outliers	187428	1479 (1.94-1.94)
RSRZ outliers	180081	1453 (1.94-1.94)

The table below summarises the geometric issues observed across the polymeric chains and their fit to the electron density. The red, orange, yellow and green segments of the lower bar indicate the fraction of residues that contain outliers for ≥ 3 , 2, 1 and 0 types of geometric quality criteria respectively. A grey segment represents the fraction of residues that are not modelled. The numeric value for each fraction is indicated below the corresponding segment, with a dot representing fractions $\leq 5\%$. The upper red bar (where present) indicates the fraction of residues that have poor fit to the electron density. The numeric value is given above the bar.

Mol	Chain	Length	Quality of chain
1	A	474	% 94% • •
1	B	474	% 92% 5% •
1	C	474	% 94% • •
1	D	474	% 94% • •

2 Entry composition

There are 4 unique types of molecules in this entry. The entry contains 15229 atoms, of which 0 are hydrogens and 0 are deuteriums.

In the tables below, the ZeroOcc column contains the number of atoms modelled with zero occupancy, the AltConf column contains the number of residues with at least one atom in alternate conformation and the Trace column contains the number of residues modelled with at most 2 atoms.

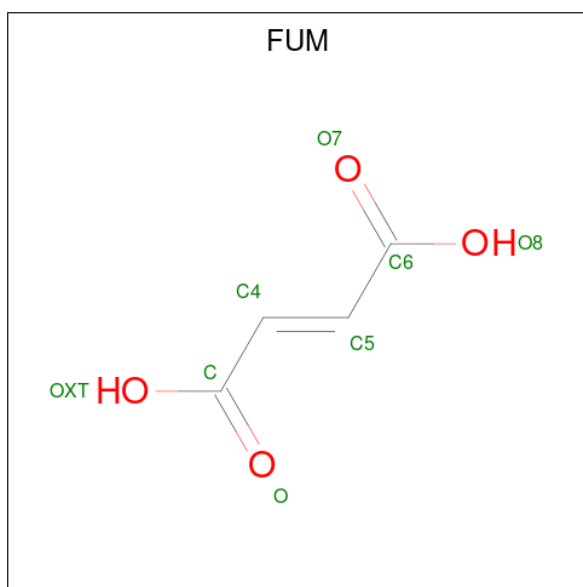
- Molecule 1 is a protein called FUMARATE HYDRATASE CLASS II.

Mol	Chain	Residues	Atoms					ZeroOcc	AltConf	Trace
1	A	460	Total	C	N	O	S	0	2	0
			3381	2106	610	652	13			
1	B	460	Total	C	N	O	S	0	4	0
			3382	2107	608	654	13			
1	C	460	Total	C	N	O	S	0	2	0
			3387	2110	610	654	13			
1	D	462	Total	C	N	O	S	0	0	0
			3383	2107	611	652	13			

There are 8 discrepancies between the modelled and reference sequences:

Chain	Residue	Modelled	Actual	Comment	Reference
A	1	GLY	-	expression tag	UNP O53446
A	318	CYS	SER	engineered mutation	UNP O53446
B	1	GLY	-	expression tag	UNP O53446
B	318	CYS	SER	engineered mutation	UNP O53446
C	1	GLY	-	expression tag	UNP O53446
C	318	CYS	SER	engineered mutation	UNP O53446
D	1	GLY	-	expression tag	UNP O53446
D	318	CYS	SER	engineered mutation	UNP O53446

- Molecule 2 is FUMARIC ACID (CCD ID: FUM) (formula: C₄H₄O₄).



Mol	Chain	Residues	Atoms	ZeroOcc	AltConf
2	A	1	Total C O 8 4 4	0	0
2	B	1	Total C O 8 4 4	0	0
2	C	1	Total C O 8 4 4	0	0
2	D	1	Total C O 8 4 4	0	0

- Molecule 3 is CALCIUM ION (CCD ID: CA) (formula: Ca).

Mol	Chain	Residues	Atoms	ZeroOcc	AltConf
3	A	1	Total Ca 1 1	0	0
3	B	1	Total Ca 1 1	0	0
3	D	1	Total Ca 1 1	0	0

- Molecule 4 is water.

Mol	Chain	Residues	Atoms	ZeroOcc	AltConf
4	A	467	Total O 467 467	0	0
4	B	430	Total O 430 430	0	0

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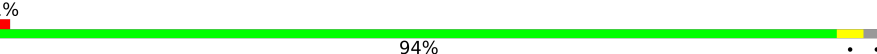
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Mol	Chain	Residues	Atoms		ZeroOcc	AltConf
4	C	381	Total 381	O 381	0	0
4	D	383	Total 383	O 383	0	0

3 Residue-property plots [i](#)

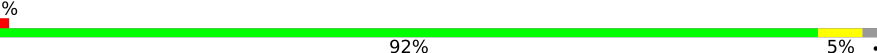
These plots are drawn for all protein, RNA, DNA and oligosaccharide chains in the entry. The first graphic for a chain summarises the proportions of the various outlier classes displayed in the second graphic. The second graphic shows the sequence view annotated by issues in geometry and electron density. Residues are color-coded according to the number of geometric quality criteria for which they contain at least one outlier: green = 0, yellow = 1, orange = 2 and red = 3 or more. A red dot above a residue indicates a poor fit to the electron density ($RSRZ > 2$). Stretches of 2 or more consecutive residues without any outlier are shown as a green connector. Residues present in the sample, but not in the model, are shown in grey.

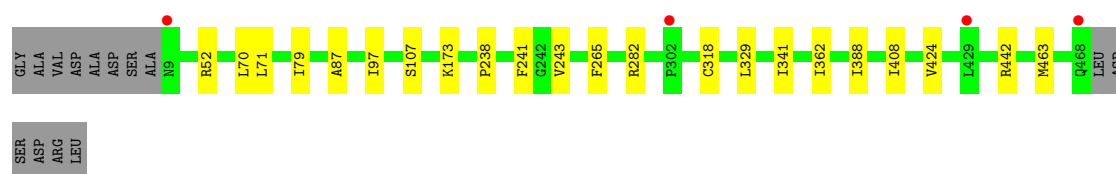
• Molecule 1: FUMARATE HYDRATASE CLASS II

Chain A: 

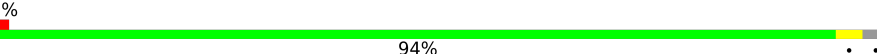


• Molecule 1: FUMARATE HYDRATASE CLASS II

Chain B: 

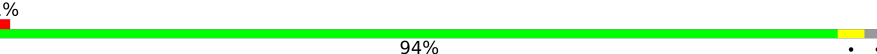


• Molecule 1: FUMARATE HYDRATASE CLASS II

Chain C: 



• Molecule 1: FUMARATE HYDRATASE CLASS II

Chain D: 



4 Data and refinement statistics

Property	Value	Source
Space group	P 21 21 21	Depositor
Cell constants a, b, c, α , β , γ	98.00Å 98.74Å 188.17Å 90.00° 90.00° 90.00°	Depositor
Resolution (Å)	49.37 – 1.94 49.37 – 1.94	Depositor EDS
% Data completeness (in resolution range)	99.5 (49.37-1.94) 99.5 (49.37-1.94)	Depositor EDS
R_{merge}	0.08	Depositor
R_{sym}	(Not available)	Depositor
$\langle I/\sigma(I) \rangle$ ¹	2.41 (at 1.94Å)	Xtriage
Refinement program	BUSTER 2.11.2	Depositor
R, R_{free}	0.147 , 0.174 0.153 , 0.182	Depositor DCC
R_{free} test set	6773 reflections (5.02%)	wwPDB-VP
Wilson B-factor (Å ²)	21.0	Xtriage
Anisotropy	0.740	Xtriage
Bulk solvent k_{sol} (e/Å ³), B_{sol} (Å ²)	0.34 , 56.9	EDS
L-test for twinning ²	$\langle L \rangle = 0.48$, $\langle L^2 \rangle = 0.31$	Xtriage
Estimated twinning fraction	0.019 for k,h,-l	Xtriage
F_o, F_c correlation	0.97	EDS
Total number of atoms	15229	wwPDB-VP
Average B, all atoms (Å ²)	27.0	wwPDB-VP

Xtriage's analysis on translational NCS is as follows: *The largest off-origin peak in the Patterson function is 5.57% of the height of the origin peak. No significant pseudotranslation is detected.*

¹Intensities estimated from amplitudes.

²Theoretical values of $\langle |L| \rangle$, $\langle L^2 \rangle$ for acentric reflections are 0.5, 0.333 respectively for untwinned datasets, and 0.375, 0.2 for perfectly twinned datasets.

5 Model quality [i](#)

5.1 Standard geometry [i](#)

Bond lengths and bond angles in the following residue types are not validated in this section: FUM, CA

The Z score for a bond length (or angle) is the number of standard deviations the observed value is removed from the expected value. A bond length (or angle) with $|Z| > 5$ is considered an outlier worth inspection. RMSZ is the root-mean-square of all Z scores of the bond lengths (or angles).

Mol	Chain	Bond lengths		Bond angles	
		RMSZ	$\# Z > 5$	RMSZ	$\# Z > 5$
1	A	0.85	0/3436	1.13	1/4679 (0.0%)
1	B	0.84	0/3442	1.13	2/4688 (0.0%)
1	C	0.84	0/3442	1.14	1/4687 (0.0%)
1	D	0.86	0/3432	1.14	3/4676 (0.1%)
All	All	0.85	0/13752	1.13	7/18730 (0.0%)

There are no bond length outliers.

All (7) bond angle outliers are listed below:

Mol	Chain	Res	Type	Atoms	Z	Observed(°)	Ideal(°)
1	D	176	ASP	CA-CB-CG	6.86	119.46	112.60
1	C	265	PHE	CA-CB-CG	-6.08	107.72	113.80
1	D	362	ILE	N-CA-CB	5.86	115.02	110.45
1	A	362	ILE	N-CA-CB	5.62	114.83	110.45
1	B	362	ILE	N-CA-CB	5.46	114.71	110.45
1	B	265	PHE	CA-CB-CG	-5.43	108.37	113.80
1	D	265	PHE	CA-CB-CG	-5.35	108.45	113.80

There are no chirality outliers.

There are no planarity outliers.

5.2 Too-close contacts [i](#)

In the following table, the Non-H and H(model) columns list the number of non-hydrogen atoms and hydrogen atoms in the chain respectively. The H(added) column lists the number of hydrogen atoms added and optimized by MolProbity. The Clashes column lists the number of clashes within the asymmetric unit, whereas Symm-Clashes lists symmetry-related clashes.

Mol	Chain	Non-H	H(model)	H(added)	Clashes	Symm-Clashes
1	A	3381	0	3374	9	0
1	B	3382	0	3378	12	0
1	C	3387	0	3386	10	0
1	D	3383	0	3367	7	0
2	A	8	0	1	3	0
2	B	8	0	1	3	0
2	C	8	0	1	3	0
2	D	8	0	1	3	0
3	A	1	0	0	0	0
3	B	1	0	0	0	0
3	D	1	0	0	0	0
4	A	467	0	0	0	0
4	B	430	0	0	0	0
4	C	381	0	0	0	0
4	D	383	0	0	0	0
All	All	15229	0	13509	38	0

The all-atom clashscore is defined as the number of clashes found per 1000 atoms (including hydrogen atoms). The all-atom clashscore for this structure is 1.

All (38) close contacts within the same asymmetric unit are listed below, sorted by their clash magnitude.

Atom-1	Atom-2	Interatomic distance (Å)	Clash overlap (Å)
1:A:318:CYS:SG	2:A:1469:FUM:C5	2.54	0.96
1:B:318:CYS:SG	2:B:1469:FUM:C4	2.54	0.95
1:C:318:CYS:SG	2:C:1469:FUM:C5	2.55	0.94
1:D:318:CYS:SG	2:D:1471:FUM:C4	2.58	0.92
1:D:318:CYS:SG	2:D:1471:FUM:C5	2.60	0.90
1:B:318:CYS:SG	2:B:1469:FUM:C5	2.62	0.87
1:A:318:CYS:SG	2:A:1469:FUM:C4	2.63	0.87
1:C:318:CYS:SG	2:C:1469:FUM:C4	2.71	0.79
1:C:318:CYS:SG	2:C:1469:FUM:C6	3.00	0.50
1:D:408:ILE:HB	1:D:463:MET:HE1	1.96	0.48
1:A:318:CYS:SG	2:A:1469:FUM:C6	3.03	0.47
1:C:70:LEU:HD11	1:C:238:PRO:HG3	1.96	0.47
1:C:408:ILE:HB	1:C:463:MET:HE1	1.98	0.46
1:B:97:ILE:HD13	1:B:107:SER:HB3	1.98	0.46
1:A:52:ARG:HA	1:A:87:ALA:HA	1.98	0.45
1:A:97:ILE:HD13	1:A:107:SER:HB3	1.98	0.45
1:D:238:PRO:HD2	1:D:241:PHE:HB2	1.98	0.45
1:A:408:ILE:HB	1:A:463:MET:HE1	1.99	0.45
1:D:97:ILE:HD13	1:D:107:SER:HB3	1.99	0.44

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Atom-1	Atom-2	Interatomic distance (Å)	Clash overlap (Å)
1:B:408:ILE:HB	1:B:463:MET:HE1	1.99	0.44
1:B:52:ARG:HA	1:B:87:ALA:HA	2.00	0.43
1:B:238:PRO:HD2	1:B:241:PHE:HB2	2.00	0.43
1:C:424:VAL:HG22	1:C:442:ARG:HD3	2.00	0.43
1:C:238:PRO:HD2	1:C:241:PHE:HB2	2.01	0.42
1:A:238:PRO:HD2	1:A:241:PHE:HB2	2.00	0.42
1:D:318:CYS:SG	2:D:1471:FUM:C	3.07	0.42
1:B:173:LYS:HE2	1:B:388:ILE:O	2.18	0.42
1:B:70:LEU:HD11	1:B:238:PRO:HG3	2.02	0.42
1:C:97:ILE:HD13	1:C:107:SER:HB3	2.01	0.42
1:B:318:CYS:SG	2:B:1469:FUM:C	3.08	0.41
1:A:282:ARG:HG2	1:A:341:ILE:CD1	2.51	0.41
1:B:71:LEU:HD21	1:B:79:ILE:HD12	2.03	0.41
1:B:424:VAL:HG22	1:B:442:ARG:HD3	2.03	0.41
1:C:71:LEU:HD21	1:C:79:ILE:HD12	2.03	0.41
1:B:282:ARG:HG2	1:B:341:ILE:CD1	2.51	0.41
1:C:412:LEU:HD23	1:C:457:ARG:HD2	2.03	0.40
1:D:412:LEU:HD23	1:D:457:ARG:HD2	2.03	0.40
1:A:71:LEU:HD21	1:A:79:ILE:HD12	2.02	0.40

There are no symmetry-related clashes.

5.3 Torsion angles ⓘ

5.3.1 Protein backbone ⓘ

In the following table, the Percentiles column shows the percent Ramachandran outliers of the chain as a percentile score with respect to all X-ray entries followed by that with respect to entries of similar resolution.

The Analysed column shows the number of residues for which the backbone conformation was analysed, and the total number of residues.

Mol	Chain	Analysed	Favoured	Allowed	Outliers	Percentiles	
1	A	460/474 (97%)	446 (97%)	14 (3%)	0	100	100
1	B	462/474 (98%)	450 (97%)	12 (3%)	0	100	100
1	C	460/474 (97%)	449 (98%)	11 (2%)	0	100	100
1	D	460/474 (97%)	448 (97%)	12 (3%)	0	100	100
All	All	1842/1896 (97%)	1793 (97%)	49 (3%)	0	100	100

There are no Ramachandran outliers to report.

5.3.2 Protein sidechains ⓘ

In the following table, the Percentiles column shows the percent sidechain outliers of the chain as a percentile score with respect to all X-ray entries followed by that with respect to entries of similar resolution.

The Analysed column shows the number of residues for which the sidechain conformation was analysed, and the total number of residues.

Mol	Chain	Analysed	Rotameric	Outliers	Percentiles	
1	A	343/363 (94%)	341 (99%)	2 (1%)	78	78
1	B	344/363 (95%)	342 (99%)	2 (1%)	78	78
1	C	345/363 (95%)	344 (100%)	1 (0%)	86	86
1	D	342/363 (94%)	339 (99%)	3 (1%)	70	67
All	All	1374/1452 (95%)	1366 (99%)	8 (1%)	78	78

All (8) residues with a non-rotameric sidechain are listed below:

Mol	Chain	Res	Type
1	A	329	LEU
1	A	379	VAL
1	B	243	VAL
1	B	329	LEU
1	C	329	LEU
1	D	329	LEU
1	D	396	GLU
1	D	451	ILE

Sometimes sidechains can be flipped to improve hydrogen bonding and reduce clashes. All (31) such sidechains are listed below:

Mol	Chain	Res	Type
1	A	63	GLN
1	A	252	GLN
1	A	310	GLN
1	A	339	GLN
1	A	368	ASN
1	A	394	ASN
1	B	31	GLN
1	B	63	GLN
1	B	339	GLN

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Mol	Chain	Res	Type
1	B	353	ASN
1	B	368	ASN
1	C	31	GLN
1	C	164	GLN
1	C	165	GLN
1	C	310	GLN
1	C	339	GLN
1	C	353	ASN
1	C	368	ASN
1	C	385	GLN
1	C	394	ASN
1	D	31	GLN
1	D	140	ASN
1	D	158	HIS
1	D	165	GLN
1	D	252	GLN
1	D	339	GLN
1	D	353	ASN
1	D	368	ASN
1	D	385	GLN
1	D	394	ASN
1	D	413	ASN

5.3.3 RNA [i](#)

There are no RNA molecules in this entry.

5.4 Non-standard residues in protein, DNA, RNA chains [i](#)

There are no non-standard protein/DNA/RNA residues in this entry.

5.5 Carbohydrates [i](#)

There are no oligosaccharides in this entry.

5.6 Ligand geometry [i](#)

Of 7 ligands modelled in this entry, 3 are monoatomic - leaving 4 for Mogul analysis.

In the following table, the Counts columns list the number of bonds (or angles) for which Mogul statistics could be retrieved, the number of bonds (or angles) that are observed in the model and

the number of bonds (or angles) that are defined in the Chemical Component Dictionary. The Link column lists molecule types, if any, to which the group is linked. The Z score for a bond length (or angle) is the number of standard deviations the observed value is removed from the expected value. A bond length (or angle) with $|Z| > 2$ is considered an outlier worth inspection. RMSZ is the root-mean-square of all Z scores of the bond lengths (or angles).

Mol	Type	Chain	Res	Link	Bond lengths			Bond angles		
					Counts	RMSZ	# Z > 2	Counts	RMSZ	# Z > 2
2	FUM	C	1469	-	7,7,7	1.22	1 (14%)	8,8,8	0.64	0
2	FUM	A	1469	-	7,7,7	1.24	2 (28%)	8,8,8	0.64	0
2	FUM	D	1471	-	7,7,7	1.34	1 (14%)	8,8,8	0.63	0
2	FUM	B	1469	-	7,7,7	1.19	0	8,8,8	0.75	0

In the following table, the Chirals column lists the number of chiral outliers, the number of chiral centers analysed, the number of these observed in the model and the number defined in the Chemical Component Dictionary. Similar counts are reported in the Torsion and Rings columns. '-' means no outliers of that kind were identified.

Mol	Type	Chain	Res	Link	Chirals	Torsions	Rings
2	FUM	C	1469	-	-	0/5/5/5	-
2	FUM	A	1469	-	-	0/5/5/5	-
2	FUM	D	1471	-	-	0/5/5/5	-
2	FUM	B	1469	-	-	0/5/5/5	-

All (4) bond length outliers are listed below:

Mol	Chain	Res	Type	Atoms	Z	Observed(Å)	Ideal(Å)
2	D	1471	FUM	O8-C6	-2.42	1.24	1.30
2	A	1469	FUM	O8-C6	-2.02	1.25	1.30
2	A	1469	FUM	OXT-C	-2.01	1.25	1.30
2	C	1469	FUM	O8-C6	-2.01	1.25	1.30

There are no bond angle outliers.

There are no chirality outliers.

There are no torsion outliers.

There are no ring outliers.

4 monomers are involved in 12 short contacts:

Mol	Chain	Res	Type	Clashes	Symm-Clashes
2	C	1469	FUM	3	0
2	A	1469	FUM	3	0
2	D	1471	FUM	3	0

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Mol	Chain	Res	Type	Clashes	Symm-Clashes
2	B	1469	FUM	3	0

5.7 Other polymers [i](#)

There are no such residues in this entry.

5.8 Polymer linkage issues [i](#)

There are no chain breaks in this entry.

6 Fit of model and data

6.1 Protein, DNA and RNA chains

In the following table, the column labelled ‘#RSRZ> 2’ contains the number (and percentage) of RSRZ outliers, followed by percent RSRZ outliers for the chain as percentile scores relative to all X-ray entries and entries of similar resolution. The OWAB column contains the minimum, median, 95th percentile and maximum values of the occupancy-weighted average B-factor per residue. The column labelled ‘Q< 0.9’ lists the number of (and percentage) of residues with an average occupancy less than 0.9.

Mol	Chain	Analysed	<RSRZ>	#RSRZ>2	OWAB(Å ²)	Q<0.9
1	A	460/474 (97%)	-0.38	6 (1%) 75 80	14, 25, 51, 82	2 (0%)
1	B	460/474 (97%)	-0.51	4 (0%) 81 85	13, 23, 42, 85	4 (0%)
1	C	460/474 (97%)	-0.41	3 (0%) 84 88	15, 25, 52, 83	2 (0%)
1	D	462/474 (97%)	-0.42	7 (1%) 72 78	14, 23, 45, 90	0
All	All	1842/1896 (97%)	-0.43	20 (1%) 78 83	13, 24, 48, 90	8 (0%)

All (20) RSRZ outliers are listed below:

Mol	Chain	Res	Type	RSRZ
1	B	468	GLN	3.9
1	C	468	GLN	3.7
1	A	429	LEU	3.7
1	D	470	ASP	3.5
1	D	429	LEU	3.3
1	B	302	PRO	3.2
1	D	428	ALA	3.1
1	D	433	LYS	3.1
1	A	468	GLN	3.1
1	D	10	TYR	2.6
1	A	433	LYS	2.5
1	C	9	ASN	2.5
1	B	429	LEU	2.5
1	C	429	LEU	2.4
1	D	430	LYS	2.4
1	A	10	TYR	2.3
1	A	9	ASN	2.3
1	D	448	ARG	2.3
1	B	9	ASN	2.1
1	A	428	ALA	2.1

6.2 Non-standard residues in protein, DNA, RNA chains [i](#)

There are no non-standard protein/DNA/RNA residues in this entry.

6.3 Carbohydrates [i](#)

There are no oligosaccharides in this entry.

6.4 Ligands [i](#)

In the following table, the Atoms column lists the number of modelled atoms in the group and the number defined in the chemical component dictionary. The B-factors column lists the minimum, median, 95th percentile and maximum values of B factors of atoms in the group. The column labelled 'Q< 0.9' lists the number of atoms with occupancy less than 0.9.

Mol	Type	Chain	Res	Atoms	RSCC	RSR	B-factors($\text{\AA}^2$)	Q<0.9
2	FUM	C	1469	8/8	0.92	0.09	24,25,27,28	0
2	FUM	B	1469	8/8	0.94	0.09	22,25,27,28	0
2	FUM	A	1469	8/8	0.94	0.08	17,20,22,22	0
2	FUM	D	1471	8/8	0.95	0.07	18,22,25,28	0
3	CA	A	1470	1/1	0.96	0.05	56,56,56,56	0
3	CA	B	1470	1/1	0.97	0.08	42,42,42,42	0
3	CA	D	1472	1/1	0.99	0.06	30,30,30,30	0

6.5 Other polymers [i](#)

There are no such residues in this entry.